Northeast Fisheries Science Center Reference Document 01-05

A Report of the 32nd Northeast Regional Stock Assessment Workshop

32nd Northeast Regional Stock Assessment Workshop (32nd 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

April 2001

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MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) meeting of the 32nd Northeast Regional Stock Assessment Workshop (32nd SAW) was held in the Aquarium Conference Room of the Northeast Fisheries Science Center's Woods Hole Laboratory, Woods Hole, MA during 27 November - 1 December, 2000. The SARC Chairman was Dr. Robin Cook, Aberdeen Marine Laboratory, UK. 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), the Canadian Department of Fisheries and Oceans, and the Alaskan Fisheries Science Center. Support for Drs. Cook and Medley was provided by the Center for Independent Experts - University of Miami (Table 1). In addition, 37 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.

Robin Cooke(Aberdeen Laboratory, UK - CIE)

NEFSC experts chosen by the Chair:
Frank Almeida
Han-Lin Lai
William Overholtz
Gary Shepherd

NMFS Northeast Regional Office:
John Witzig, NMFS/NERO

Regional Fishery Management Councils:
Andrew Applegate, NEFMC

Atlantic States Marine Fisheries Commission/States:
Steve Correia, MA

Other experts:
Paul Medley (Consultant, London - CIE)
Michael Sigler (NMFS/AKFSC)
Stephen Smith (DFO/BIO)

Opening

Dr. John Boreman, NEFSC Deputy Scienc and Research Director welcomed the meetin participants and Dr. Terry Smith, Stoc Assessment Workshop (SAW) Chairmar briefly reviewed the overall SAW process Dr. Cook reviewed the agenda and discusse the conduct of the meeting.

Table 2. List of Participants.

NMFS, Northeast Fisheries Science Center

Jon Brodziak
Russell Brown
Steve Cadrin
Steve Clark
Christine Esteves
Joseph Idoine
Wendy Gabriel
Devora Hart
Larry Jacobson
Chad Keith
Chris Legault
Jason Link
Ralph Mayo
Steven Murawski
Paul Nitschke
Loretta O'Brien
Paul Rago
Fredric Serchuk
Pie Smith
Terry Smith
Katherine Sosebee
Mark Terceiro
Michelle Thompson
James Weinberg
Stuart Whipple
Susan Wigley

NOAA/NMFS, Headquarters

Elizabeth Clarke
William Fox

ASMFC/States/Industry

Jon Chesto, Ottaway Newspapers
Steve Correira, MA
Dan Farnham, Consultant
Bill Gerencer, Consultant
Ken Halanch, WHOI
Arnie Howe, MA
Rob Johnston, MA
Trevor Kenchington, Consultant
Jim McLelland, Consultant
Ronald Smolowitz, Consultant
Kevin Stokesbury, SMAST/UMass
Richard Taylor, NEFMC
William Train, Commercial Fisherman

Table 3. Agenda of the 32nd Northeast regional Stock Assessment Workshop (SAW-32) Stock Assessment Review Committee (SARC) meeting.

Aquarium Conference Room
NEFSC Woods Hole Laboratory
Woods Hole, Massachusetts
27 November (1:00 PM) - 1 December (6:00 PM), 2000

AGENDA

TOPIC	WORKING GROUP & PRESENTER(S)	SARC LEADER	RAPPORTEUR
MONDAY, 27 November (1:00 PM - 6:00 PM)........			
Opening			
Welcome	**Terry Smith, SAW Chairman**		**P. Smith**
Introduction	**Robin Cook, SARC Chairman**		
Agenda			
Conduct of meeting			
American Plaice (A)	**L. O'Brien**	**S. Correia**	**P. Nitschke**
Informal social (6:30 PM) - Sissenwine residence, Falmouth			
TUESDAY, 28 November (8:30 AM - 6:00 PM)........			
Sea Scallops (B)	**D.Hart/P. Rago**	**S. Smith**	**K. Sosebee**
WEDNESDAY, 29 November (8:30 AM - 5:00 PM)........			
Silver Hake (C)	**J. Brodziak**	**F. Almeida**	**R.K. Mayo**
THURSDAY, 30 November (8:30 AM - 6:00 PM)........			
Gulf of Maine Haddock (D)	**R. Brown**	**M. Sigler**	**S. Wigley**
Review Advisory Reports and Sections for the SARC Report			
FRIDAY, 1 December (8:30 AM - 6:00 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 (NMFS/NEFSC, NMFS/NER, NEFMC, MAFMC, ASMFC). 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 known as the *Advisory Report on Stock Status*.

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

Table 4. SAW-32 Working Group meetings and participants.

Working Group and Participants	Meeting Date	Stock/Species
Northern Demersal Working Group	11/6-9/00	Gulf of Maine Haddock
J. Brodziak, NEFSC		American Plaice
S. Cadrin, NEFSC		Silver Hake
D. Farnham, NY		
L. Jacobson, NEFSC		
C. Legault, NEFSC		
R.K. Mayo (Chair), NEFSC		
L. O'Brien, NEFSC		
K. Sosebee, NEFSC		
M. Terceiro, NEFSC		
S. Wigley, NEFSC		
G. Yerman, CT		
Invertebrate Subcommittee	10/30-31/00, 11/16/00	Sea Scallops
A. Applegate, NEFMC		
D. Hart, NEFSC		
L. Jacobson (Chair), NEFSC		
C. Keith, NEFSC		
T. Kenchington, Industry		
V. Nordahl, NEFSC		
P. Rago, NEFSC		
R. Smolowitz, Industry		
K. Stokesbury, SMAST		
J. Weinberg, NEFSC		

Agenda and Reports

The SAW-32 SARC agenda (Table 3) included presentations on assessments for American plaice, sea scallops, silver hake, and Gulf of Maine haddock. 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 (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 the SAW-32 Public Review Workshops that were held in conjunction with Regional Council meetings by the NEFMC on 25 January and the MAFMC on 7 February. Following the Public Review Workshops, the documents will be published in the NEFSC Reference Document series as the *32nd^{h} SARC Consensus Summary of Assessments* (this document) and the 32nd^{h} *SAW Public Review Workshop* Report (the latter document includes the final version of the Advisory Report, NEFSC Ref. Doc. 01-04).

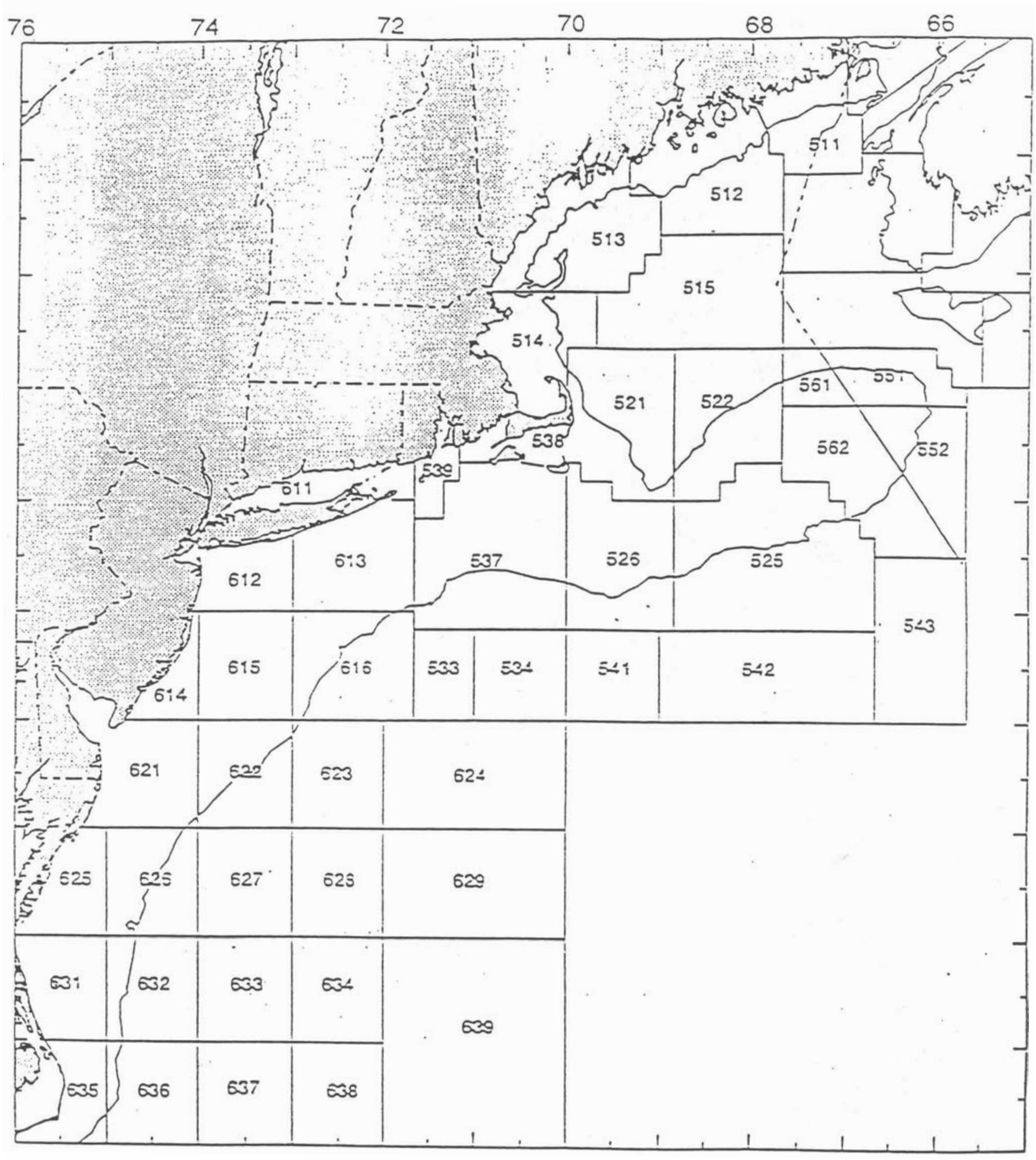

Figure 1. Statistical areas used for catch monitoring in offshore fisheries in the Northeast United States.

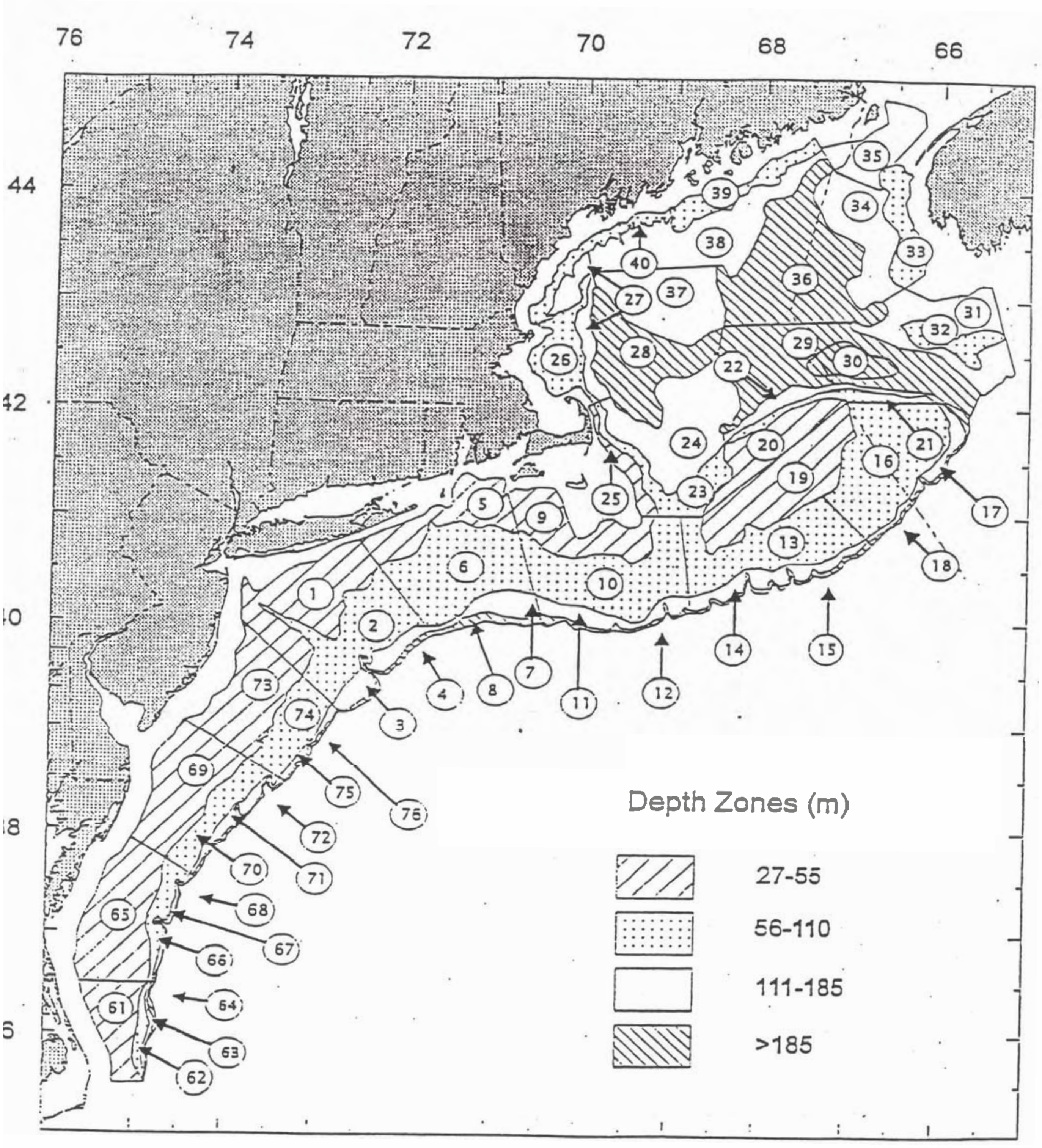

Figure 2. Offshore sampling strata used in NEFSC bottom trawl surveys.

A. AMERICAN PLAICE

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 American Plaice reviewed by the Stock Assessment Review Committee (SARC) 32 in November, 2000:

(1) Update the status of the American plaice stock, providing, the extent practicable, estimates of fishing mortality and stock size. Characterize the uncertainty in the estimates.

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

(3) Provide projections of biomass in 2000 and 2001 and catch in 2000 under various fishing mortality rate options.

INTRODUCTION

American plaice, *Hippoglossoides platessoides*, is distributed along the continental shelf from southern Labrador to Montauk Point, New York. In U.S waters, plaice are most abundant in the deeper (> 50 m) waters of the Gulf of Maine and off the northern edge of Georges Bank (Figure A1). Spawning occurs in the spring from February to June, with peak spawning occurring in April and May. Median maturity for females occurs at 3.6 years and 26.8 cm, and for males at 3.0 years and 22.1 cm (O'Brien *et al.* 1993). The maximum age attained is between 24-30 years and the maximum size is 70-80 cm (Bigelow and Schroeder 1953). After age four, the growth rate for females is faster than that of males (Sullivan 1981).

The fishery for American plaice developed in the mid-seventies as other popular flounder stocks became less abundant and fisheries more heavily regulated (Sullivan 1981). Historically, American plaice had either been discarded or used as bait (Lange and Lux 1979).

This report presents an updated and revised analytical assessment of the Gulf of Maine-Georges Bank American plaice stock for the period 1980-1999 based on analysis of commercial discards, landings and effort data, and research vessel survey data through 1999. The previous assessments of this stock were conducted in 1992 (O'Brien *et al.* 1992) and 1998 (O'Brien *et al.* 1999).

THE FISHERY

Commercial Landings

The collecting and processing of the commercial fishery and landings data has been conducted using two methods during the time series. Prior to 1994, information of 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 from the interview was used to augment the total catch information obtained from the dealer.

In 1994, a mandatory reporting system was initiated requiring anyone fishing for or purchasing regulated groundfish in the Northeast to submit either vessel trip reports (logbooks) or dealer reports, respectively (Power *et al.* 1997 WP). Information on fishing effort (number of hauls, average haul time) and catch location were now obtained from logbooks submitted to NMFS by vessel captains instead of personal interviews. Estimates of total catch by species and market category were now obtained from mandatory dealer reports submitted on a trip basis to NMFS.

A master database for the 1994-1999 commercial landings has not currently been developed. In the future, the landings information from the dealer reports will be augmented with information from the vessel trip reports (VTR) to create a master database similar to what exists prior to 1994.

The analyses conducted in this assessment using data from the commercial database from 1994-1999 are, therefore, considered provisional. Although the estimate of total landings may not change, the allocation by area, Georges Bank or the Gulf of Maine, may change. In addition, other results such as estimation of discards in both the large mesh and shrimp fishery and estimates of landings per day fished (LPUE) and effort in the fishery, which all rely on unaudited data fields (ntrips, days fished), will change when derived using the final master data base.

Since 1960, US landings of American plaice have ranged from 1,309 mt (1960) to 15,126 mt (1982) (Table A1, Figure A2). As the fishery developed, landings gradually increased from an average of 2,280 mt during 1972-1976 to an average of 12,694 mt during 1979-1984. Subsequently, landings declined to 2,300 mt in 1989, then increased to 6,400 mt by 1992. Landings have declined annually since 1992 and were 3,134 mt in 1999.

Otter trawl gear has accounted for the largest percentage of American plaice landings each year since 1980. In 1999, 94% of the landings were caught by otter trawl and 2% by both shrimp trawl and gill net gear. The fishery occurs primarily during the second and third quarter of the year. Historically, the majority of the landings were in the large (large + jumbo) market category for all four quarters, however, in 1988, the majority of the landings shifted to the small category (small + peewee) in quarters 3 and 4. Since 1991 landings have been primarily in the small category in all four quarters (Table A2).

Commercial Fishery Sampling Intensity

The numbers of length and age samples are summarized for each year by quarter and market category in Table A3. The number of metric tons landed per length frequency sample by market category, ranged from 34 to 116 mt during 1985-1991. During 1992-1995, the sampling intensity decreased, ranging between 97 to 336 mt per sample. Sampling intensity has increased since 1996, ranging between 31 and 189 mt per sample. Sampling intensity was high in 1999 and similar to the 1985-1991 period.

Commercial Landings Age Composition

Age-length keys

American plaice landings have been sampled for both length composition and age at length since 1975, however, adequate numbers of samples by market category and season are only available since 1982. Commercial age samples are now routinely aged and currently available for 1985 through 1999. The age

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American plaice landings have been sampled for both length composition and age at length since 1975, however, adequate numbers of samples by market category and season are only available since 1982. Commercial age samples are now routinely aged and currently available for 1985 through 1999. The age data for 1982-1984 will be available for the next benchmark assessment. The age composition for 1980-1984 landings was estimated using the NEFSC bottom trawl survey age-length relationship (O'Brien *et al.* 1992).

A study by Esteves and Burnett (1993) concluded that there were significant growth differences between American plaice in the Gulf of Maine and Georges Bank based on analyses of 1988 samples from both commercial landings and NEFSC spring and autumn bottom trawl surveys. This conclusion was tested further using commercial age at length data pooled from 1985-1990 (O'Brien *et al.* 1999). The results indicated a difference in the age at length between the Gulf of Maine and Georges Bank American plaice.

Based on the conclusion of Esteves and Burnett (1993) and the results from O'Brien *et al.* (1999), the age composition of the 1985-1993 commercial landings were derived separately for the Gulf of Maine and Georges Bank area, and areas were pooled only when sampling was not adequate. The 1994-1999 data were pooled over the entire area because of inadequate sampling by area and uncertainty in the spatial assignment of samples and landings. Samples were generally applied on a quarterly basis, but when samples were not adequate, pooling to semi-annual or annual level was necessary.

Age composition

The pooled age composition of the 1980-1984 landings from the Gulf of Maine-Georges Bank region was estimated, by market category, from seasonal age-length keys derived from the NEFSC groundfish surveys and quarterly length compositions derived from the sampled commercial landings (O'Brien *et al.* 1992). The age composition of the 1985-1993 landings were estimated separately for the Gulf of Maine and for Georges Bank, by market category, from commercial length frequency and age samples, pooled by calendar quarter. The pooled age composition of the 1994-1999 landings from the Gulf of Maine-Georges Bank region were estimated by market category from commercial length frequency and age samples pooled by calendar quarter. In quarters where the sampling was not adequate samples were pooled semi-annually or annually (Table A3). Due to the lack of adequate sampling in every market category for each area, the five market categories were collapsed to three: small + peewee, medium, and large + jumbo. Landed mean weights were estimated by applying the American plaice length weight equation (Lux 1969):

$$Weight(kg) = (2.4548 \times 10^{-6}) \times Length(cm)^{3.345}$$

to quarterly length frequencies, by market category. Total numbers landed by quarter were estimated by dividing the mean weights into quarterly landings, by market category, and prorating according to the sample length frequency. Age-length keys were then applied to the quarterly numbers at length, by market category, to obtain the quarterly catch at age. Numbers at age were summed over market category within each quarter and annual estimates of landings at age were obtained by summing over quarters. Numbers at age for the Gulf of Maine and for Georges Bank were combined to obtain the estimated annual numbers at age and were expanded to total landings (Table A1) by the ratio of (total landings)/ (Gulf of Maine-Georges Bank landings). The ratios varied between 1% and 12%. The total landings in numbers and weight (mt) and the mean weight at age for the landed commercial catch are presented in Table A4.

Commercial Fishery Discards

Data for estimating discarded catch is available in the Sea Sampling Database (SSDBS; 1989-1997) and the Vessel Trip Log (VTR; 1994-1999) database. The number trips, by gear, and metric tons of kept and discarded catch are summarized for Massachusetts state sea sampled trips and for NEFSC sea sampled trips and the number of lengths samples taken on NEFSC sea sampled trips is also summarized in O'Brien (*in prep*). In addition, the number of trips and amount of American plaice landed or discarded is summarized from a subset of trips (VTRs) with a history of reporting discards of any species (O'Brien *in prep*). Only the NEFSC sea sampling data from the shrimp fishery was used in the estimation of discarded catch of American plaice.

The quantity of discarded catch of American plaice in the Northern shrimp fishery and in the large mesh otter trawl fishery was estimated using different methodology for each fishery, although both incorporate NEFSC bottom trawl survey abundance estimates at length in the analysis. A method of estimating discards for the small mesh otter trawl fishery has not been developed yet.

Northern Shrimp Fishery

The total number of American plaice discarded, by length, in the Gulf of Maine northern shrimp fishery were derived based on two estimation procedures which are described by Mayo *et al.* (1992). An indirect estimation of discards for 1980-1988 and 1998-1999 was derived from NEFSC bottom trawl data and shrimp effort and a direct estimation of discards for 1989-1997 was calculated from NEFSC sea-sampling data. In both the direct and indirect method, discards were estimated for 3 time periods, based on the seasonality of the shrimp fishery, which varies from year to year, but is generally prosecuted from December to May. The winter fishing season was defined by combining trips landed in January and February, and the spring season was defined by combining all trips landed in March, April, and May, and December trips were treated as a single group. The total number of shrimp otter trawl trips, by month, is summarized in Table A5.

Indirect Method

Estimates of discarded American plaice in the shrimp fishery during 1980-1988 and 1998-1999 time periods were derived for the winter and spring season, and in December using the indirect method (Mayo *et al.* 1992). Discards were estimated based on NEFSC research survey abundance data (NEFSC offshore survey strata 26, 27, 38, and 40), a mesh selectivity ogive, a sorting ogive based on the current minimum size regulations, shrimp effort (number of trips) and the proportionality constant (q) between catch per unit effort (discards/trip) of a commercial shrimp trawl and the survey abundance index adjusted for mesh selection. The discards/trip were estimated from the sea sampling database for 1989-1997. The methodology is described in more detail in Mayo *et al.* (1992) and O'Brien (*in prep*).

The age composition of the estimated discarded numbers at length were derived by applying seasonal age length keys from the NEFSC bottom trawl surveys to the seasonal estimates of discards. The age composition of the discards from the winter season were derived by applying the previous autumn bottom trawl survey age-length key for American plaice, lagged forward by one age and one year. Age composition of discards from the spring season were derived by applying the spring bottom trawl age-length key of the current year, and the age composition of the December discards were derived by applying the autumn age-length key of the current year.

Direct Method

Direct estimates of discard rates (lbs/trip) during 1989-1997 were estimated for the winter and spring season, and in December for two fishing areas using NEFSC sea-sampling data. Fishing Area 1 and 2 were defined, respectively, as north and south of 43 degrees 15 minutes latitude as described by Clark and Power (1991). A geometric mean discard per trip was computed by exponentiation of the mean (log discard per trip) (Table A6). Discard rates (lbs/trip) for each year-season-area stratum were then raised to total discarded weight by the number of trips for each stratum. Discard weights were combined by area to obtain total discards (lbs) by season. The length-weight equation for American plaice (Lux 1969) was applied to the sea sample length frequency by season to obtain a sample mean weight. Total discard numbers by season were estimated by dividing the total discard weight by the sample mean weight. Total discards at length were derived by prorating the total numbers to the sampled length frequency. The age composition of the discard length frequency was derived by applying age samples obtained from sea sampling supplemented with seasonal age-length keys from the NEFSC surveys. The seasonal age compositions were summarized to obtain an annual age composition of discarded American plaice in the shrimp fishery (Table A7).

Large Mesh Otter Trawl

The total number of American plaice discarded, at length, in the large mesh otter trawl fishery in the Gulf of Maine-Georges Bank region was derived using the survey method described by Mayo *et al.* (1992). The model utilizes abundance of American plaice at length as indicated by NEFSC bottom trawl survey indices filtered through a large mesh selection ogive and a culling ogive to approximate the relative composition of the retained and discarded components of the catch. The minimum regulated mesh size increased over the time period from 130 mm (5.0") to 140 mm (5.5") to 155 mm (6") diamond or square mesh to 165 mm (6.5") square and remaining at 6" diamond. Mesh selection ogives were derived from studies by Walsh *et al.* (1992).

The retained portion of the survey length composition was compared to the estimated number landed at length, and coefficients relating landings and retained survey abundance of plaice were determined from linear regression analysis for each semi-annual period from 1980-1999. The coefficients were then applied to the discarded portion of the survey length composition for the same semi-annual periods to expand the indices at length to estimated numbers discarded. The numbers discarded were adjusted by the proportion of large mesh otter trawl gear with the appropriate mesh (5.5", 6.0" or 6.5"). The age composition of the discard length frequency was then derived by applying age length keys obtained from sea sampling supplemented with seasonal age-length keys from the NEFSC surveys. The semi-annual age compositions were summarized to obtain an annual age composition of discarded

American plaice in the large mesh otter trawl fishery (Table A8).

Total Commercial Fishery Age Composition and Mean Weight at Age

The catch in numbers and weight (mt) and the mean weight at age for the total commercial catch including landings and discarded catch from the shrimp and large mesh otter trawl fishery are presented in Table A9 (ages 1-14) for the Gulf of Maine-Georges Bank region for 1980-1999. The 1987 year-class and the 1992 year-class appear dominant in the catch at age through age 6. The recent average mean weights (1995-1999) are slightly lower than the long term average (1980-1999) for ages 1-9, and slightly higher for ages 10-14. The variability in mean weight in the older year classes is most likely due to poor sampling.

Commercial Catch Rates

The landings per day fished (L/DF) for otter trawl trips from the Gulf of Maine-Georges Bank area were estimated for ton classes 2-4 for trips that landed any amount of American plaice and for trips that landed 50% or more American plaice (50% trips) during 1964-1999. The total L/DF was estimated by summing the individual ton class L/DF weighted by the percentage of the total landings. The total L/DF for the 50% trips and for all trips landing American plaice generally declined from 1964 to 1972 then gradually increased to a record high in 1977, peaked again in 1981, and then gradually declined to a record low in 1988. Catch rates have been variable but relatively stable from 1989-1999 (Figure A3). Nominal fishing effort (of days fished) for all trips landing any amount of plaice increased between 1971-1985, remained relatively high between 1985 and 1992, but has declined during 1993-1999 (Figure A4).

Research Survey Indices

Indices of abundance and biomass were estimated for American plaice from both the NEFSC and the Massachusetts Division of Marine Fisheries (MADMF) spring and autumn bottom trawl surveys. The NEFSC stratified mean number per tow by age and stratified mean weight per tow estimates, adjusted for differences in fishing power of the Albatross IV and the Delaware II, are presented in Table A10 and Figures A5-A6. Abundance indices were adjusted by 0.82 and biomass indices were adjusted by 0.69 for surveys conducted by the Delaware II (NEFSC 1991). Indices of abundance from the NEFSC surveys (offshore strata 13-30, 36-40) indicate strong year classes occurring in 1979, 1981, 1987 and 1992. The 1998 year class is above average at age 1 and just about average at age 2 (Table A11. Figure A7a). The MADMF survey (region 4 and 5) indicates strong year classes in 1984, 1987, and 1992 (Table A12, Figure A7b).

Mortality

Instantaneous natural mortality was assumed to be 0.2, based on studies of unexploited stocks by Pitt (1972). Estimates of instantaneous total mortality (Z) were estimated from survey catch per tow at age for the NEFSC and Massachusetts state research surveys for spring and autumn. For the NEFSC surveys, Z was estimated as the ln (ages 4+/5+) in the spring and ln (ages 3+/4+) in the autumn. For the Massachusetts state surveys, Z was similarly estimated as the ln (ages 3+/4+) in the spring and ln (ages 2+/3+) in the autumn. Different age groups were used for spring and autumn so that Z values could be evaluated for identical year classes.

Estimates of fishing mortality (Z-0.2) are plotted annually for each season and fit with a 3-point moving average for the NEFSC surveys and for the Massachusetts state surveys and compared to the VPA mean F (ages 5-8, unweighted) (Figure A8). NEFSC survey estimated F, denoted by the 3 year moving average, is similar to the VPA F trend throughout the time series (1980-1989). The MADMF survey F does not follow the VPA F trend well during the first half of the time series (1980-1991), however, in the latter half the trends are more similar.

Maturation

Logistic regression was used to estimate annual maturity ogives and median age at maturity (A_{50}) for age and maturity data collected on spring NEFSC research bottom trawl surveys during 1981 and 1983- 2000. Numbers of samples were higher from the Gulf of Maine than from Georges Bank reflecting the distribution of the stock. Maturity ogives were derived for both females and males from both areas. Results indicate that American plaice males mature one year earlier than the females in the Gulf of Maine, and ½ year earlier than the females on Georges Bank, based on the long term average A_{50} (1983-2000). The differences in A_{50} between females from the Gulf of Maine and those from Georges Bank ranged from no difference to a difference of one age, but the differences were not always in the same direction. Given the low sampling size from Georges Bank and the lack of trend in the difference of A_{50} between areas, the samples were pooled from the Gulf of Maine and Georges Bank. Since the females mature at a later age than the males, maturity ogives were derived for females only. Annual maturity ogives were compared graphically, and data from years with similar ogives were combined to derive pooled ogives: 1981+1983-1985, 1986-1987, 1988-1992, 1993-1997, and 1998-2000.

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Virtual Population Analysis Calibration

The ADAPT calibration method (Parrack 1986, Gavaris 1988, Conser and Powers 1990) was used to derive estimates of fishing mortality in 1999 and beginning year stock sizes in 2000. The catch-at-age used in the VPA consisted of combined commercial landings and estimated discards from 1980-1999 for ages 1-8 with a 9+ age group. The indices of abundance used to calibrate the VPA included the NEFSC 1980-1999 spring research survey abundance indices for ages 1-8, the MADMF 1982-2000 spring research survey abundance indices for ages 1-5, the NEFSC 1980-1999 autumn research survey abundances for ages 1-7, and the MADMF 1982-1999 autumn research survey abundance indices for ages 1-5. The autumn survey indices were lagged forward one age and one year to match cohorts in the subsequent year.

The final ADAPT formulation provided stock size estimates for ages 1-8 in 2000 and corresponding F estimates for ages 1-7 in 1999. Assuming full recruitment at age 5, the F on age 8 in the terminal year was estimated as the average of the F on ages 5 through 7. The F on age 8 in all years prior to the terminal year was derived from weighted estimates of Z for ages 5 to 7. For all years, the F on age 8 was applied to the 9+ age group. Spawning stock biomass (SSB) estimates were derived by applying maturity ogives pooled by years: 1980-1985, 1986-1987,1988-1992,1993-1997, and 1998-2000.

The final ADAPT calibration results for estimates of F, stock size, and SSB at age are presented in Table A13. Estimates of stock size were more precise for ages 2-8 (CVs ranging from 0.17 to 0.26) than for age 1 (CV=0.45). The residuals (observed indices-predicted) indicated a pattern of positive residuals in the early years and negative residuals in the later years for ages 1 and 2, primarily for the Massachusetts spring indices. The residual pattern in ages 5 and 6 were negative in the early years and positive in the later years. All indices in 2000 were positive indicating that the numbers in the catch at age are too low (Figure A9).

Average fully recruited fishing mortality (ages 5-8) in 1999 was estimated as 0.27, the lowest in the time series (Table A13, Figure A10). The 1999 estimate of SSB was 14,056 mt, a decrease of 9% from 1998 (Table A13, Figure A11). Since 1980, recruitment has ranged from 13 million (1996 year class) to 53 million (1979 year class). The 1998 year class (34 million age 1 fish) is the first above average (31 million age 1 fish) year class since the 1993 year class (42 million age 1 fish) (Table A13, Figure A11).

The relationship of recruitment at age 1 to spawning stock biomass is presented in Figure A12. The typical stock-recruit relationship of increased recruitment with increasing spawning stock biomass is not apparent for this stock. During 1986-1993 the stock appears to have been under a different regime than during 1980-1985 and 1994-1996 suggesting that recruitment was strongly influenced by factors (i.e. temperature, predation) other than spawning stock biomass. Including back-calculated estimates of stock-recruit for 1976-1979 suggests that a more typical stock-recruit relationship may exist if sufficient data were available. Back-calculated estimates of SSB for 1976-1979 were derived based on the relationship of VPA estimates of SSB and the spring survey index for 1980-1999 and estimates of recruits were back-calculated by applying fishing mortality and natural mortality to stock size at ages 1-4 in 1980.

Precision Estimates of F and SSB

A conditional non-parametric bootstrap procedure (Efron 1982) was used to evaluate the uncertainty associated with the estimates of fishing mortality and spawning stock biomass from the final VPA. One thousand bootstrap iterations were performed to estimate standard errors, coefficients of variation (CVs), and bias for age 1-8 stock size estimates at the start of 2000, catchability estimates (q) for indices of abundance, and age 1 to 7 F's in 1999 (O'Brien *in prep*).

The bootstrap results indicate that stock sizes were well estimated for ages 2 to 8 with CVs varying between 0.16 and 0.25, however age 1 was not as well estimated with a CV of 0.5. The CVs for the catchability coefficients for all indices ranged between 0.13 and 0.14. The fully recruited F for ages 5+ was well estimated with a CV=0.11. The bootstrap estimate of 0.271 was only slightly higher than the NLLS estimate of 0.267. The distribution of the 1999 fully recruited average F estimates, derived from the 1000 bootstrap iterations, ranged from 0.20 to 0.40. There is an 80% probability that the average F in 1999 is between 0.23 and 0.30 (Figure A13).

The bootstrap results indicate that spawning stock biomass was reasonably well estimated (CV=0.10) and slightly higher than the NLLS estimate of 14,056 mt. The distribution of the 1999 spawning stock biomass estimates, derived from the 1000 bootstrap iterations, ranged from 10,500 to 19,000 mt (Figure A13). There is an 80% probability that the 1999 SSB is between 12,400 and 15,700 mt.

Retrospective Analysis

A retrospective analysis was performed to evaluate how well the current ADAPT calibration would estimate spawning stock biomass, fishing mortality, and recruits at age 1 for the five years prior to the current assessment, 1994-1998. Convergence of the estimates generally occurs after about six years (Figures A14a-A14c). The retrospective analysis indicates a pattern of underestimating the recruits at age 1 (Figure A14a). Estimates of SSB appear to be only slightly underestimated (Figure A14b) and estimates of F are overestimated (Figure A14c). A pattern of overestimation of F suggests that the catch at age is too low. The retrospective pattern in F observed here is the opposite of the pattern observed in the 1998 assessment (O'Brien *et al.* 1999).

BIOLOGICAL REFERENCE POINTS

Yield- and Spawning-Stock-Biomass per Recruit

Yield, total stock biomass, and spawning stock biomass per recruit were estimated using methodology of Thompson and Bell (1934). The input parameters for the yield- and spawning stock biomass per recruit analysis and the results presented in Table A14 are from the analyses performed in 1998 (O'Brien *et al.* 1999). The estimates of mean weight at age are the arithmetic means of the 1994-1996 catch mean weight at age and stock mean weight at age from O'Brien *et al.* (1999). Proportion mature at age were obtained from O'Brien *et al.* (1992). A partial recruitment (PR) vector was calculated from the geometric mean of the 1994-1996 F estimates from the final VPA in 1998 (O'Brien *et al.* 1999), coinciding with the change in mesh regulations in 1994. The final exploitation pattern was derived by dividing the geometric mean F at age by the geometric mean of the unweighted average F for ages 5 to 8 and smoothed by applying full exploitation at ages 5 and older. Input values and results for the yield-per-recruit analysis are provided in Table A14 and Figure A15. The resulting biological reference points were $F_{0.1}$=0.19 and F_{max}=.35. The estimation of $F_{0.1}$ and SSB/R was influenced by the inclusion of discarded catch, however, discarding continues to occur and contributes to the overall mortality on the stock.

A second yield- and spawning stock biomass per recruit analysis was performed using results from the current VPA. The $F_{0.1}$ estimated was almost identical to the previous analysis (O'Brien *et al.* 1999) because the input parameters of mean weights and PR vectors had not changed substantially. The biological reference points from the 1998 analysis (O'Brien *et al.* 1999) are therefore used in all further analyses.

MSY Based Reference Points

Estimates of maximum sustainable yield (MSY) and SSB_{MSY} were derived using the long term average recruitment and yield per recruit (Y/R) and spawning stock biomass per recruit (SSB/R) at $F_{0.1}$ as derived in the 1998 assessment (O'Brien *et al.* 1999). MSY was estimated to be about 4,400 mt and SSB_{MSY} was estimated to be about 24,200 mt using a geometric mean recruitment of 24,695 mt (1980-1997) (O'Brien *et al.* 1999). These estimates differed from those provided by the Overfishing Definition Review Panel

(NEFMC 1998) which appeared to be incorrect. Updated biological reference points derived from the same Y/R and SSB/R values as in 1998 (O'Brien *et al.* 1999), but with an updated geometric mean recruitment of 28,091 mt (1980-1999) from the current VPA indicate that MSY = 5,034 mt and SSB_{MSY} = 27,504 mt.

The Panel recommended a control law with $F_{0.1}$ as the maximum fishing mortality threshold when the stock is greater than SSB_{MSY} then decreasing linearly to zero at 1/4 of SSB_{MSY} (NEFMC 1998). Given our current estimate of $F_{0.1}$ (0.19) and SSB_{MSY} (24,200 mt) and the control law recommended by the Panel, the target F would be set at 60% of the $F_{0.1}$ (0.11) when SSB is above SSB_{MSY} and would decrease linearly to zero at ½ of SSB_{MSY} (12,100 mt) (Figure A16). The 1999 SSB estimate is 14,100 mt, just above ½ SSB_{MSY}.

PROJECTIONS

Short term, three year stochastic projections were performed to estimate landings and SSB during 2001-2002 under the F scenarios of F_{99} = 0.27, $F_{0.1}$ = 0.19, and $F_{control\ rule}$ =0.04.

The partial recruitment (PR) vector of landed catch was calculated from the geometric mean of the 1995-1999 F estimates from the final VPA. The discard fraction was calculated as the percentage of total discards at age (in numbers) to total catch at age (in numbers). Mean weight at age for the stock and for landed and discarded catch was estimated as the average mean weight for 1995-1999. The proportion mature used was the pooled maturity ogive for 1998-2000. Recruitment in 2000-2002 was estimated from re-sampling of the distribution of the observed 1980-1999 recruits at age one (Table A13).

At the status quo fishing mortality of 0.27, landings are projected to increase to 3,701 mt in 2000 and 3,760 mt in 2001 (Table A15, Figure A17). SSB increases to 16,076 mt in 2000 and to 16,747 mt in 2001. Fishing at $F_{0.1}$= 0.19, landings will decline to 2,743 mt in 2001 and SSB will increase to 17,068 mt in 2001. If fishing mortality is reduced to F= 0.04 , landings will decline to 619 mt in 2001 and SSB will increase to17,679 mt in 2001 and 22,618 mt in 2002 (Table A15).

CONCLUSIONS

The Gulf of Maine-Georges Bank stock of American plaice is not overfished but overfishing is occurring. Biomass is low, compared to the mean biomass early in the time series (1980-1984). Biomass indices derived from autumn research surveys indicate that the stock has been near or below the long term average since 1984 with the exception of the 1987 and 1992 year classes. Fishing mortality increased rapidly from 1991 (0.43) to a record high in 1995 (0.64). Fishing mortality in 1999 was 0.27, the lowest in the time series, but 37% higher than $F_{0.1}$= 0.19. Spawning stock biomass declined steadily from 47,000 mt in 1980 to a record low value in 1989 (7,500 mt), and has since increased to 14,100 mt in 1999. The last strong year classes occurred in 1992 and 1993 followed by below average recruiting year classes (1994, 1995,1996), however, the 1998 year class appears to be about average.

SARC COMMENTS

Input data

The SARC noted that a single length-weight equation was used in deriving mean weights. Annual length-weight equations may be more applicable for determining mean weights because many flounders exhibit density dependent variation in weight at length. In addition, using age length keys pooled by sex may lead to smearing of cohorts because of growth differences between sexes. Smearing of cohorts may also be caused by poor sampling.

Biological sampling has improved in recent years, but concern was expressed with the precision of the catch at age. The SARC recommended quantifying ageing error. In addition, statistical catch at age models that assume error in the catch at age should be explored.

Mean weights of discarded fish at older ages appeared to be stable, however, mean weights of ages 5 and younger displayed some instability (some cohorts lose weight as they age). This may be a function of selection of slower growing fish within an age group. Stability of mean weights at older ages could be a function of using the same length –weight equations across the entire time-series. The SARC noted that the mean weights at age of the shrimp discards are much lighter than the mean weights at age of the large-mesh discards.

The MADMF surveys are aged with NEFSC survey age-length keys. The SARC recommends ageing archived age samples from both the MADMF and other surveys.
Female maturity ogives were pooled into time periods based on a determination of similarity by visually comparing ogives. The SARC noted that statistically testing for differences by year and sex before pooling ogives provides better justification for pooling or separating ogives.

Discards estimation

The SARC raised a concern about using a raising factor ("mean q") in the indirect method of estimating discards when annual values of q are not normally distributed. A pooled q will result in underestimating or overestimating discards in some years. Discards dropped markedly in 1998 and 1999, which could be an effect of using a pooled q. However, this could also be caused by a decline in effort in the shrimp fishery. Fishery selectivity ogives were based on two periods (pre-1992, and post 1992 which accounts for the effect of the Nordmore grate). The SARC cautioned that annual effects such as environmentally induced changes in availability to the fishery could impact annual fishery selectivity. The SARC recommended a resumption of the sea sampling of the shrimp fishery and implementation of sea sampling of the large mesh fishery in order to continue monitoring of discards and to ensure that the indirect methods to estimate discards remain appropriate. It also recommended investigating the use of the northern shrimp and Massachusetts inshore surveys in the indirect method for estimating discards.

Model calibration

A question was raised on why age 9+ was used instead of older ages. Many age nine and older indices contain years with zeros. The SARC noted fish as old as age 20 were caught in the survey in the early 1980's, implying that the survey can catch old fish. At this time, few older fish are captured by the NEFSC survey. Including older true ages in the catch at age may not add precision to the assessment but this should be investigated. The choice of maximum age in the assessment needs to be investigated.

Fishing mortality on the older ages is estimated by back-calculated stock sizes from age groups of ages 5, 6, 7, 8. The SARC recommended investigating various methods for estimating F on the oldest true age.

Discarding is substantial and the SARC recommended including discards in the final calibration of the VPA. The SARC examined sensitivity runs with and without discards. Trends in fishing mortality, recruitment, and spawning stock biomass were not sensitive to estimates of discards.

Spawning stock biomass

The SARC also noted that female maturity ogives were applied to the total stock for estimation of spawning stock biomass. This may bias the estimate of spawning stock biomass because males mature earlier than females.

The SARC reviewed fishing mortality and SSB estimates from individual VPA runs that used a set of single survey tuning indices (MADMF spring only, etc) with the same final formulation. The MADMF survey series estimated higher fishing mortality and lower SSB than the NEFSC surveys. However, MADMF surveys are only used to tune age 5 and the younger partially recruited age groups while the NEFSC surveys tune to ages 1-8. The SARC noted that the fishing mortality and SSB from the final VPA calibration using all surveys was similar to estimates from the NEFSC survey. The SARC recommended considering weighting tuning indices by the inverse of the variance.

The SARC commented on the lack of a stock-recruit relationship. However, the SARC noted that excluding recruitment prior to 1980 (beginning year of VPA) cuts off a period of high recruitment (based on back calculating ages 2, 3 in 1980) when stock biomass was high. The method used to derive SSB target was discussed, but no change to the existing method was deemed necessary.

RESEARCH RECOMMENDATIONS

- Statistically test maturity ogives for differences before pooling or separating ogives.
- Investigate the most appropriate choice of maximum age in the VPA and method for estimating F on the oldest age.
- Given the importance of discards in the stock, an appropriate at sea monitoring program needs to be developed and maintained.
- Investigate using the shrimp and Massachusetts inshore surveys in the indirect method for estimating discards.
- Re-examine the indirect method and other methods for estimating discards.

  Investigate using statistical catch at age models to account for ageing errors in the catch at age. This recommendation applies to all the analytical assessments reviewed by the SARC and should be taken as a general recommendation.
- Age archived samples from Massachusetts inshore survey.

Examine trends of survey indices by geographic area in order to evaluate the appropriateness of pooling biological parameters by area.

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Table A1.Commercial landings (metric tons, live weight) of American plaice from the Gulf of Maine, Georges Bank, Southern New England and the Mid-Atlantic, 1960-1999.

Year	Gulf of Maine			Georges Bank					Southern New England				Mid - Atlantic			Grand Total		
	USA	Can	Total	USA	Can	USSR	Other	Total	USA	USSR	Other	Total	USA	Other	Total	USA	Other	Total
1960	620	1	621	689				689		-	-	0	-	-	0	1309	1	1310
1961	692	-	692	830				830		-	-	0	-	-	0	1522	0	1522
1962	694	-	694	1233	44	-		1277		-	-	0		-	0	1927	44	1971
1963	693	-	693	1489	127	24	-	1640		-	-	0		-	0	2182	151	2333
1964	811	-	811	2800	177	-	11	2988			-	0		-	0	3611	188	3799
1965	967	-	967	2376	180	112	-	2668		-	-	0	-	-	0	3343	292	3635
1966	955	2	957	2388	242	279	1	2910		-	-	0	-	-	0	3343	524	3867
1967	1066	6	1072	2166	203	1018	10	3397	-	-	-	0	4	-	4	3236	1237	4473
1968	904	5	909	1695	173	193	5	2066	637	145	-	782	18	2	20	3254	523	3777
1969	1059	7	1066	1738	71	63	17	1889	505	349	-	854	130	-	130	3432	507	3939
1970	895	-	895	1603	92	927	658	3280	88	18	40	146	8	-	8	2594	1735	4329
1971	648	5	653	1511	38	228	296	2071	11	112	206	329	6	2	8	2176	887	3063
1972	569	-	569	1222	22	358	-	1602	3	71	-	74	-	-	0	1794	451	2245
1973	687	-	687	910	38	289	-	1237	5	158	-	163		-	0	1602	485	2087
1974	945	2	947	1039	27	16	2	1084	92	4	-	96		-	0	2076	51	2127
1975	1507	-	1507	913	25	148	-	1086	3	-	-	3	-	-	0	2423	173	2596
1976	2550	-	2550	948	24	3	-	975	10	-	-	10	1	-	1	3509	27	3536
1977	5647	-	5647	1408	35	50	-	1493	6	78	-	84	7	-	7	7068	163	7231
1978	7287	30	7317	2193	77	-	-	2270	15	-	-	15	8	--	8	9503	107	9610
1979	8835	-	8835	2478	23	-	-	2501	13	-	7	20	4	-	4	11330	30	11360
1980	11139	-	11139	2399	43	-	5	2447	10	-	-	10	1	-	1	13549	48	13597
1981	10327	1	10328	2482	15	-	2	2499	26	-	2	28	46	-	46	12881	20	12901
1982	11147	-	11147	3935	27	-	1	3963	35	-	2	37	9	-	9	15126	30	15156
1983	9142	7	9149	3955	30	-		3985	40	-	-	40	4	-	4	13141	37	13178
1984	6833	2	6835	3277	6	-		3283	17	-	-	17	7	-	7	10134	8	10142
1985	4766	1	4767	2249	40	-		2289	12	-	-	12	2	-	2	7029	41	7070
1986	3319	-	3319	1146	34	-		1180	4	-	-	4	3	-	3	4472	34	4506
1987	2766	-	2766	1032	48	-		1080	2	-	-	2	1	-	1	3801	48	3849
1988	2271	-	2271	1097	108	-		1205	13	-	-	13	1	-	1	3382	108	3490
1989	1646	-	1646	703	68	-		771	1	-	-	1	3	-	3	2353	68	2421
1990	1802	-	1802	639	52	-		690	2	-	-	2	2	-	2	2445	52	2497
1991	2936	-	2936	1310	26	-		1310	15	-	-	15	0	-	0	4261	26	4287
1992	4564	-	4566	1838	3	-		1838	10	-	-	10	4	-	4	6416	3	6419
1993	3865	-	3865	1838				1838	11	-	-	11	4	-	4	5718	-	5718
1994	3357	-	3431	1683	30	-		1562	22	-	-	22	4	-	4	5066	30	5096
1995	3105	-	3126	1505	2	-		1486	15	-	-	15	20	-	20	4645	2	4647
1996	2912	-	2922	1430	2	-		1423	40	-	-	40	15	-	15	4396	2	4398
1997	2312	-	2396	1576	65	-		1560	23	-	-	23	26	-	26	3937	65	4002
1998	2234	-	2234	1385	20	-		1405	23			23	20		20	3663	20	3683
1999	1718	-	1718	1384	123	-		1507	11			11	21		21	3134	123	3257

** 1994-1999 data are provisional and spatially distributed based on proportions of landings recorded by area in the VTR database.

Table A2. Landings by market category (Sm = small + peewee; Md=medium; Lg=large+jumbo; Un=unclassified) for statistical areas 511-515, 521-522, 525-526, 561-562 for American plaice, 1980-1999. (1994-1999 includes all areas.)

	Quarter 1				Quarter 2				Quarter 3				Quarter 4				Total			
YEAR	Sm	Md	Lg	Un	Sm	Md	Lg	Un	Sm	Md	Lg	Un	Sm	Md	Lg	Un	Sm	Md	Lg	Un
1980	565	0	1527	3	1398	0	3667	100	1026	0	2399	16	479	0	1488	1	3468	0	9081	120
1981	730	0	1775	26	1233	0	3557	253	993	0	2209	34	457	0	1532	2	3413	0	9073	315
1982	581	0	1468	11	1353	5	4350	318	1191	524	2643	131	571	299	1570	40	3696	827	10031	500
1983	580	356	1624	5	1488	713	3148	57	1027	497	1816	18	399	276	1090	3	3494	1843	7678	83
1984	431	247	1071	10	954	649	2355	27	812	479	1444	19	372	309	909	13	2568	1684	5779	70
1985	512	253	708	14	709	511	1548	22	503	369	1046	13	239	188	521	9	1963	1321	3823	59
1986	187	132	409	13	539	350	1014	33	342	201	536	11	202	146	349	6	1269	829	2308	63
1987	169	108	304	20	460	275	744	43	367	203	475	20	199	126	246	35	1195	711	1768	117
1988	203	94	279	39	447	244	529	75	433	186	303	47	155	88	143	36	1238	612	1254	197
1989	117	76	158	25	300	208	423	68	222	126	222	29	139	81	135	21	778	491	938	142
1990	101	66	142	19	269	194	317	49	323	196	273	20	190	118	146	19	883	573	879	107
1991	138	78	116	20	594	347	367	61	773	378	353	40	435	263	241	41	1939	1066	1077	162
1992	302	174	291	35	902	634	805	112	887	624	674	80	426	278	394	17	2517	1710	2164	244
1993	276	181	410	17	702	515	867	80	589	371	602	26	423	232	401	14	1990	1299	2280	137
1994	237	120	243	22	685	434	711	15	692	387	506	8	437	218	345	6	2051	1159	1805	51
1995	214	117	198	10	811	425	585	29	800	287	327	9	436	178	216	4	2261	1007	1326	52
1996	240	108	180	4	808	343	434	22	913	242	253	10	493	159	183	3	2454	852	1050	39
1997	322	99	158	2	696	390	360	56	550	406	245	16	321	176	139	2	1889	1071	902	76
1998	175	148	153	2	637	478	391	30	404	336	264	5	222	180	233	6	1438	1142	1041	43
1999	162	163	225	4	395	330	368	13	353	234	242	2	262	178	199	3	1172	905	1034	22

Table A3. Sampling of commercial American plaice landings, by market category, foi the Gulf of Maine and Georges Bank areas (NAFO Division 5Y and 5Z, 1985-1999. Outline indicates samples pooled to estimate landings at age.

	Small					Medium					Large					Number of tons landed / sample		
	Q1	Q2	Q3	Q4	Sum	Q1	Q2	Q3	Q4	Sum	Q1	Q2	Q3	Q4	Sum	Sm.	Med.	Lrg.
1985GB	2	4	14	3		---	2	2	2		---	3	7	1				
GM	2	5	5	5		3	1	9	5		1	10	6	5				
total	4	9	19	8	40	3	3	11	7	24	1	13	13	6	33	49	55	116
1986GB	3	6	5	3		2	4	3	2		1	4	3	2				
GM	9	5	3	5		3	4	5	1		10	10	7	4				
total	12	11	8	8	39	5	8	8	3	24	11	14	10	6	41	33	35	56
1987GB	4	5	5	1		---	2	3	2		2	4	4	1				
GM	2	6	5	3		1	5	2	3		3	3	6	5				
total	6	11	10	4	31	1	7	5	5	18	5	7	10	6	28	39	40	63
1988GB	3	7	4	2		1	3	4	2		4	5	2	4				
GM	4	7	4	5		6	6	4	3		6	5	3	2				
total	7	14	8	7	36	7	9	8	5	29	10	10	5	6	31	34	21	40
1989GB	2	5	5	---		1	1	6	1		5	3	3	---				
GM	1	3	3	3		1	---	4	3		2	1	---	1				
total	3	8	8	3	22	2	1	10	4	17	7	4	3	1	15	35	29	63
1990GB	---	5	6	---		2	1	2	2		---	2	5	---				
GM	5	5	3	3		1	6	3	5		1	5	3	5				
total	5	10	9	3	27	3	7	5	7	22	1	7	8	5	21	33	26	42
1991GB	---	3	1	---		3	1	1	---		3	3	2	---				
GM	5	3	7	6		3	1	4	3		---	1	5	2				
total	5	6	8	6	25	6	2	5	3	16	3	4	7	2	16	78	67	67
1992GB	---	4	1	---		---	1	1	---		---	2	2	1				
GM	1	5	2	2		1	4	3	2		2	2	3	2				
total	1	9	3	2	15	1	5	4	2	12	2	4	5	3	14	168	143	155
1993GB	---	2	1	1		---	1	---	---		---	3	2	1				
GM	2	4	4	1		---	2	2	---		---	1	2	---				
total	2	6	5	2	15	0	3	2	0	5	0	4	4	1	9	133	260	253
1994GB	---	---	---	---		---	---	1	1		---	1	---	1				
GM	---	2	5	3		---	4	3	3		---	2	3	3				
total	0	2	5	3	10	0	4	4	4	12	0	3	3	4	10	205	97	181
1995GB	1	---	---	---		1	---	---	---		1	---	---	---				
GM	1	3	---	[illegible]		---	2	---	---		---	2	---	1				
total	2	3	0	2	7	1	2	0	0	3	1	2	0	1	4	323	336	332
1996GB	---	2	2	1		---	1	4	---		---	2	1	1				
GM	2	3	2	1		2	1	3	5		3	1	4	2				
total	2	5	4	2	13	2	2	7	5	16	3	3	5	3	14	189	53	75
1997GB	2	4	2	3		---	2	3	1		---	2	---	---				
GM	4	4	3	1		2	3	3	---		1	5	3	2				
total	6	8	5	4	23	2	5	6	1	14	1	7	3	2	13	82	77	69
1998GB	1	4	1	---		2	1	1	1		1	1	1	1				
GM	2	3	1	1		6	3	7	7		2	2	2	2				
total	3	7	2	1	13	8	4	8	8	28	3	3	3	3		111	41	87
1999GB	4	4	---	1		5	2	1	---		---	4	1	---				
GM	6	8	6	9		7	4	5	7		1	6	3	2				
total	10	12	6	10	38	12	6	6	7	31	1	10	4	2		31	29	61

Table A4. Landings at age (thousands of fish; metric tons), mean weight (kg), and mean length (cm) at age of commercial landings of American plaice from Gulf of Maine - Georges Bank, and South, 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
							Landings in Numbers (000's) at Age									
1980	0	0	0	22	770	3129	3903	3629	1185	1139	850	323	155	215	687	16006.9
1981	0	0	587	1332	4331	5100	3618	2381	1573	645	440	196	146	45	234	20627.9
1982	0	0	113	2134	3495	4295	3481	3293	2038	1256	737	317	34	137	230	21558.4
1983	0	0	1	438	3735	4270	3809	2252	1271	697	450	455	230	59	168	17833.7
1984	0	0	3	253	1298	4819	2865	1913	577	274	307	65	57	0	647	13078
1985	0	0	0	60	786	2066	2787	2213	1081	438	267	79	54	19	30	9880.579
1986	0	0	1	198	1082	1502	1462	1307	631	255	105	51	26	7	15	6644.024
1987	0	0	15	343	486	1703	1271	891	541	187	62	26	15	14	5	5557
1988	0	0	1	446	1148	1456	1427	543	270	177	88	25	13	11	6	5612.471
1989	0	0	0	76	451	686	504	749	469	193	103	35	29	22	31	3345.721
1990	0	0	0	202	846	1049	500	290	349	193	96	74	42	16	29	3685.842
1991	0	0	0	23	1850	2818	1105	319	164	201	97	66	23	9	6	6682.389
1992	0	0	0	46	739	4871	2563	812	191	131	118	38	33	18	4	9564.445
1993	0	0	0	123	1028	2036	2452	1382	265	287	151	71	22	7	25	7847.836
1994	0	0	24	200	914	1903	1287	1178	608	239	153	64	49	26	157	6800.286
1995	0	0	0	141	717	2880	1745	646	582	212	53	26	16	0	8	7027.585
1996	0	0	101	175	2515	2396	1412	533	241	125	35	21	15	22	5	7597.954
1997	0	0	0	2	1275	2615	1558	620	184	86	67	48	19	11	41	6524.796
1998	0	0	0	6	175	1501	1899	1002	319	60	57	24	22	22	87	5175
1999	0	0	0	2	218	958	1617	1125	429	143	41	42	23	3	10	4610
							Landings at Age (mt)									Total
1980	0	0	0	6	271	1387	2562	3008	1232	1347	1168	508	269	391	1448	13597
1981	0	0	78	276	1485	2318	2832	2122	1545	729	552	266	257	82	358	12898
1982	0	0	23	620	1166	1845	2007	3164	2320	1502	1144	551	65	224	524	15153
1983	0	0	0	149	1720	2484	2596	1864	1326	867	650	638	405	108	380	13187
1984	0	0	1	84	549	2913	1957	1713	688	310	421	134	93	0	1279	10142
1985	0	0	0	13	212	747	1516	1884	1263	603	445	158	115	42	73	7070
1986	0	0	0	53	349	616	864	1101	741	380	183	102	58	17	42	4506
1987	0	0	3	97	187	809	797	797	636	278	107	56	34	32	15	3849
1988	0	0	0	126	413	689	922	484	333	247	151	49	29	26	20	3490
1989	0	0	0	26	177	335	295	553	403	257	150	62	51	46	66	2421
1990	0	0	0	78	355	547	330	240	338	210	125	104	76	30	62	2496
1991	0	0	0	8	839	1532	790	307	191	256	150	107	46	18	17	4261
1992	0	0	0	22	314	2623	1895	774	237	173	193	72	63	40	13	6418
1993	0	0	0	51	463	1054	1591	1305	327	399	238	126	55	13	94	5718
1994	0	0	3	48	391	1008	807	938	659	308	217	106	92	54	466	5097
1995	0	0	0	51	301	1482	1141	531	652	283	112	51	28	0	17	4648
1996	0	0	17	59	1017	1236	918	490	290	172	55	41	33	57	13	4398
1997	0	0	0	0	541	1245	992	510	208	115	105	82	40	32	131	4002
1998	0	0	0	2	68	649	1090	818	325	80	83	38	57	59	351	3620
1999	0	0	0	0	94	466	953	841	395	158	59	75	46	6	20	3113

Table A4. Cont. Landings at age (thousands of fish; metric tons), mean weight (kg), and mean length (cm) at age of commercial landings of American plaice from Gulf of Maine - Georges Bank, and South, 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
								Mean Weight at age (kg)								Average
1980	-----	-----	-----	0.285	0.352	0.443	0.656	0.829	1.039	1.183	1.374	1.573	1.732	1.815	2.109	0.849
1981	-----	-----	0.133	0.207	0.343	0.454	0.783	0.891	0.982	1.130	1.254	1.354	1.755	1.836	1.534	0.625
1982	-----	-----	0.200	0.291	0.334	0.429	0.577	0.961	1.138	1.196	1.552	1.737	1.944	1.636	2.281	0.703
1983	-----	-----	0.184	0.341	0.460	0.582	0.682	0.828	1.043	1.244	1.446	1.404	1.762	1.843	2.255	0.740
1984	-----	-----	0.180	0.331	0.423	0.605	0.683	0.895	1.192	1.133	1.369	2.058	1.628	0.000	1.977	0.775
1985	-----	-----	0.000	0.221	0.270	0.362	0.544	0.852	1.167	1.377	1.665	1.991	2.115	2.254	2.437	0.715
1986	-----	-----	0.191	0.267	0.322	0.410	0.591	0.842	1.174	1.491	1.747	2.002	2.207	2.344	2.751	0.678
1987	-----	-----	0.201	0.284	0.386	0.475	0.627	0.895	1.177	1.483	1.732	2.148	2.213	2.359	2.988	0.692
1988	-----	-----	0.151	0.282	0.360	0.473	0.646	0.893	1.231	1.396	1.717	1.991	2.265	2.278	3.074	0.622
1989	-----	-----	-----	0.339	0.393	0.489	0.586	0.739	0.858	1.334	1.463	1.789	1.780	2.106	2.142	0.724
1990	-----	-----	-----	0.384	0.420	0.522	0.660	0.826	0.968	1.089	1.305	1.409	1.811	1.881	2.154	0.678
1991	-----	-----	-----	0.333	0.453	0.543	0.715	0.963	1.161	1.276	1.541	1.618	2.012	2.050	2.837	0.639
1992	-----	-----	-----	0.473	0.424	0.538	0.739	0.953	1.240	1.319	1.640	1.902	1.928	2.151	2.884	0.671
1993	-----	-----	-----	0.416	0.451	0.518	0.649	0.945	1.234	1.394	1.577	1.784	2.468	1.989	3.750	0.729
1994	-----	-----	0.138	0.239	0.427	0.530	0.627	0.796	1.083	1.289	1.424	1.657	1.880	2.082	2.963	0.750
1995	-----	-----	0.000	0.359	0.420	0.517	0.685	0.914	1.168	1.099	2.105	1.934	1.757	0.000	2.213	0.517
1996	-----	-----	0.166	0.339	0.404	0.516	0.650	0.919	1.202	1.383	1.565	1.962	2.127	2.525	2.486	0.579
1997	-----	-----	-----	0.214	0.424	0.476	0.636	0.822	1.127	1.336	1.570	1.709	2.138	3.084	3.231	0.613
1998	-----	-----	-----	0.343	0.395	0.437	0.581	0.826	1.031	1.350	1.463	1.628	2.622	2.703	4.066	0.708
1999	-----	-----	-----	0.255	0.437	0.490	0.593	0.753	0.925	1.113	1.462	1.799	2.020	2.082	2.067	0.680
								Mean Length at age (cm)								Average
1980	-----	-----	-----	32.6	34.7	37.1	41.7	44.8	47.9	49.9	52.2	54.4	56.0	56.7	59.1	44.1
1981	-----	-----	25.8	28.8	34.0	36.9	43.3	45.2	46.7	48.8	50.3	51.8	55.6	57.0	53.8	39.4
1982	-----	-----	29.0	32.4	33.7	36.4	39.5	46.3	48.8	49.9	53.9	55.7	58.0	55.0	60.7	40.8
1983	-----	-----	28.7	34.2	37.2	39.8	41.9	44.2	47.5	50.2	52.9	52.2	56.1	56.9	60.1	42.2
1984	-----	-----	28.5	33.9	36.3	40.3	41.8	45.3	49.9	49.3	52.2	59.0	54.9	0.0	59.3	42.8
1985	-----	-----	-----	30.0	31.9	34.6	39.1	45.0	49.6	52.0	55.2	58.2	59.3	60.4	61.8	41.4
1986	-----	-----	29.0	31.9	33.6	36.0	40.1	44.6	49.5	53.3	56.0	58.4	60.0	61.1	64.2	40.7
1987	-----	-----	29.4	32.5	35.5	37.8	41.0	45.6	49.5	53.3	55.8	59.6	60.2	61.3	65.7	41.3
1988	-----	-----	27.0	32.4	34.8	37.6	41.4	45.6	50.4	52.3	55.7	58.3	60.6	60.6	66.4	39.9
1989	-----	-----	-----	34.3	35.8	38.2	40.2	43.0	44.6	51.5	52.9	56.2	56.2	59.2	59.4	41.9
1990	-----	-----	-----	35.6	36.5	38.9	41.6	44.5	46.7	48.3	51.1	52.3	56.6	57.3	59.5	41.3
1991	-----	-----	-----	34.2	37.4	39.4	42.6	46.6	49.3	50.6	53.9	54.5	58.5	58.6	64.8	40.8
1992	-----	-----	-----	38.0	36.7	39.2	43.1	46.4	50.5	51.4	54.9	57.5	57.7	59.6	65.2	41.5
1993	-----	-----	-----	36.5	37.3	38.8	41.4	46.6	50.5	52.4	54.4	56.5	62.2	58.3	70.4	42.3
1994	-----	-----	26.2	30.4	36.7	39.2	41.2	44.2	48.6	51.2	52.6	55.2	57.4	59.2	65.6	42.3
1995	-----	-----	0.0	35.0	36.6	38.8	41.6	44.6	49.0	51.7	59.4	57.9	56.1	-----	60.3	41.3
1996	-----	-----	27.7	34.1	36.2	38.8	41.4	46.1	50.0	52.1	54.3	58.1	59.5	62.6	62.1	39.5
1997	-----	-----	-----	30.0	36.7	37.9	41.3	44.5	49.0	51.7	54.2	55.6	59.6	66.5	66.9	40.2
1998	-----	-----	-----	34.5	35.9	37.0	40.1	44.7	47.8	51.8	53.0	54.9	63.4	63.9	72.2	41.5
1999	-----	-----	-----	31.6	36.9	38.2	40.4	43.4	46.2	48.9	52.9	56.3	58.2	59.2	59.0	41.7

Table A5. Total number of trips in the Gulf of Maine northern shrimp fishery by y
season, and month, 1980-2000.

	Winter		Spring			Winter	
	Jan	Feb	Mar	Apr	May	Dec	Tota
1980	0	299	263	55	72	0	689
1981	329	653	874	291	4	0	2151
1982	831	1074	1152	252	14	190	3513
1983	1185	1504	796	317	92	467	4361
1984	2017	2328	1457	174	0	777	6753
1985	1785	2079	1348	361	104	852	6529
1986	1704	2980	1367	383	489	1273	8196
1987	2601	3266	2489	884	652	1068	10960
1988	2587	2987	1466	197	147	1158	8542
1989	3149	2816	1102	534	154	1359	9114
1990	2485	1883	2099	1059	350	1093	8969
1991	1980	2502	1283	611	280	570	7226
1992	2366	2647	1246	320	158	381	7118
1993	1451	2096	1310	497	5	502	5861
1994*	1666	2290	1190	150	0	1904	7200
1995*	2784	2823	1712	1097	0	1858	10274
1996*	2556	4114	2044	740	606	2291	12351
1997*	2285	3404	1703	1238	853	1224	10707
1998*	2089	2119	814	551	375	322	6270
1999*	787	1211	573	567	356	15	3509
2000*	73	187	49	8	12		329

*Provisional

Table A6. Discard rate (lbs/trip), number of trips and total discards (lbs) of American plaice in the Northern Shrimp fishery Area I (N of 4315 degrees latitude) and Area 2 fishery for Area I(S of 4315 degrees Latitude), 1993-1997.

	AREA 1 (N of 4315 Degrees)				AREA 2 (S <= of 4315 Degrees)					
Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Total Disc. (lbs)
1989					**1989**					
Winter	Jan	8.17	1398	11,422	Winter	Jan	33.12	1751	57,993	
	Feb	8.17	1591	12,998		Feb	33.12	1225	40,572	
	total		2989	24420.13				2976	98565.1	122,985
Spring	Mar	298.87	469	140,170	Spring	Mar	99.48	633	62,971	
	Apr	298.87	37	11,058		Apr	99.48	497	49,442	
	May	298.87	2	598		May	99.48	152	15,121	
	total		508	151,826		Total		1282	127,533	279,359
	Dec	109.95	343	37,713		Dec	121.51	1016	123,454	161,167
Annual Total			3840	213958.9				5274	349553	563,512
1990					**1990**					
Winter	Jan	109.95	1041	114,458	Winter	Jan	121.51	1444	175,460	
	Feb	109.95	910	100,055		Feb	121.51	973	118,229	
	total		1951	214512.5				2417	293690	508,202
Spring	Mar	99.48	1335	132,806	Spring	Mar	81.45	764	62,228	
	Apr	99.48	460	45,761		Apr	81.45	599	48,789	
	May	99.48	44	4,377		May	81.45	306	24,924	
	total		1839	182,944		Total		1669	135,940	318,884
	Dec	18.17	273	4,960		Dec	73.7	820	60,434	65,394
Annual Total			4063	402416.6				4906	490064	892,480
1991					**1991**					
Winter	Jan	18.17	685	12,446	Winter	Jan	73.7	1295	95,442	
	Feb	18.17	1376	25,002		Feb	73.7	1126	82,986	
	total		2061	37448.37				2421	178428	215,876
Spring	Mar	12.18	654	7,966	Spring	Mar	81.45	629	51,232	
	Apr	12.18	183	2,229		Apr	81.45	428	34,861	
	May	12.18	30	365		May	81.45	250	20,363	
	total		867	10,560		Total		1307	106,455	117,015
	Dec	6.69	235	1,572		Dec	44.7	335	14,975	16,547
Annual Total			3163	49580.58				4063	299857	349,438

Table A6. Discard rate (lbs/trip), number of trips and total discards (lbs) of American plaice in
Cont. the Northern Shrimp fishery for Area I (N of 4315 degrees latitude) and Area 2 (S of 4315 degrees Latitude), 1993-1997.

	AREA 1 (N of 4315 Degrees)				AREA 2 (S <= of 4315 Degrees)					
Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Total Disc. (lbs)
1992					**1992**					
Winter	Jan	6.69	2366	15,819	Winter	Jan	44.70	0	0	
	Feb	6.69	2269	15,170		Feb	44.70	378	16,897	
	total		4635	30,989				378	16,897	47,886
Spring	Mar	5.47	822	4,500	Spring	Mar	22.20	424	9,412	
	Apr	5.47	137	750		Apr	22.20	183	4,062	
	May	5.47	10	55		May	22.20	148	3,285	
	total		969	5,304		Total		755	16,759	22,064
	Dec	5.47	129	706		Dec	14.88	252	3,750	4,456
Annual Total			5733	36999.51				1385	37406.2	74,406
1993					**1993**					
Winter	Jan	5.47	901	4,932	Winter	Jan	14.88	550	8,184	
	Feb	5.47	1382	7,565		Feb	14.88	714	10,624	
	total		2283	12,497				1264	18,808	31,305
Spring	Mar	4.48	526	2,357	Spring	Mar	16.44	784	12,893	
	Apr	4.48	111	497		Apr	16.44	386	6,348	
	May	4.48	0	0		May	16.44	5	82	
	total		637	2,855		Total		1175	19,322	22,177
	Dec	3.67	173	634.7883		Dec	12.18	329	4008.04	4,643
Annual Total			3093	15,987				2768	42,138	58,125
1994					**1994**					
Winter	Jan	3.67	893	3,277	Winter	Jan	12.18	773	9,417	
	Feb	3.67	1243	4,561		Feb	12.18	1047	12,755	
	total		2136	7,838				1820	22,172	30,010
Spring	Mar	4.95	561	2,779	Spring	Mar	3.67	629	2,308	
	Apr	4.95	38	188		Apr	3.67	112	411	
	May	4.95	0	0		May	3.67	0	0	
	total		599	2966.866		Total		741	2718.95	5,686
	Dec	24.53	271	6,648		Dec	7.38	1633	12,052	18,699
Annual Total			3006	17,452				4194	36,943	54,395

Table A6. Cont. Discard rate (lbs/trip), number of trips and total discards (lbs) of American plaice in the Northern Shrimp fishery for Area I (N of Area 2 (S of 4315 degrees Latitude), 1993-1997.

AREA 1 (N of 4315 Degrees)					AREA 2 (S <= of 4315 Degrees)					
Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Year	Month	Disc. Rate lbs / trip	No. Trips	Total Disc. (lbs)	Total Disc. (lbs)
1995					**1995**					
Winter	Jan	24.53	276	6,770	Winter	Jan	7.38	2508	18,509	
	Feb	24.53	480	11,774		Feb	7.38	2343	17,291	
	total		756	18,545				4851	35,800	54,345
Spring	Mar	14.89	146	2,174	Spring	Mar	54.60	1566	85,504	
	Apr	14.89	21	312.69		Apr	54.60	1076	58749.6	
	May	14.89	0	0		May	54.60	0	0	
	total		167	2,487		Total		2642	144,253	146,740
	Dec	9.03	132	1,192		Dec	24.53	1726	42,339	43,531
Annual Total			1055	22,223				9219	222,392	244,616
1996					**1996**					
Winter	Jan	9.03	227	2,050	Winter	Jan	24.53	2329	57,130	
	Feb	9.03	621	5,608		Feb	24.53	3493	85,683	
	total		848	7,657				5822	142,814	150,471
Spring	Mar	81.45	323	26308.35	Spring	Mar	27.11	1721	46656.3	
	Apr	81.45	31	2,525		Apr	27.11	709	19,221	
	May	81.45	12	977		May	27.11	594	16,103	
	total		366	29,811		Total		3024	81,981	111,791
	Dec	7.39	113	835		Dec	18.17	2178	39,574	40,409
Annual Total			1327	38,303				11024	264,369	302,672
1997					**1997**					
Winter	Jan	7.39	208	1,537	Winter	Jan	18.17	2077	37,739	
	Feb	7.39	319	2357.41		Feb	18.17	3085	56054.5	
	total		527	3894.53				5162	93793.5	97,688
Spring	Mar	*81.45*	72	5864.4	Spring	Mar	29.96	1631	48864.8	
	Apr	*81.45*	42	3420.9		Apr	29.96	1703	51021.9	
	May	*81.45*	25	2036.25		May	29.96	1238	37090.5	
	total		139	11321.55		Total		4572	136977	148,299
	Dec	*7.39*	28	206.92		Dec	*18.17*	1196	21731.3	21,938
Annual Total		-	694	15423				10930	252502	267,925

Table A7. Discards at age (thousands of fish; metric tons) and mean weight (kg) at age of American plaice discarded in the northern shrimp fishery in the Gulf of Maine region, 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	
						Discards in Numbers (000's) at Age						Total
1980	0.0	0.0	0.0	114.0	115.1	28.7	0.0	0.0	0.0	0.0	0.0	257.8
1981	0.0	0.9	147.8	364.4	287.2	79.6	0.4	0.0	2.9	0.0	0.0	883.2
1982	0.0	6.9	154.7	545.6	632.7	105.9	95.7	4.2	0.0	0.0	0.0	1545.7
1983	0.2	14.0	614.3	641.0	760.7	319.9	51.0	5.9	0.0	0.7	0.0	2407.8
1984	0.0	2.5	302.0	488.3	575.1	494.6	98.1	5.9	2.8	0.0	0.0	1969.3
1985	0.0	53.9	103.2	930.9	464.9	307.8	79.0	14.8	0.0	0.0	0.0	1954.6
1986	0.2	53.7	552.0	399.9	933.5	131.9	9.9	0.0	0.1	0.0	0.0	2081.2
1987	0.0	31.4	439.1	1107.6	609.5	338.4	12.8	0.7	0.0	0.0	0.0	2539.6
1988	0.0	283.1	587.4	786.4	408.4	90.8	11.8	10.1	0.0	0.0	0.0	2178.0
1989	0.0	129.0	1458.3	1180.6	325.7	24.1	0.8	0.0	0.0	0.0	0.0	3118.4
1990	0.0	61.0	597.9	1965.4	1004.4	151.6	8.9	0.0	0.0	0.0	0.0	3789.2
1991	0.0	7.5	191.3	436.2	467.3	92.4	2.8	1.1	0.0	0.0	0.0	1198.7
1992	0.0	20.0	68.8	173.4	79.6	24.7	1.5	0.3	0.3	0.0	0.0	368.5
1993	0.0	81.9	95.8	113.2	85.2	22.7	4.3	0.0	0.0	0.2	0.0	403.4
1994	0.7	288.2	475.7	123.3	19.9	5.8	1.5	0.5	0.0	0.0	0.0	915.6
1995	1.1	518.3	1470.5	717.3	96.7	11.9	4.6	0.2	0.6	0.0	0.0	2821.1
1996	0.0	194.7	834.5	1041.0	359.3	53.4	19.9	6.9	0.1	0.0	0.0	2509.8
1997	0.0	158.0	1365.4	511.5	358.7	85.6	14.6	0.7	0.0	0.0	0.0	2494.5
1998	0.0	37.2	61.3	127.0	78.3	48.7	7.3	1.3	0.0	0.0	0.0	361.3
1999	0.0	4.2	200.0	73.6	79.0	41.5	26.0	6.8	0.6	0.0	0.0	431.6
						Discards at age (mt)						Total
1980	0.0	0.0	0.0	11.9	19.6	6.0	0.0	0.0	0.0	0.0	0.0	37.5
1981	0.0	0.0	5.9	31.9	43.4	15.2	0.1	0.0	0.7	0.0	0.0	97.3
1982	0.0	0.1	4.6	49.4	87.9	20.9	17.2	1.0	0.0	0.0	0.0	181.1
1983	0.0	0.2	18.0	58.3	103.4	53.4	9.8	1.1	0.0	0.2	0.0	244.3
1984	0.0	0.0	9.5	35.4	73.2	73.2	17.5	1.2	0.7	0.0	0.0	210.6
1985	0.0	0.8	4.4	63.2	56.2	44.4	16.7	2.9	0.0	0.0	0.0	188.6
1986	0.0	0.7	20.5	31.2	129.5	24.1	2.0	0.0	0.0	0.0	0.0	208.1
1987	0.0	0.3	12.7	83.0	80.3	66.1	3.2	0.2	0.0	0.0	0.0	245.8
1988	0.0	4.4	22.4	66.6	54.6	15.9	3.0	2.1	0.0	0.0	0.0	168.9
1989	0.0	1.6	55.5	124.8	51.1	5.5	0.2	0.0	0.0	0.0	0.0	238.6
1990	0.0	1.3	34.0	168.8	143.8	29.7	2.4	0.0	0.0	0.0	0.0	380.0
1991	0.0	0.1	8.8	39.5	75.4	24.6	1.0	0.4	0.0	0.0	0.0	149.8
1992	0.0	0.4	2.1	10.8	11.8	6.0	0.4	0.1	0.1	0.0	0.0	31.7
1993	0.0	1.3	3.6	4.9	8.5	5.0	1.2	0.0	0.0	0.1	0.0	24.6
1994	0.0	4.1	10.1	5.6	1.9	1.2	0.4	0.2	0.0	0.0	0.0	23.4
1995	0.0	6.4	37.5	40.1	13.0	3.0	1.2	0.1	0.2	0.0	0.0	101.4
1996	0.0	2.7	18.4	49.1	39.6	11.1	5.3	1.8	0.1	0.0	0.0	128.0
1997	0.0	2.1	27.5	28.6	38.2	12.4	2.8	0.3	0.0	0.0	0.0	111.9
1998	0.0	0.5	1.7	7.8	8.3	8.2	1.8	0.3	0.0	0.0	0.0	28.7
1999	0.0	0.0	3.4	3.2	7.9	5.1	4.4	1.8	0.2	0.0	0.0	26.0

Table A7 Cont. Discards at age (thousands of fish; metric tons) and mean weight (kg) at age of American plaice discarded in the northern shrimp fishery in the Gulf of Maine region , 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	
					Mean weight at age (kg)							Average
1980	---	---	---	0.104	0.170	0.210	0.359	---	---	---	----	0.145
1981	---	0.007	0.040	0.087	0.151	0.192	0.320	---	0.239	---	----	0.110
1982	---	0.014	0.030	0.091	0.139	0.197	0.180	0.239	0.000	---	----	0.117
1983	0.002	0.013	0.029	0.091	0.136	0.167	0.193	0.177	0.359	0.295	----	0.101
1984	---	0.004	0.032	0.072	0.127	0.148	0.178	0.198	0.239	---	----	0.107
1985	---	0.015	0.043	0.068	0.121	0.144	0.211	0.196	0.000	---	----	0.096
1986	0.001	0.014	0.037	0.078	0.139	0.183	0.204	0.000	0.359	---	----	0.100
1987	---	0.011	0.029	0.075	0.132	0.195	0.247	0.307	---	---	----	0.097
1988	---	0.016	0.038	0.085	0.134	0.175	0.253	0.209	---	---	----	0.078
1989	---	0.012	0.038	0.106	0.157	0.227	0.313	---	---	---	----	0.077
1990	---	0.021	0.057	0.086	0.143	0.196	0.265	---	---	---	----	0.100
1991	---	0.013	0.046	0.091	0.161	0.266	0.370	0.359	---	---	----	0.125
1992	---	0.018	0.031	0.062	0.149	0.241	0.299	0.359	0.239	---	----	0.086
1993	---	0.016	0.037	0.044	0.100	0.221	0.278	---	---	0.239	----	0.061
1994	0.001	0.014	0.021	0.045	0.095	0.205	0.240	0.359	---	---	----	0.026
1995	0.001	0.012	0.026	0.056	0.134	0.248	0.266	0.359	0.289	---	----	0.036
1996	---	0.014	0.022	0.047	0.110	0.208	0.267	0.256	0.359	---	----	0.051
1997	---	0.014	0.020	0.056	0.107	0.145	0.191	0.361	---	---	----	0.045
1998	0.001	0.013	0.027	0.062	0.106	0.168	0.248	0.258	0.604	0.714	----	0.079
1999	---	0.008	0.017	0.044	0.100	0.124	0.171	0.259	0.295	0.533	----	0.060
					Mean Length at age (cm)							Average
1980	----	----	----	23.84	27.69	29.60	35.00	----	----	----	----	26.20
1981	----	11.00	17.90	22.51	26.65	28.78	33.79	----	31.00	----	----	23.67
1982	----	13.18	16.22	22.56	26.00	28.90	28.30	31.00	----	----	----	24.10
1983	6.76	12.60	16.31	22.90	25.77	27.49	28.95	28.10	35.00	33.00	----	22.82
1984	----	8.55	16.11	21.08	25.12	26.31	28.21	29.25	31.00	----	----	23.19
1985	----	13.33	17.96	20.57	24.87	26.25	29.71	29.04	----	----	----	22.58
1986	5.00	13.20	16.84	21.62	25.86	28.32	29.50	----	35.00	----	----	22.50
1987	----	11.86	15.86	21.60	25.59	29.01	31.19	33.38	----	----	----	22.49
1988	----	13.56	17.19	22.01	25.68	27.97	31.49	29.70	----	----	----	20.64
1989	----	12.67	16.24	22.05	27.75	31.85	33.66	----	----	----	----	21.26
1990	----	13.12	18.04	20.33	23.94	26.02	31.08	----	----	----	----	19.26
1991	----	12.79	15.27	20.61	25.00	28.43	35.00	35.00	----	----	----	19.05
1992	3.00	14.74	16.92	18.90	24.92	28.54	31.24	35.00	31.00	----	----	19.91
1993	3.00	12.57	17.37	21.49	23.67	28.44	29.17	----	----	31.00	----	19.13
1994	5.00	13.63	17.25	21.69	24.12	28.07	27.58	29.57	----	----	----	17.41
1995	5.00	12.98	15.06	19.29	24.85	28.25	28.17	35.00	29.12	----	----	17.81
1996	5.00	13.57	15.14	19.23	23.99	28.62	30.74	31.26	37.19	----	----	19.71
1997	----	13.61	15.79	20.36	24.20	26.27	28.59	35.49	43.00	35.70	----	20.68
1998	5.00	12.77	15.87	20.32	23.84	27.51	30.78	31.36	40.80	43.00	----	20.77
1999	----	9.96	13.61	18.43	23.39	24.84	27.61	31.52	32.90	39.39	----	18.42

Table A8. Discards at age (thousands of fish; metric tons) and mean weight (kg) at age of American plaice discarded in the large mesh fishery in the Gulf of Maine-Georges Bank region , 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	Total
					Discards in Numbers (000's) at Age							
1980	0.0	5.2	98.9	935.7	1786.7	781.2	30.2	2.9	0.0	0.0	0.0	3640.8
1981	0.0	4.2	246.7	495.9	436.9	157.6	29.8	19.9	5.4	0.0	0.0	1396.4
1982	0.0	2.7	335.4	668.9	446.8	101.8	21.7	0.0	0.0	0.0	0.0	1577.3
1983	0.0	0.6	47.8	399.5	681.4	327.8	52.6	12.2	1.4	3.4	0.0	1526.6
1984	0.0	0.0	65.0	249.1	549.4	718.1	281.5	16.3	0.3	0.0	0.0	1879.8
1985	0.0	10.9	54.6	227.0	85.8	30.8	5.6	0.0	0.0	0.0	0.0	414.5
1986	0.0	5.6	85.9	139.6	268.3	65.7	4.4	0.1	0.0	0.0	0.0	569.6
1987	0.0	7.1	135.9	390.4	343.7	241.1	53.2	3.8	1.9	0.0	0.0	1177.1
1988	0.0	30.4	197.1	606.9	276.6	50.3	5.7	0.2	0.0	0.0	0.0	1167.0
1989	0.0	3.4	194.6	574.8	347.7	119.2	31.5	4.0	1.1	0.0	0.0	1276.3
1990	0.0	6.9	77.9	1221.4	814.0	168.3	22.1	1.0	0.1	0.0	0.0	2311.7
1991	0.0	5.6	132.1	541.9	2092.5	492.0	14.8	0.8	0.0	0.0	0.0	3279.7
1992	0.0	17.3	162.1	863.4	1403.5	1913.9	160.3	6.3	7.3	0.0	0.0	4533.9
1993	0.0	24.9	330.1	1795.9	3027.9	1523.5	683.4	20.9	0.0	0.0	0.0	7406.5
1994 *	0.0	0.0	6.9	299.6	1693.0	2550.8	414.3	110.4	0.0	0.5	0.0	5075.5
1995 *	0.0	0.0	17.6	1426.0	5689.0	1933.9	251.5	7.2	1.0	0.0	0.0	9326.3
1996 *	0.0	0.0	0.7	201.8	1568.8	508.8	38.9	8.7	8.8	0.0	0.0	2336.6
1997 *	0.0	0.0	9.7	289.5	1104.8	1219.2	128.2	97.0	45.6	42.5	21.9	2958.5
1998 *	0.0	0.0	1.4	148.1	630.3	1056.9	569.2	40.2	0.5	0.0	0.0	2446.6
1999 *	0.0	0.0	2.1	130.1	688.8	712.8	429.9	141.7	33.1	0.2	0.0	2138.6
					Discards at age (mt)							
1980	0.0	0.2	7.5	147.2	423.8	218.3	9.4	1.1	0.0	0.0	0.0	807.6
1981	0.0	0.2	21.9	61.7	70.0	26.7	5.6	3.4	1.1	0.0	0.0	190.6
1982	0.0	0.1	42.1	98.8	69.3	18.6	3.8	0.0	0.0	0.0	0.0	232.6
1983	0.0	0.0	4.0	65.8	134.5	69.7	12.0	2.8	0.4	0.8	0.0	290.0
1984	0.0	0.0	6.7	40.2	112.4	172.8	71.3	5.2	0.1	0.0	0.0	408.7
1985	0.0	0.3	4.8	25.4	11.3	4.8	0.9	0.0	0.0	0.0	0.0	47.6
1986	0.0	0.2	6.2	17.9	44.7	12.4	0.7	0.0	0.0	0.0	0.0	82.2
1987	0.0	0.1	11.4	60.2	69.5	59.2	15.2	1.1	0.2	0.0	0.0	216.9
1988	0.0	0.6	13.5	100.1	53.5	11.3	1.5	0.1	0.0	0.0	0.0	180.5
1989	0.0	0.1	12.8	96.5	81.0	29.2	7.5	0.8	0.4	0.0	0.0	228.2
1990	0.0	0.1	5.2	222.8	207.9	45.5	6.6	0.4	0.0	0.0	0.0	488.4
1991	0.0	0.1	8.4	73.1	543.5	139.9	6.0	0.4	0.0	0.0	0.0	771.4
1992	0.0	0.7	12.8	139.9	375.4	674.6	60.0	1.8	1.7	0.0	0.0	1267.0
1993	0.0	0.4	29.5	374.4	787.5	496.6	259.9	7.7	0.0	0.0	0.0	1956.1
1994	0.0	0.0	0.7	67.4	470.7	856.4	153.7	45.8	0.0	0.3	0.0	1595.0
1995	0.0	0.0	2.7	373.2	1776.5	693.5	95.5	3.5	0.3	0.0	0.0	2945.3
1996	0.0	0.0	0.1	47.1	446.6	156.2	13.6	3.2	3.2	0.0	0.0	669.9
1997	0.0	0.0	1.7	59.9	285.8	319.5	36.0	25.2	10.9	12.5	6.5	758.0
1998	0.0	0.0	0.2	36.5	170.5	303.4	176.6	12.0	0.3	0.0	0.0	699.6
1999	0.0	0.0	0.3	37.1	216.6	240.6	146.4	45.8	9.6	0.1	0.0	696.5
					Mean weight at age (kg)							
1980	----	0.030	0.076	0.157	0.237	0.279	0.311	0.392	0.000	----	----	0.222
1981	----	0.037	0.089	0.124	0.160	0.169	0.189	0.171	0.209	----	----	0.136
1982	----	0.029	0.126	0.148	0.155	0.182	0.173	----	----	----	----	0.147
1983	0.007	0.024	0.083	0.165	0.197	0.213	0.228	0.234	0.308	0.229	----	0.190
1984	----	----	0.103	0.162	0.205	0.241	0.253	0.317	0.432	----	----	0.217
1985	----	0.030	0.088	0.112	0.132	0.155	0.168	0.000	0.000	----	----	0.115
1986	----	0.035	0.072	0.128	0.167	0.189	0.171	0.295	----	----	----	0.144
1987	----	0.020	0.084	0.154	0.202	0.246	0.286	0.295	0.116	----	----	0.184
1988	----	0.019	0.068	0.165	0.193	0.226	0.262	0.359	----	----	----	0.155
1989	----	0.017	0.066	0.168	0.233	0.245	0.239	0.209	0.369	----	----	0.179
1990	----	0.015	0.067	0.182	0.255	0.270	0.300	0.359	0.432	----	----	0.211
1991	----	0.019	0.063	0.135	0.260	0.284	0.406	0.515	----	----	----	0.235
1992	----	0.039	0.079	0.162	0.267	0.353	0.374	0.290	0.239	----	----	0.279
1993	----	0.017	0.090	0.208	0.260	0.326	0.380	0.371	----	----	----	0.264
1994	----	0.047	0.102	0.225	0.278	0.336	0.371	0.415	----	0.609	----	0.314
1995	----	----	0.156	0.262	0.312	0.359	0.380	0.489	0.295	0.000	----	0.316
1996	----	0.065	0.101	0.233	0.285	0.307	0.349	0.366	0.359	0.000	----	0.287
1997	----	0.065	0.170	0.207	0.259	0.262	0.281	0.260	0.239	0.295	0.295	0.256
1998	0.065	0.138	0.246	0.271	0.287	0.310	0.299	0.515	----	----	----	0.286
1999	----	0.143	0.285	0.314	0.337	0.341	0.323	0.291	0.515	----	----	0.326

* Provisional

Table A9. Catch at age (thousands of fish; metric tons) and mean weight (kg), of commercial landings, and large mesh and northern shrimp fishery discards of American plaice from Gulf of Maine - Georges Bank, and South, 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Catch in Numbers (000's) at Age																
1980	0	5	99	1072	2672	3939	3933	3632	1185	1139	850	323	155	215	687	19906
1981	0	5	982	2192	5055	5337	3648	2401	1582	645	440	196	146	45	234	22907
1982	0	10	603	3348	4574	4503	3599	3297	2038	1256	737	317	34	137	230	24681
1983	0	15	663	1478	5177	4918	3913	2270	1272	701	450	455	230	59	168	21768
1984	1	3	370	991	2422	6031	3244	1936	580	274	307	65	57	0	647	16928
1985	0	65	158	1217	1336	2405	2872	2228	1081	438	267	79	54	19	30	12250
1986	0	59	639	738	2284	1700	1476	1307	631	255	105	51	26	7	15	9295
1987	0	38	590	1840	1439	2282	1337	895	543	187	62	26	15	14	5	9274
1988	0	314	786	1840	1833	1597	1444	553	270	177	88	25	13	11	6	8957
1989	0	132	1653	1831	1125	829	536	753	471	193	103	35	29	22	31	7740
1990	0	68	676	3389	2664	1369	531	291	349	193	96	74	42	16	29	9787
1991	0	13	323	1001	4410	3403	1123	321	164	201	97	66	23	9	6	11161
1992	0	37	231	1083	2222	6810	2724	819	198	131	118	38	33	18	4	14467
1993	0	107	426	2032	4141	3583	3139	1403	265	287	151	71	22	7	25	15658
1994*	1	288	506	623	2627	4459	1703	1288	608	240	153	64	49	26	157	12791
1995*	1	518	1488	2285	6503	4826	2001	654	584	212	53	26	16	0	8	19175
1996*	0	195	936	1418	4443	2958	1471	549	250	125	35	21	15	22	5	12444
1997*	0	158	1375	803	2739	3919	1701	718	230	128	89	48	19	11	41	11978
1998*	0	37	63	281	883	2607	2476	1044	320	60	57	24	22	22	87	7983
1999*	0	4	202	205	985	1713	2073	1273	463	143	41	42	23	3	10	7180
Catch at Age (mt)																Total
1980	0	0	10	160	705	1609	2571	3009	1232	1347	1168	508	269	391	1448	14429
1981	0	1	106	353	1570	2351	2838	2126	1547	729	552	266	257	82	358	13134
1982	0	1	75	735	1277	1870	2020	3164	2320	1502	1144	551	65	224	524	15471
1983	0	1	16	179	1781	2527	2608	1872	1334	876	660	649	417	121	394	13436
1984	0	1	14	144	700	3105	2037	1719	688	310	421	134	93	0	1279	10644
1985	0	1	15	62	249	769	1525	1884	1263	603	445	158	115	42	73	7203
1986	0	2	15	100	412	637	865	1101	741	380	183	102	58	17	42	4655
1987	0	2	30	187	295	883	813	798	637	278	107	56	34	32	15	4165
1988	0	3	28	247	483	705	925	484	333	247	151	49	29	26	20	3730
1989	0	2	68	247	309	370	303	554	403	257	150	62	51	46	66	2888
1990	0	1	39	469	707	623	339	240	338	210	125	104	76	30	62	3364
1991	0	0	17	120	1458	1696	797	308	191	256	150	107	46	18	17	5182
1992	0	1	15	173	701	3304	1956	776	238	173	193	72	63	40	13	7717
1993	0	2	33	430	1259	1556	1852	1313	327	399	238	126	55	13	94	7699
1994	0	4	14	121	863	1866	961	984	659	309	217	106	92	54	466	6715
1995	0	6	40	464	2091	2178	1238	534	653	283	112	51	28	0	17	7695
1996	0	3	35	155	1503	1403	937	495	294	172	55	41	33	57	13	5196
1997	0	2	29	89	865	1577	1030	536	219	127	112	82	40	32	131	4872
1998	0	1	2	46	247	960	1268	830	326	80	83	38	57	59	351	4348
1999	0	0	4	41	319	712	1104	888	405	158	59	75	46	6	20	3835

Table A9. Cont. Catch at age (thousands of fish; metric tons) and mean weight (kg), of commercial landings, and large mesh and northern shrimp fishery discards of American plaice from Gulf of Maine - Georges Bank, and South, 1980-1999.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
							Mean Weight at Age (kg)									Average
1980	0.000	0.030	0.076	0.154	0.267	0.409	0.653	0.829	1.039	1.183	1.374	1.573	1.732	1.815	2.109	0.725
1981	0.000	0.032	0.108	0.168	0.316	0.442	0.778	0.885	0.978	1.130	1.254	1.354	1.755	1.836	1.534	0.576
1982	0.000	0.018	0.115	0.230	0.290	0.418	0.564	0.960	1.138	1.196	1.552	1.737	1.944	1.636	2.281	0.631
1983	0.002	0.013	0.033	0.185	0.378	0.530	0.670	0.823	1.042	1.238	1.446	1.404	1.762	1.843	2.255	0.630
1984	0.000	0.004	0.045	0.161	0.303	0.524	0.630	0.888	1.187	1.133	1.369	2.058	1.628	2.014	1.977	0.636
1985	0.000	0.018	0.058	0.084	0.209	0.331	0.534	0.847	1.167	1.377	1.665	1.991	2.115	2.254	2.437	0.596
1986	0.001	0.016	0.042	0.138	0.229	0.384	0.587	0.842	1.174	1.491	1.747	2.002	2.207	2.344	2.751	0.516
1987	0.000	0.013	0.046	0.131	0.234	0.409	0.609	0.892	1.173	1.483	1.732	2.148	2.213	2.359	2.988	0.465
1988	0.000	0.016	0.046	0.159	0.284	0.449	0.641	0.880	1.231	1.396	1.717	1.991	2.265	2.278	3.074	0.429
1989	0.000	0.012	0.041	0.135	0.275	0.446	0.566	0.736	0.857	1.334	1.463	1.789	1.780	2.106	2.142	0.373
1990	0.000	0.021	0.058	0.138	0.265	0.455	0.639	0.824	0.968	1.089	1.305	1.409	1.811	1.881	2.154	0.344
1991	0.000	0.015	0.053	0.120	0.330	0.498	0.710	0.960	1.161	1.276	1.541	1.618	2.012	2.050	2.837	0.464
1992	0.000	0.028	0.065	0.159	0.315	0.485	0.717	0.948	1.202	1.319	1.640	1.902	1.928	2.151	2.884	0.533
1993	0.000	0.016	0.078	0.212	0.304	0.434	0.590	0.936	1.234	1.393	1.577	1.784	2.468	1.989	3.750	0.492
1994	0.001	0.014	0.028	0.194	0.328	0.418	0.564	0.763	1.083	1.287	1.424	1.657	1.880	2.082	2.963	0.525
1995	0.001	0.012	0.027	0.203	0.322	0.453	0.646	0.909	1.166	1.099	2.105	1.934	1.757	0.000	2.213	0.407
1996	0.000	0.014	0.038	0.110	0.338	0.474	0.637	0.902	1.172	1.383	1.565	1.962	2.127	2.525	2.486	0.418
1997	0.000	0.014	0.021	0.111	0.316	0.402	0.605	0.746	0.951	0.992	1.256	1.709	2.138	3.084	3.231	0.407
1998	0.001	0.013	0.030	0.165	0.281	0.371	0.518	0.805	1.031	1.350	1.463	1.628	2.622	2.703	4.066	0.550
1999	0.000	0.008	0.018	0.198	0.324	0.417	0.535	0.702	0.879	1.112	1.462	1.799	2.020	2.082	2.067	0.537
1980-	0.001	0.016	0.051	0.158	0.296	0.438	0.620	0.854	1.092	1.263	1.533	1.772	2.008	2.051	2.610	0.513
1995-	0.001	0.012	0.027	0.157	0.316	0.424	0.588	0.813	1.040	1.187	1.570	1.806	2.133	2.079	2.813	0.464

* Provisional

Table A10. Standardized stratified mean number and mean weight per tow (kg) of American plaice in NEFSC spring and autumn bottom trawl surveys in the Gulf of Maine - Georges Bank area, 1963 -2000 (Offshore strata 26-30,36-40,13-25).

	SPRING		**AUTUMN**	
	Number	Weight	Number	Weight
1963	---	---	14.17	5.87
1964	---	---	8.20	2.84
1965	---	---	11.95	3.80
1966	---	---	17.78	4.90
1967	---	---	11.05	2.69
1968	11.36	3.40	8.61	2.91
1969	8.59	2.68	7.51	2.36
1970	5.43	1.81	6.46	2.01
1971	3.80	1.26	7.47	1.96
1972	4.28	1.32	7.44	1.60
1973	7.18	1.85	6.19	1.94
1974	8.34	1.94	6.89	1.42
1975	5.78	1.72	8.12	2.43
1976	11.85	3.37	9.98	2.99
1977	14.57	5.11	11.80	3.52
1978	10.61	3.82	15.13	4.66
1979	9.23	3.62	9.96	4.00
1980	18.34	4.78	14.24	5.12
1981	18.75	5.88	13.04	5.62
1982	11.61	3.80	5.88	2.49
1983	16.94	4.60	9.34	3.45
1984	4.10	1.42	7.12	2.02
1985	4.94	1.88	6.95	2.00
1986	3.09	0.92	5.61	1.56
1987	3.50	0.81	4.38	1.09
1988	3.58	0.84	9.69	1.46
1989	4.81	0.75	9.21	1.17
1990	5.09	0.75	15.46	2.90
1991	5.91	1.05	7.71	1.56
1992	4.11	1.36	6.31	1.78
1993	5.29	1.39	11.89	2.39
1994	4.89	0.85	18.07	2.67
1995	9.43	1.94	11.84	2.58
1996	7.83	1.69	7.58	2.23
1997	7.62	1.62	6.27	1.94
1998	4.52	1.11	9.29	2.22
1999	4.18	1.20	11.03	2.57
2000	9.96	2.30		

Table A11. Standardized stratified mean number per tow by age and mean weight per tow (kg) of American plaice in NEFSC spring and autumn bottom trawl surveys in the Gulf of Maine - Georges Bank[1] area, 1980-2000

	AGE GROUP																
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	#/tow	kg/tow
Spring																	
1980	0.00	0.57	3.55	4.49	3.00	2.89	1.60	1.12	0.25	0.31	0.23	0.04	0.02	0.02	0.04	18.34	4.78
1981	0.00	0.13	3.49	4.31	3.55	2.67	1.74	1.45	0.79	0.41	0.34	0.07	0.09	0.07	0.09	18.75	5.88
1982	0.00	0.06	1.04	1.79	3.17	2.13	1.34	0.92	0.49	0.35	0.19	0.07	0.01	0.04	0.02	11.601	3.80
1983	0.00	0.20	3.68	3.33	4.48	2.64	1.18	0.58	0.32	0.15	0.15	0.11	0.05	0.02	0.04	16.94	4.60
1984	0.00	0.02	0.35	0.57	0.90	1.30	0.58	0.22	0.10	0.01	0.02	0.01	0.01	0.00	0.03	4.10	1.42
1985	0.00	0.03	0.32	0.98	0.86	0.73	0.86	0.46	0.42	0.12	0.07	0.04	0.02	0.02	0.02	4.94	1.88
1986	0.00	0.01	0.46	0.34	1.01	0.59	0.29	0.21	0.10	0.04	0.04	0.00	0.00	0.00	0.00	3.09	0.92
1987	0.00	0.09	0.61	0.99	0.69	0.51	0.25	0.17	0.07	0.03	0.03	0.03	0.01	0.00	0.00	3.50	0.81
1988	0.00	0.20	0.99	0.84	0.76	0.31	0.23	0.12	0.01	0.09	0.01	0.01	0.00	0.00	0.00	3.58	0.84
1989	0.00	0.05	1.59	1.27	0.86	0.49	0.29	0.16	0.03	0.07	0.01	0.01	0.00	0.00	0.00	4.81	0.75
1990	0.00	0.00	0.57	2.65	1.02	0.54	0.17	0.06	0.04	0.05	0.00	0.00	0.00	0.00	0.00	5.09	0.75
1991	0.00	0.03	0.71	1.63	2.33	0.92	0.15	0.07	0.04	0.02	0.00	0.02	0.00	0.00	0.01	5.91	1.05
1992	0.00	0.06	0.34	1.15	0.88	1.07	0.43	0.11	0.04	0.02	0.01	0.00	0.01	0.00	0.00	4.11	1.36
1993	0.00	0.33	0.84	1.16	1.58	0.61	0.45	0.17	0.08	0.02	0.01	0.02	0.03	0.00	0.00	5.29	1.39
1994	0.00	0.03	1.43	1.14	1.12	0.75	0.23	0.10	0.03	0.01	0.00	0.01	0.01	0.01	0.01	4.88	0.85
1995	0.00	0.31	1.97	3.21	2.31	1.11	0.44	0.22	0.03	0.03	0.03	0.01	0.02	0.01	0.01	9.43	1.94
1996	0.00	0.02	0.47	1.94	3.30	1.31	0.53	0.20	0.05	0.02	0.00	0.00	0.00	0.00	0.00	7.83	1.69
1997	0.00	0.01	0.85	1.66	2.52	2.05	0.39	0.09	0.01	0.00	0.01	0.00	0.02	0.00	0.00	7.62	1.62
1998	0.00	0.06	0.19	1.02	1.12	1.22	0.68	0.16	0.06	0.01	0.01	0.003	0.01	0.00	0.00	4.52	1.11
1999	0.00	0.08	0.41	0.52	1.13	0.79	0.64	0.41	0.17	0.02	0.02	0.00	0.00	0.00	0.00	4.18	1.20
2000	0.00	0.03	1.91	2.48	2.22	1.60	0.86	0.60	0.15	0.07	0.02	0.003	0.01	0.00	0.00	9.96	2.30

Table A11. Cont. Standardized stratified mean number per tow by age and mean weight per tow (kg) of American plaice in NEFSC spring and autumn bottom trawl surveys in the Gulf of Maine - Georges Bank[1] area, 1980-2000.

	AGE GROUP															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	#/tow	kg/tow
Autumn [1]																	
1980	0.00	1.58	2.22	2.72	2.85	1.53	1.03	0.93	0.57	0.31	0.20	0.11	0.04	0.07	0.08	14.24	5.12
1981	0.00	0.43	2.79	2.22	2.62	2.30	1.55	0.63	0.58	0.07	0.20	0.20	0.02	0.02	0.12	13.04	5.62
1982	0.00	0.20	0.91	1.65	1.27	0.57	0.48	0.30	0.17	0.19	0.08	0.03	0.00	0.00	0.02	5.88	2.49
1983	0.06	0.50	1.01	2.02	2.92	1.36	0.68	0.34	0.17	0.10	0.03	0.05	0.06	0.01	0.03	9.34	3.45
1984	0.02	0.22	2.24	1.56	1.21	1.07	0.51	0.12	0.10	0.00	0.03	0.01	0.02	0.00	0.01	7.12	2.02
1985	0.02	0.91	0.83	2.64	1.05	0.79	0.41	0.19	0.05	0.03	0.02	0.00	0.00	0.01	0.00	6.95	2.00
1986	0.10	0.51	1.48	0.89	1.45	0.47	0.43	0.16	0.12	0.04	0.01	0.02	0.01	0.00	0.00	5.61	1.56
1987	0.01	0.53	1.27	0.99	0.43	0.69	0.25	0.10	0.04	0.04	0.01	0.02	0.00	0.00	0.00	4.38	1.09
1988	0.00	2.84	2.97	2.39	0.78	0.47	0.10	0.07	0.00	0.03	0.00	0.02	0.00	0.00	0.00	9.69	1.46
1989	0.05	0.48	4.45	2.86	0.98	0.19	0.10	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.00	9.21	1.17
1990	0.01	1.52	2.26	7.49	2.89	0.59	0.25	0.11	0.07	0.02	0.02	0.01	0.01	0.00	0.01	15.46	2.90
1991	0.02	0.47	2.48	2.03	1.59	0.73	0.30	0.04	0.07	0.00	0.01	0.00	0.00	0.00	0.01	7.71	1.56
1992	0.02	0.65	1.23	1.85	1.28	0.78	0.30	0.07	0.05	0.03	0.02	0.00	0.02	0.00	0.00	6.31	1.78
1993	0.01	1.71	2.35	3.47	2.28	1.05	0.80	0.11	0.04	0.04	0.04	0.00	0.00	0.00	0.00	11.89	2.39
1994	0.04	3.83	7.53	2.81	1.71	1.30	0.04	0.25	0.13	0.01	0.03	0.02	0.00	0.00	0.00	18.07	2.67
1995	0.01	0.50	3.80	3.82	2.50	0.90	0.22	0.04	0.03	0.00	0.00	0.00	0.02	0.00	0.00	11.84	2.58
1996	0.01	0.54	0.81	2.00	2.74	0.93	0.39	0.07	0.04	0.03	0.00	0.00	0.02	0.00	0.02	7.58	2.23
1997	0.01	0.36	1.06	1.55	1.86	1.04	0.32	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.02	6.27	1.94
1998	0.01	1.73	0.60	1.88	2.01	1.78	1.08	0.12	0.05	0.01	0.01	0.00	0.01	0.00	0.00	9.29	2.22
1999	0.02	2.00	2.20	2.05	2.13	1.60	0.81	0.20	0.03	0.00	0.00	0.00	0.00	0.00	0.00	11.03	2.57

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[1] Offshore strata 13-30, 36-40

Table A 12. Stratified mean number per tow by age of American plaice in Massachusetts State spring and autumn bottom trawl surveys in Massachusetts Bay and Cape Cod Bay (Regions 4+5), 1982-2000.

						Age							
Year	0	1	2	3	4	5	6	7	8	9	10	11	Total #/Tow
Spring													
1982	0.00	7.18	49.25	33.35	17.14	5.00	2.42	1.12	0.26	0.15	0.03	0.07	115.97
1983	0.00	1.93	18.76	22.42	21.46	10.22	2.37	0.73	0.20	0.19	0.06	0.10	78.44
1984	0.00	2.15	27.44	21.32	10.57	4.64	1.21	0.18	0.09	0.01	0.03	0.07	67.71
1985	0.00	21.56	17.16	24.22	9.50	3.77	2.24	0.65	0.76	0.12	0.04	0.03	80.05
1986	0.00	27.06	110.27	26.91	14.43	2.84	0.61	0.05	0.08	0.06	0.00	0.16	182.47
1987	0.00	34.36	17.26	15.79	3.90	1.76	0.51	0.10	0.02	0.00	0.00	0.00	73.70
1988	0.00	81.47	63.57	17.85	8.72	1.54	0.47	0.09	0.00	0.00	0.00	0.00	173.71
1989	0.00	8.07	127.26	44.97	11.99	3.03	1.31	0.20	0.03	0.03	0.00	0.05	196.94
1990	0.00	7.73	25.37	56.71	16.48	3.43	0.53	0.11	0.10	0.13	0.00	0.00	110.59
1991	0.00	2.10	19.98	34.77	18.98	3.24	0.18	0.07	0.01	0.00	0.00	0.00	79.33
1992	0.00	8.20	11.06	33.98	14.99	7.42	1.11	0.45	0.00	0.00	0.00	0.00	77.21
1993	0.00	11.60	18.98	16.08	9.16	3.45	0.81	0.04	0.02	0.00	0.00	0.00	60.14
1994	0.00	11.60	52.57	22.12	7.13	3.88	1.03	0.31	0.00	0.00	0.00	0.00	98.64
1995	0.00	0.54	34.65	49.64	10.32	3.16	0.62	0.17	0.03	0.05	0.02	0.00	99.20
1996	0.00	2.29	4.14	14.92	31.39	6.33	1.01	0.77	0.01	0.00	0.00	0.00	60.86
1997	0.00	1.55	7.96	13.95	17.24	12.21	2.41	0.21	0.00	0.00	0.00	0.00	55.52
1998	0.00	2.83	4.33	11.45	7.53	8.93	3.95	0.49		0.03	0.00	0.00	39.54
1999	0.00	1.35	11.65	11.65	15.11	7.57	3.96	1.62	0.35	0.01	0.00	0.00	53.27
2000	0.00	3.45	56.51	34.86	19.98	13.29	4.95	3.64	0.17	0.03	0.00	0.00	136.88
Autumn													
1982	0.17	13.24	15.46	10.22	5.11	1.14	0.56	0.14	0.05	0.05	0.01	0.08	46.23
1983	1.29	52.17	18.98	10.02	8.30	1.39	0.32	0.15	0.05	0.06	0.00	0.01	92.74
1984	0.11	3.14	13.24	4.27	1.83	0.77	0.24	0.04	0.05	0.00	0.00	0.00	23.69
1985	0.00	60.97	9.45	14.21	1.56	0.14	0.03	0.02	0.00	0.00	0.00	0.00	86.38
1986	0.23	41.27	40.08	12.07	5.30	0.39	0.13	0.01	0.00	0.00	0.00	0.00	99.48
1987	0.24	46.36	14.60	3.00	0.52	0.23	0.07	0.01	0.04	0.00	0.00	0.00	65.07
1988	0.00	85.63	41.28	13.98	1.34	0.45	0.08	0.00	0.00	0.00	0.00	0.00	142.76
1989	0.03	57.56	122.25	31.03	2.33	0.13	0.01	0.01	0.00	0.00	0.00	0.00	213.35
1990	0.08	31.99	14.20	20.12	3.93	0.21	0.03	0.00	0.00	0.00	0.00	0.00	70.56
1991	0.04	24.07	90.36	40.05	11.51	1.17	0.14	0.00	0.00	0.00	0.00	0.00	167.34
1992	0.00	46.33	12.99	29.79	11.04	1.38	0.00	0.00	0.12	0.00	0.00	0.00	101.66
1993	0.00	76.21	36.80	17.59	6.85	1.71	0.69	0.00	0.00	0.00	0.00	0.00	139.84
1994	0.00	36.71	79.31	10.76	2.91	1.56	0.23	0.14	0.00	0.00	0.00	0.00	131.62
1995	0.00	11.84	44.22	24.93	4.21	0.91	0.08	0	0.00	0.00	0.00	0.00	86.19
1996	0.09	16.25	19.25	27.55	13.96	1.39	0.28	0	0.00	0.00	0.00	0.00	78.78
1997	0.00	13.61	28.08	17.91	10.29	1.46	0.19	0.01	0.00	0.00	0.00	0.00	71.55
1998	0.16	34.56	6.12	13.80	7.10	3.76	0.62	0.01	0.00	0.00	0.00	0.00	66.13
1999	0.00	29.23	32.57	20.61	10.58	2.85	1.2	0.41	0.00	0.00	0.00	0.00	97.45
2000													

Table A13. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F) and spawning stock biomass (mt) of Gulf of Maine-Georges Bank American plaice, estimated from virtual population analysis (VPA) and calibrated using the commercial catch at age ADAPT formulation, 1980-1999.

Stock Number's (Jan 1) in thousands

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	200
1	52643	25119	21949	25120	13184	14385	18443	36859	53355	27101	33361	33777	39816	50074	41884	24426	24189	13064	27527	34453	1418
2	42217	43096	20561	17962	20553	10791	11719	15046	30143	43399	22069	27252	27643	32565	40900	34031	19529	19628	10553	22504	2820
3	35915	34475	34395	16288	14106	16492	8692	9017	11785	23968	34036	17457	22020	22423	26276	33028	26516	15142	14826	8583	1824
4	24231	28434	26242	25131	11998	10652	12402	6449	5717	7984	17966	24800	13387	17049	16520	20950	24974	20426	11671	11884	684
5	21550	17421	18706	17346	15891	7632	7512	8087	3978	3022	5519	12299	16314	8949	10211	11148	11268	16427	14245	8756	883
6	17203	14080	9434	11241	9752	7554	4072	4612	4556	1812	1724	3280	6991	7195	4085	4326	4761	6549	9903	9304	561
7	11092	10526	8227	4467	5663	5049	3586	1909	2567	2424	998	931	1669	3259	3051	1804	1731	2567	3823	5867	574
8	5101	5795	6446	3752	1603	2884	2118	1753	826	1601	1303	554	472	625	1398	1332	885	920	1452	2185	365
9+	14407	6202	8496	6026	3695	2342	1531	989	974	1386	1668	1347	806	1313	1563	710	787	1331	1226	1224	213
1 +	224359	185147	154455	127333	96445	77782	70075	84810	113900	112695	118645	121698	129116	143451	145888	131754	114639	96054	95225	104761	9346

Fishing Mortality

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	0	0	0	0	0	0.01	0	0	0.01	0.01	0	0	0	0	0.01	0.02	0.01	0.01	0	0
2	0	0.03	0.03	0.04	0.02	0.02	0.06	0.04	0.03	0.04	0.03	0.01	0.01	0.01	0.01	0.05	0.05	0.08	0.01	0.01
3	0.03	0.07	0.11	0.11	0.08	0.09	0.1	0.26	0.19	0.09	0.12	0.07	0.06	0.11	0.03	0.08	0.06	0.06	0.02	0.03
4	0.13	0.22	0.21	0.26	0.25	0.15	0.23	0.28	0.44	0.17	0.18	0.22	0.2	0.31	0.19	0.42	0.22	0.16	0.09	0.1
5	0.23	0.41	0.31	0.38	0.54	0.43	0.29	0.37	0.59	0.36	0.32	0.36	0.62	0.58	0.66	0.65	0.34	0.31	0.23	0.24
6	0.29	0.34	0.55	0.49	0.46	0.55	0.51	0.39	0.43	0.4	0.42	0.48	0.56	0.66	0.62	0.72	0.42	0.34	0.32	0.28
7	0.45	0.29	0.59	0.82	0.47	0.67	0.52	0.68	0.27	0.42	0.39	0.48	0.78	0.65	0.63	0.51	0.43	0.37	0.36	0.27
8	0.3	0.36	0.43	0.47	0.51	0.53	0.4	0.42	0.45	0.39	0.35	0.4	0.62	0.63	0.65	0.66	0.37	0.32	0.28	0.27
9+	0.3	0.36	0.43	0.47	0.51	0.53	0.4	0.42	0.45	0.39	0.35	0.4	0.62	0.63	0.65	0.66	0.37	0.32	0.28	0.27
nn 5-8,u	0.32	0.35	0.47	0.54	0.50	0.55	0.43	0.47	0.44	0.39	0.37	0.43	0.65	0.63	0.64	0.64	0.39	0.34	0.30	0.27

Table A13. Cont. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F) and spawning stock biomass (mt) of Gulf of Maine-Georges Bank American plaice, estimated from virtual population analysis (VPA) and calibrated using the commercial catch at age ADAPT formulation, 1980-1999.

SSB at the start of the spawning season - males and females (mt)

age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	24	12	8	5	0	5	11	17	0	0	0	0	0	0	0	0	0	0	0	0
2	164	186	95	32	37	12	71	92	14	21	11	17	16	15	8	6	4	3	6	10
3	878	873	1206	529	230	225	395	327	156	300	401	230	323	292	366	277	161	111	141	106
4	2413	2943	2719	3438	1321	929	1286	854	612	989	2008	3092	1526	1980	2372	2691	3536	2083	1154	1530
5	4546	4061	4723	4652	4639	1633	1788	2037	995	879	1612	3644	4999	2558	2757	3261	3616	5021	4029	2466
6	7938	6457	3632	4659	4447	3085	1488	1909	1972	779	781	1558	3420	3075	1632	1771	2169	3037	3922	3641
7	7052	6935	5724	2308	3615	2907	2012	1160	1670	1426	589	615	1071	2160	1664	1081	1128	1534	2320	3143
8	4181	4535	5528	3174	1326	2444	1818	1493	737	1198	958	467	413	550	1137	1013	791	748	1129	1635
9+	19380	7092	10734	7538	5126	3153	2243	1430	1350	1836	1964	1716	1061	1756	2281	800	1129	1828	2700	1526
Total	46575	33095	34370	26335	20741	14393	11111	9319	7505	7427	8324	11340	12828	12385	12217	10900	12533	14364	15401	14056

Percent Mature (females)

age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	3	3	3	3	3	3	7	7	0	0	0	0	0	0	0	0	0	0	0	0
2	8	8	8	8	8	8	24	24	2	2	2	2	2	1	1	1	1	1	3	3
3	24	24	24	24	24	24	55	55	17	17	17	17	17	12	12	12	12	12	17	17
4	52	52	52	52	52	52	83	83	65	65	65	65	65	60	60	60	60	60	60	60
5	79	79	79	79	79	79	95	95	94	94	94	94	94	94	94	94	94	94	92	92
6	93	93	93	93	93	93	99	99	99	99	99	99	99	99	99	99	99	99	99	99
7	98	98	98	98	98	98	100	100	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A14. Yield and Spawning Stock Biomass per recruit results for American plaice wher catch = landings discards. Results taken from O'Brien et *al*. (1998).

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992; Run Date: 24-11-1998; Time: 10:35:19.
American plaice Gulf of Maine-Georges Bank - 1998

Proportion of F before spawning: .2500; Proportion of M before spawning: .2500
Natural Mortality is Constant at: .200; Initial age is: 1; Last age is: 9 Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file: ==> APYPR9.DAT

```
----------------------------------------------------------
```

Age-specific Input data for Yield per Recruit Analysis

```
----------------------------------------------------------
Age | Fish Mort  Nat Mort | Proportion | Average Weights
    |  Pattern   Pattern  |   Mature   |  Catch   Stock
----------------------------------------------------------
 1  |   .0200    1.0000   |    .0000   |   .016    .010
 2  |   .0500    1.0000   |    .0400   |   .052    .029
 3  |   .0800    1.0000   |    .2400   |   .160    .092
 4  |   .4200    1.0000   |    .7200   |   .305    .221
 5  |  1.0000    1.0000   |    .9500   |   .449    .366
 6  |  1.0000    1.0000   |   1.0000   |   .632    .534
 7  |  1.0000    1.0000   |   1.0000   |   .866    .742
 8  |  1.0000    1.0000   |   1.0000   |  1.107    .980
 9+ |  1.0000    1.0000   |   1.0000   |  1.564   1.564
----------------------------------------------------------
```

Summary of Yield per Recruit Analysis for: American plaice Gulf of Maine-Georges Bank - 1

```
Slope of the Yield/Recruit Curve at F=0.00: -->        2.5298
  F level at slope=1/10 of the above slope (F0.1): ----->      .185
   Yield/Recruit corresponding to F0.1: ----->        .1792
  F level to produce Maximum Yield/Recruit (Fmax): ----->      .346
   Yield/Recruit corresponding to Fmax: ----->        .1940
  F level at 20 % of Max Spawning Potential (F20): ----->      .397

   SSB/Recruit corresponding to F20: -------->        .5065
```

Listing of Yield per Recruit Results for: American plaice Gulf of Maine-Georges Bank - 1998

```
      FMORT   TOTCTHN  TOTCTHW  TOTSTKN  TOTSTKW  SPNSTKN  SPNSTKW   % MSP
-----------------------------------------------------------------------------
       .000   .00000   .00000   5.5167   2.7847   2.8966   2.5330   100.00
       .050   .10278   .09231   5.0049   2.0916   2.3887   1.8518    73.11
       .100   .17196   .14135   4.6610   1.6510   2.0487   1.4214    56.12
       .150   .22193   .16810   4.4131   1.3517   1.8047   1.1308    44.64
F0.1 . .185   .24967   .17920   4.2757   1.1945   1.6701    .9791    38.65
       .200   .25989   .18256   4.2251   1.1384   1.6207    .9251    36.52
       .250   .28983   .18996   4.0772    .9809   1.4766    .7741    30.56
       .300   .31416   .19320   3.9574    .8611   1.3607    .6601    26.06
Fmax   .346   .33281   .19396   3.8656    .7750   1.2725    .5785    22.84
       .350   .33439   .19395   3.8579    .7679   1.2651    .5719    22.58
F20%   .397   .35046   .19332   3.7790    .6984   1.1899    .5065    20.00
       .400   .35155   .19323   3.7737    .6939   1.1848    .5023    19.83
       .450   .36634   .19165   3.7013    .6341   1.1163    .4464    17.62
       .500   .37926   .18959   3.6382    .5851   1.0571    .4008    15.82
       .550   .39069   .18727   3.5825    .5443   1.0053    .3632    14.34
       .600   .40089   .18486   3.5329    .5100    .9596    .3317    13.10
       .650   .41009   .18243   3.4883    .4808    .9188    .3051    12.04
       .700   .41845   .18005   3.4478    .4557    .8822    .2823    11.14
       .750   .42609   .17775   3.4108    .4339    .8491    .2626    10.37
       .800   .43313   .17553   3.3768    .4148    .8190    .2456     9.69
       .850   .43964   .17341   3.3454    .3980    .7915    .2306     9.10
       .900   .44570   .17139   3.3163    .3831    .7662    .2173     8.58
       .950   .45136   .16947   3.2890    .3697    .7429    .2056     8.12
```

Table A15. Input and summary of stochastic projections for Gulf of Maine-Georges Ban American plaice for fishing mortalities of $F_{0.1}$=0.19, F_{99}= 0.27, and F_{ctl} =0.04 in 2000-2002.

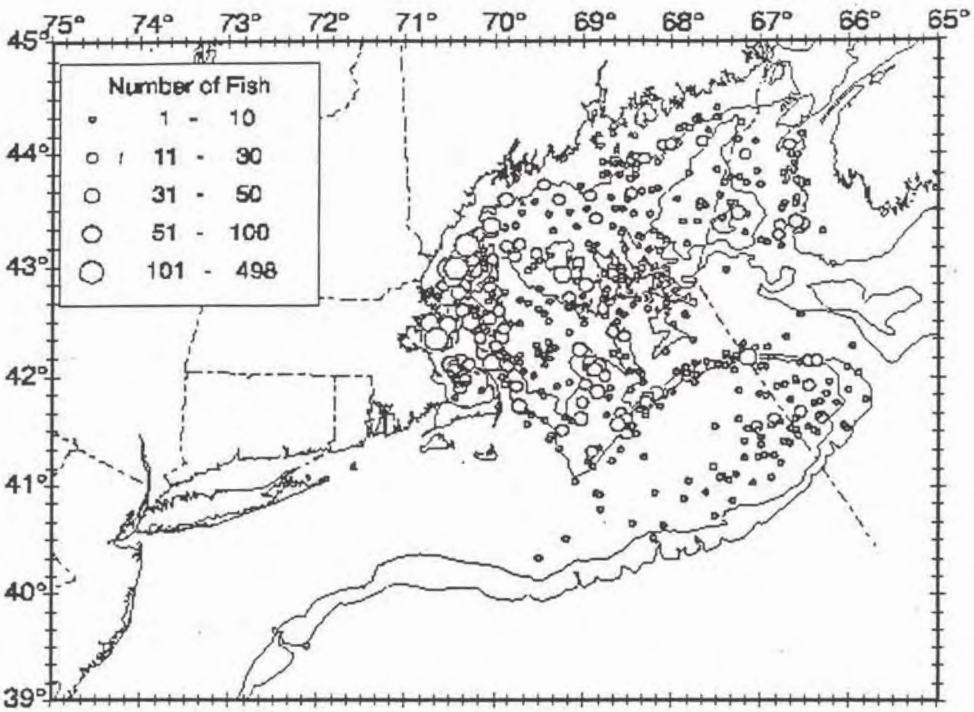
Input for Projections:

Age	Fishing Mortality(PR)	Discard Fraction	% Mature	Average Weight Stock	Landed	Discarde
1	0.03	1.00	0.00	0.009	0.012	0.012
2	0.08	1.00	0.03	0.018	0.027	0.024
3	0.12	1.00	0.17	0.066	0.157	0.148
4	0.46	0.54	0.60	0.221	0.316	0.266
5	1.00	0.33	0.92	0.366	0.423	0.303
6	1.00	0.16	0.99	0.499	0.588	0.322
7	1.00	0.10	1.00	0.694	0.813	0.336
8	1.00	0.10	1.00	0.924	1.040	0.340
9	1.00	0.00	1.00	1.701	1.701	0.509

Projection results:

Year	Recruitment	F	Median Landings	Median Discards	Median SSB
2000	27101	0.27	3701	524	16076
2001	27101	0.27	3760	549	16747
2002	27527	0.27	3945	638	17833
2000	27101	0.27	3701	524	16076
2001	27101	0.19	2743	395	17068
2002	27527	0.19	3080	474	19370
2000	27101	0.27	3701	524	16076
2001	27101	0.04	619	87	17679
2002	27527	0.04	790	111	22618

Spring Surveys 1995-2000



Autumn Surveys 1995-1999

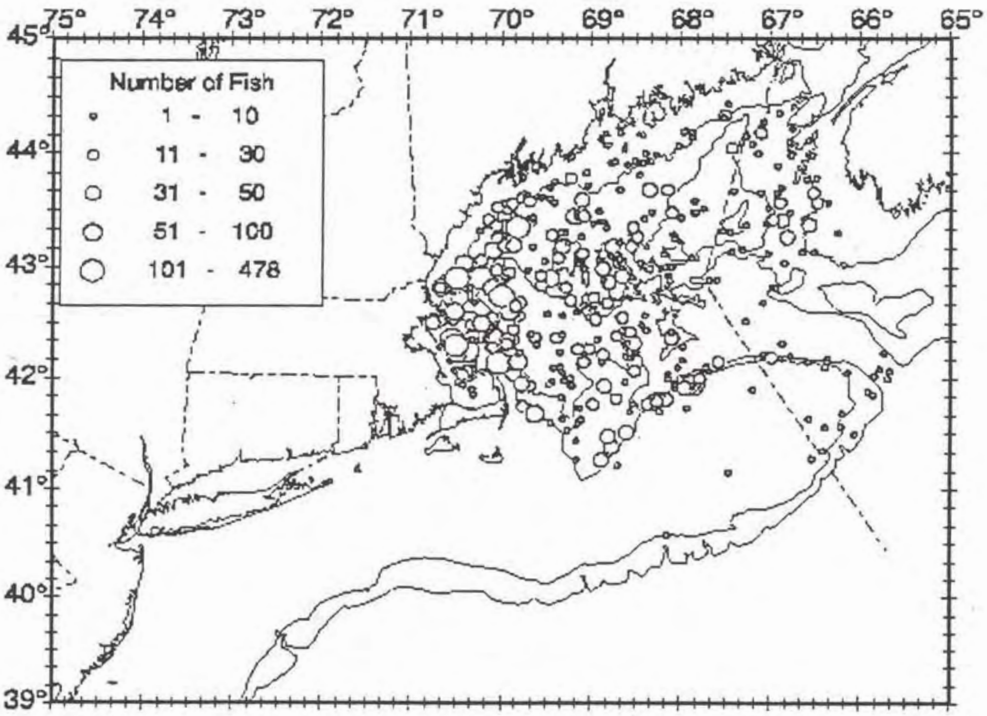


Figure A1. Distribution of American plaice in the NEFSC spring and autumn bottom trawl surv
1996-2000.

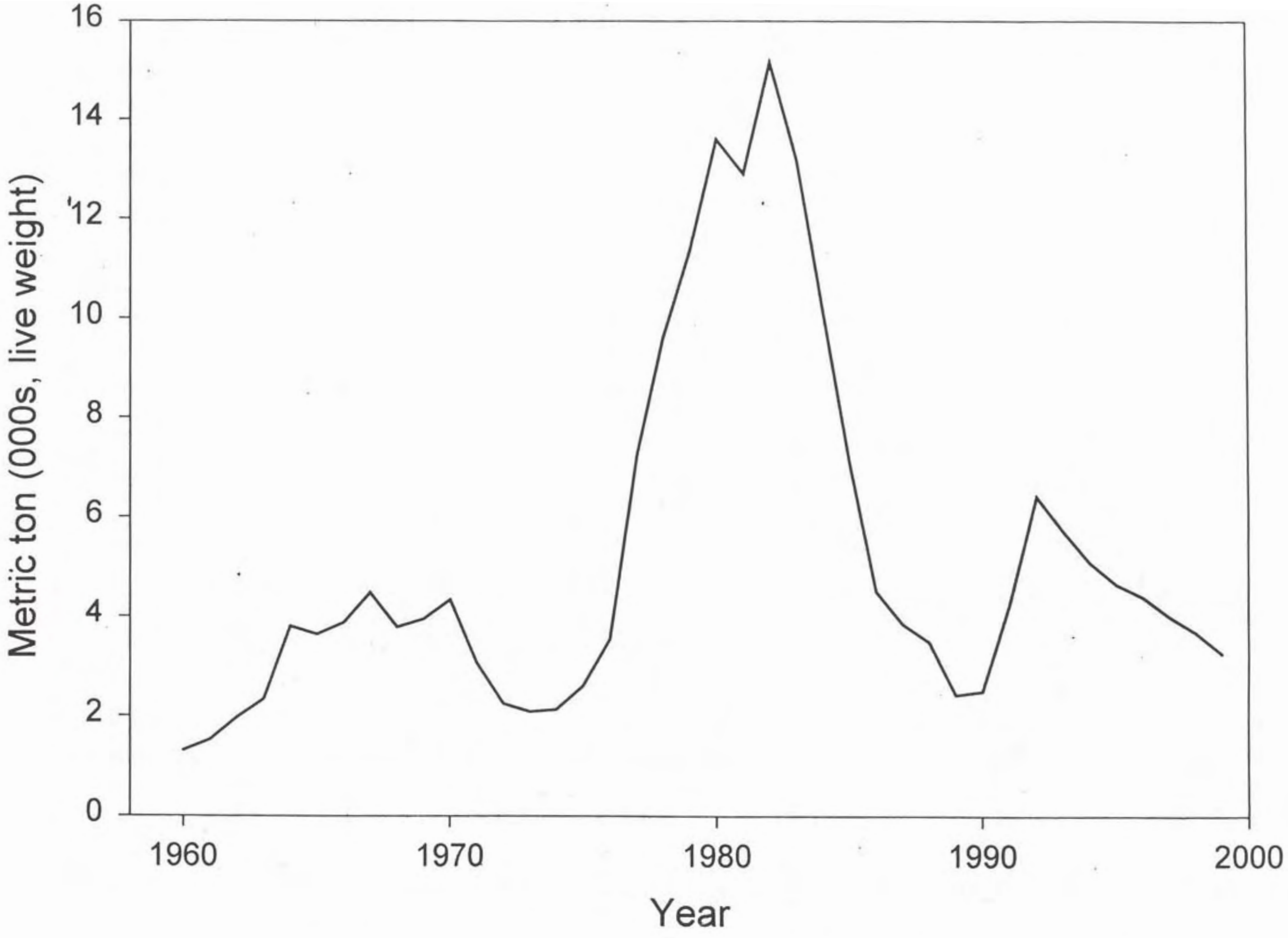


Figure A2. Total commecial landings of Gulf of Maine-Georges Bank American plaice (Division 5Z and 6), 1960-1999.

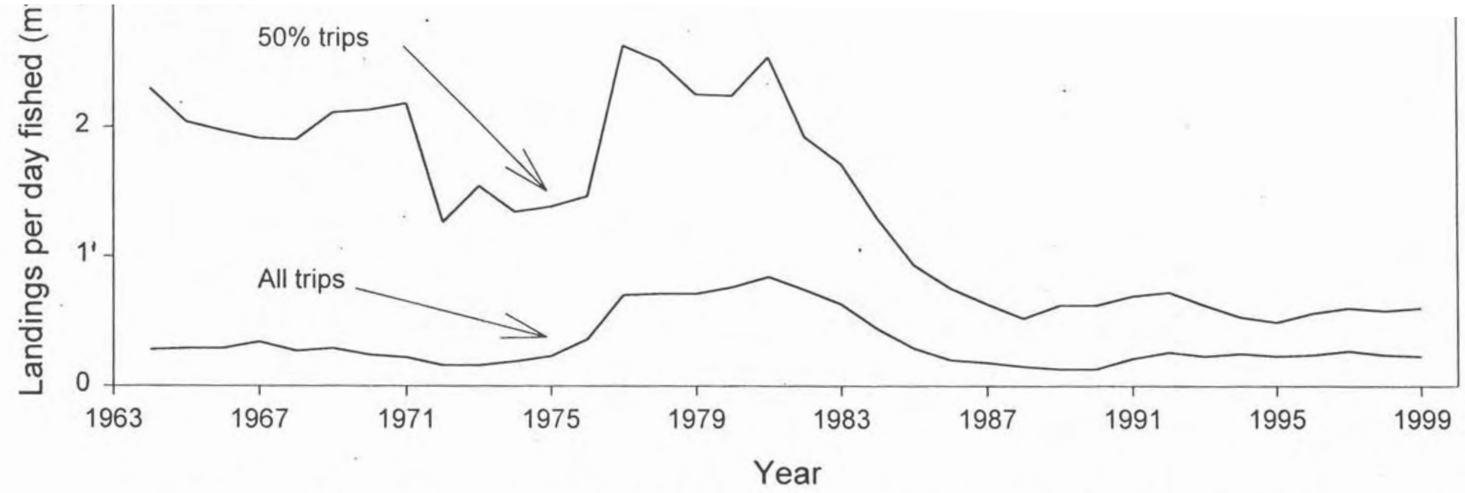


Figure A3. Trends in catch rates (landings per day (mt)) of Gulf of Maine-Georges Bank Ameican plaice for all trips landing plaice and for trips with 50% or more of the landings comprised of plaice, 1964-1999.

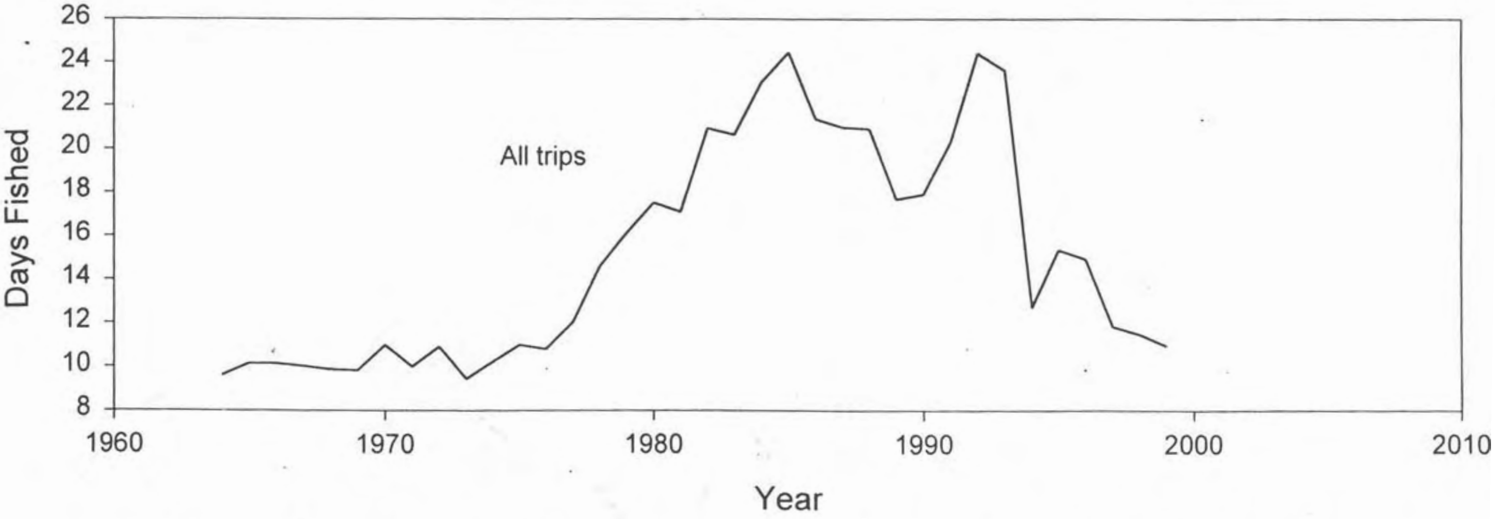


Figure A4. Trends in nominal fishing effort (days fished) for otter trawl trips landing American plaice in the Gulf of Maine-Georges Bank region, 1964-1999.

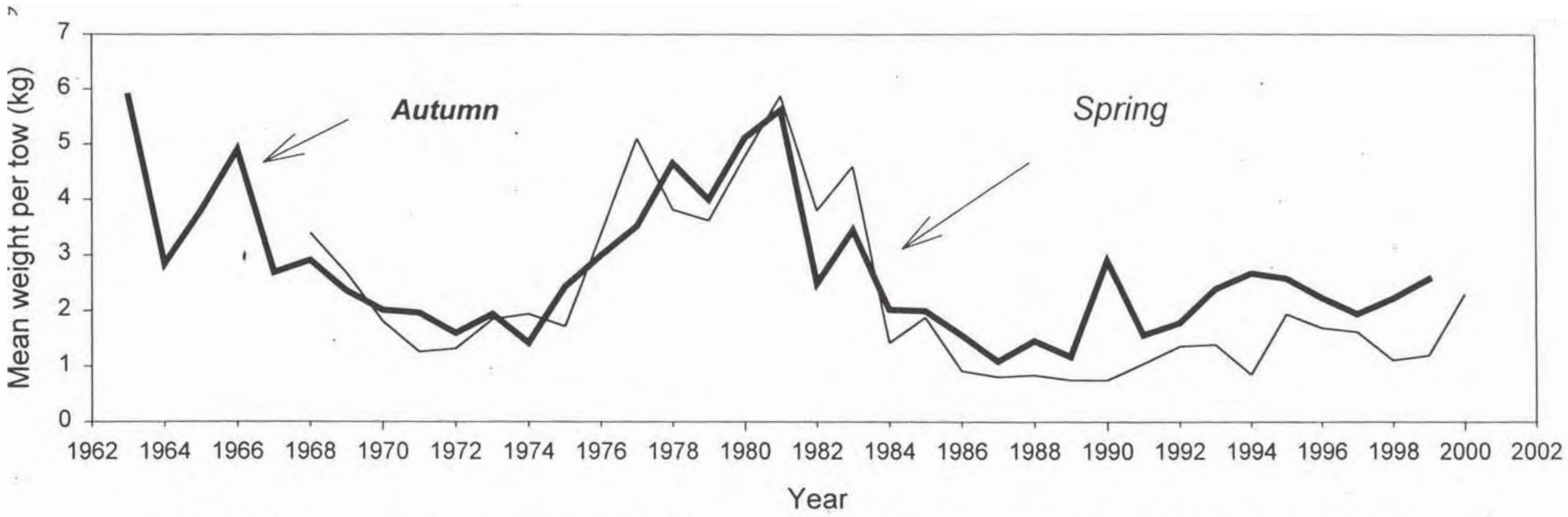


Figure A5. Standardized stratified mean weight per tow (kg) of American plaice in NEFSC spring and autumn research vessel bottom trawl survey in the Gulf of Maine-Georges Bank region, 1963-2000.

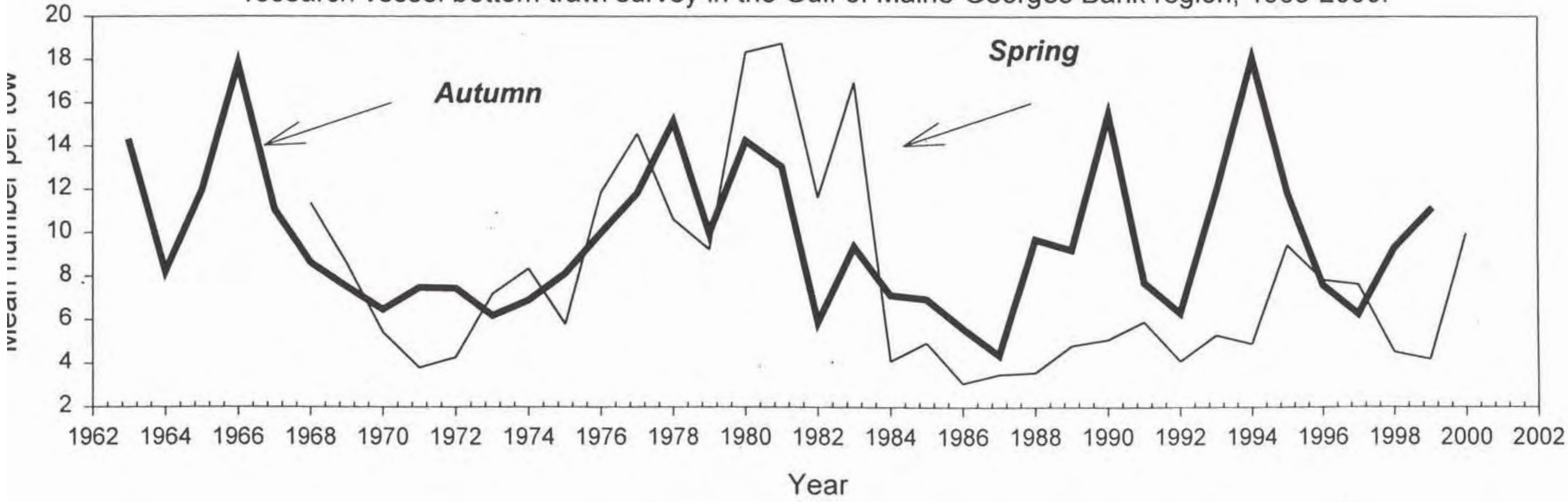


Figure A6. Standardized stratified mean number per tow (kg) of American plaice in NEFSC spring and autumn research vessel bottom trawl survey in the Gulf of Maine-Georges Bank region, 1963-2000.

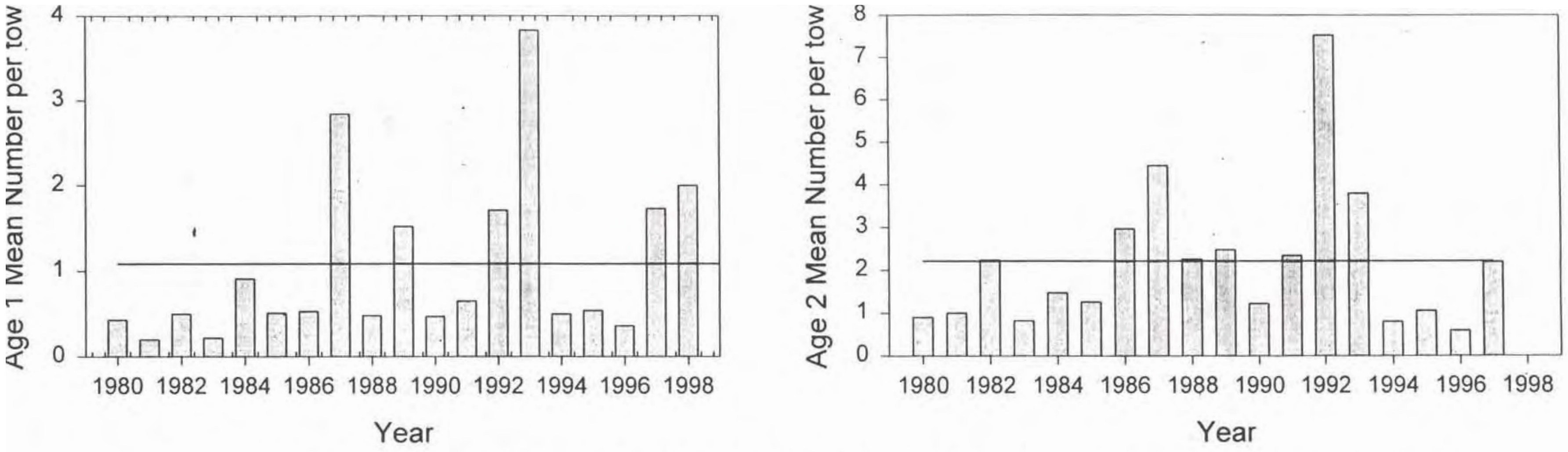


Figure A7a. Relative year class strength of age 1 and age 2 Gulf of Maine-George Bank American plaice from standardized catch (number) per tow indices from NEFSC autumn research vessel bottom trwl surveys, 1980-1999.

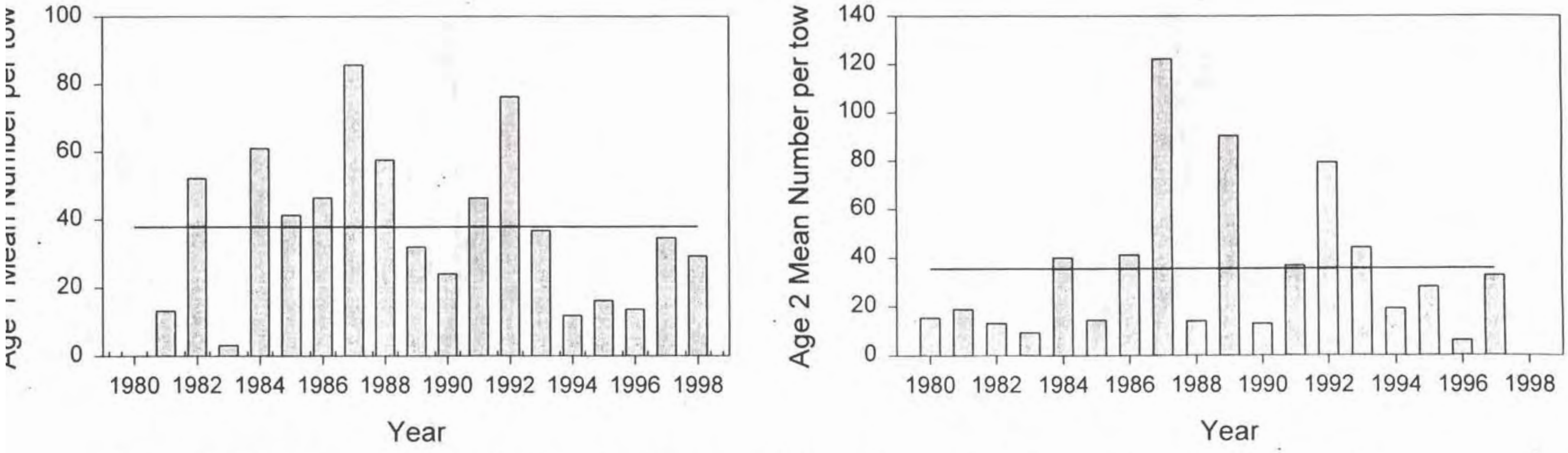


Figure A7b. Relative year class strength of age 1 and age 2 Gulf of Maine-George Bank American plaice from standardized catch (number) per tow indices from MADMF autumn research vessel bottom trwl surveys, 1980-1999.

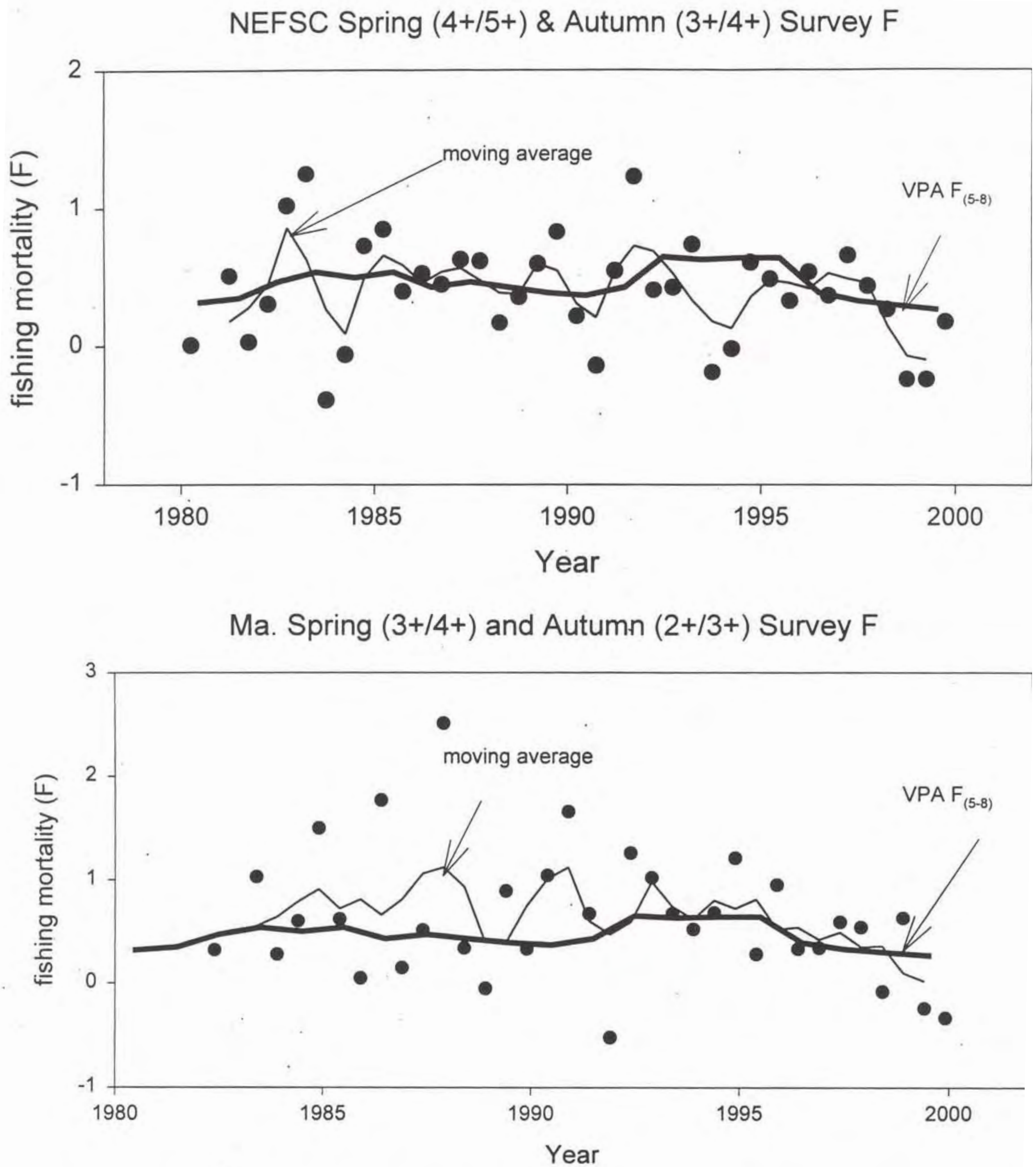


Figure A8. Mortality estimates from NEFSC (Panel A) and MADMF (Panel b) spring and autumn research bottom trawl surveys(solid circles) fitted with a smoothed 3 point running average (solid line), 1980-2000. The dashed line is the VPA estimate of mean F (ages 5-8, unweighted).

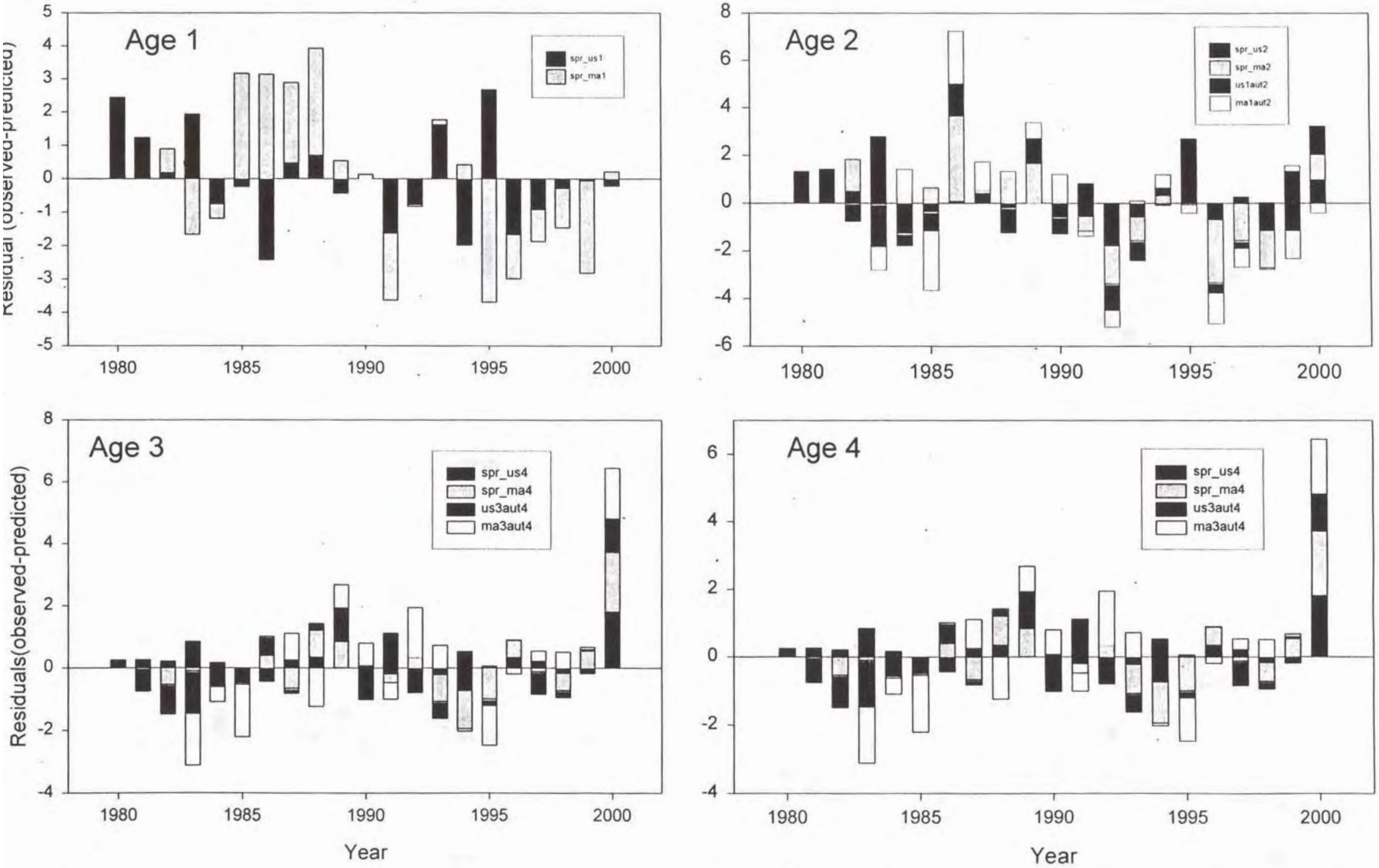


Figure A9. Residual plots (observed-predicted) for ages 1-8 for USA and ages 1-5 for Massachusetts spring abundance indices, and ages 2-8 for the USA and ages 2-6 for the Massachusetts autumn abundance indices.

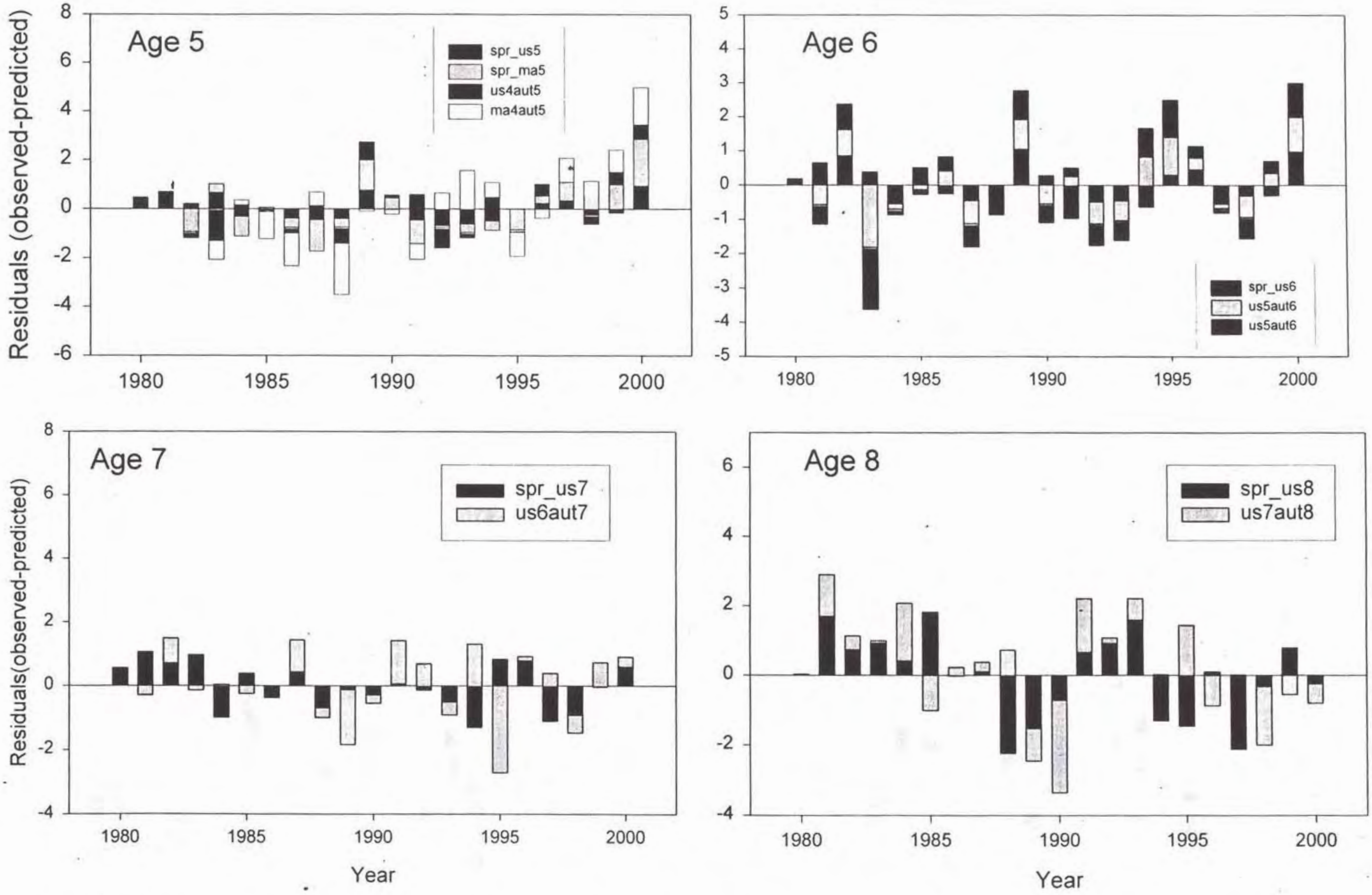


Figure A9 continued. Residual plots (observed-predicted) for ages 1-8 for USA and ages 1-5 for Massachusetts spring abundance indices, and ages 2-8 for the USA and ages 2-6 for the Massachusetts autumn abundance indices.

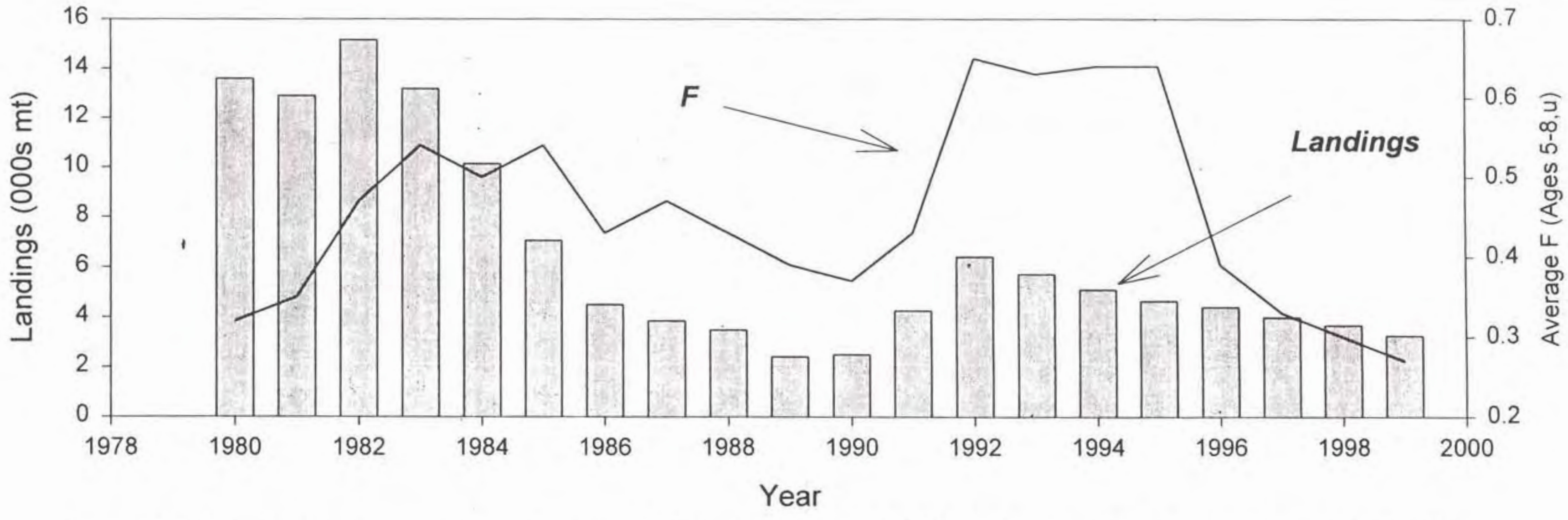


Figure A10. Trends in total commercial landings and fishing mortality for Gulf of Maine-Georges Bank American plaice, 1980-1999.

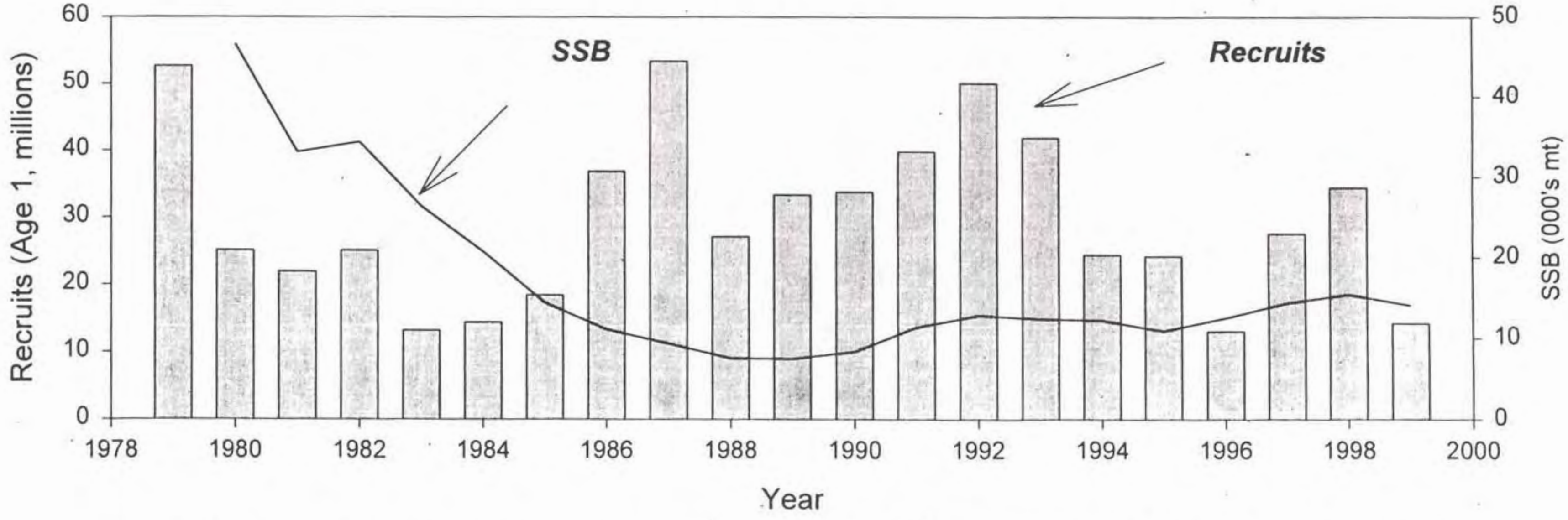


Figure A11. Trends in recruitment and spawning stock biomass for Gulf of Maine-Georges Bank American plaice, 1980-1999.

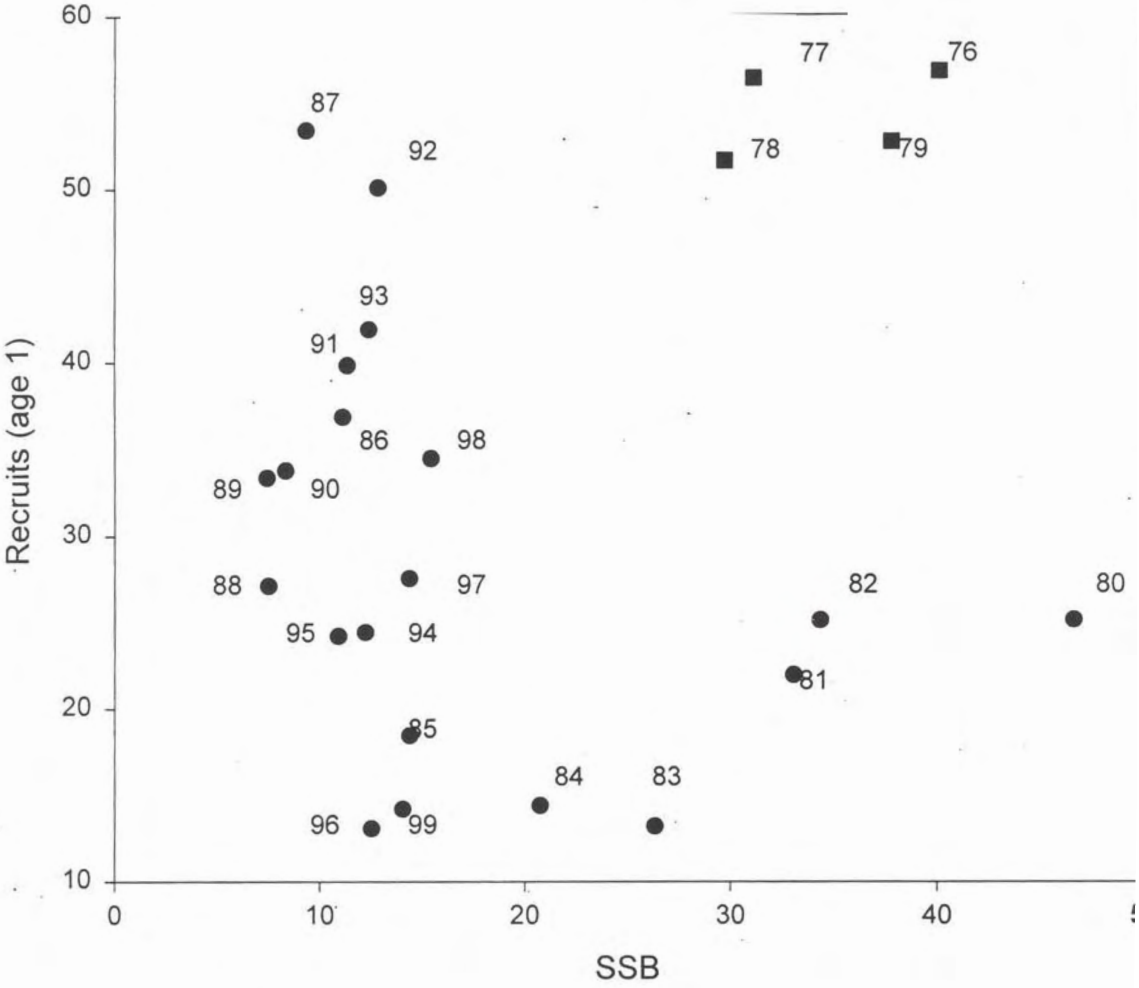


Figure A12. Spawning stock biomass and recruits (age1) for Gulf of Maine-Georges Bank American plaice, 1980-1999 (1976-1979 are backcalulated).

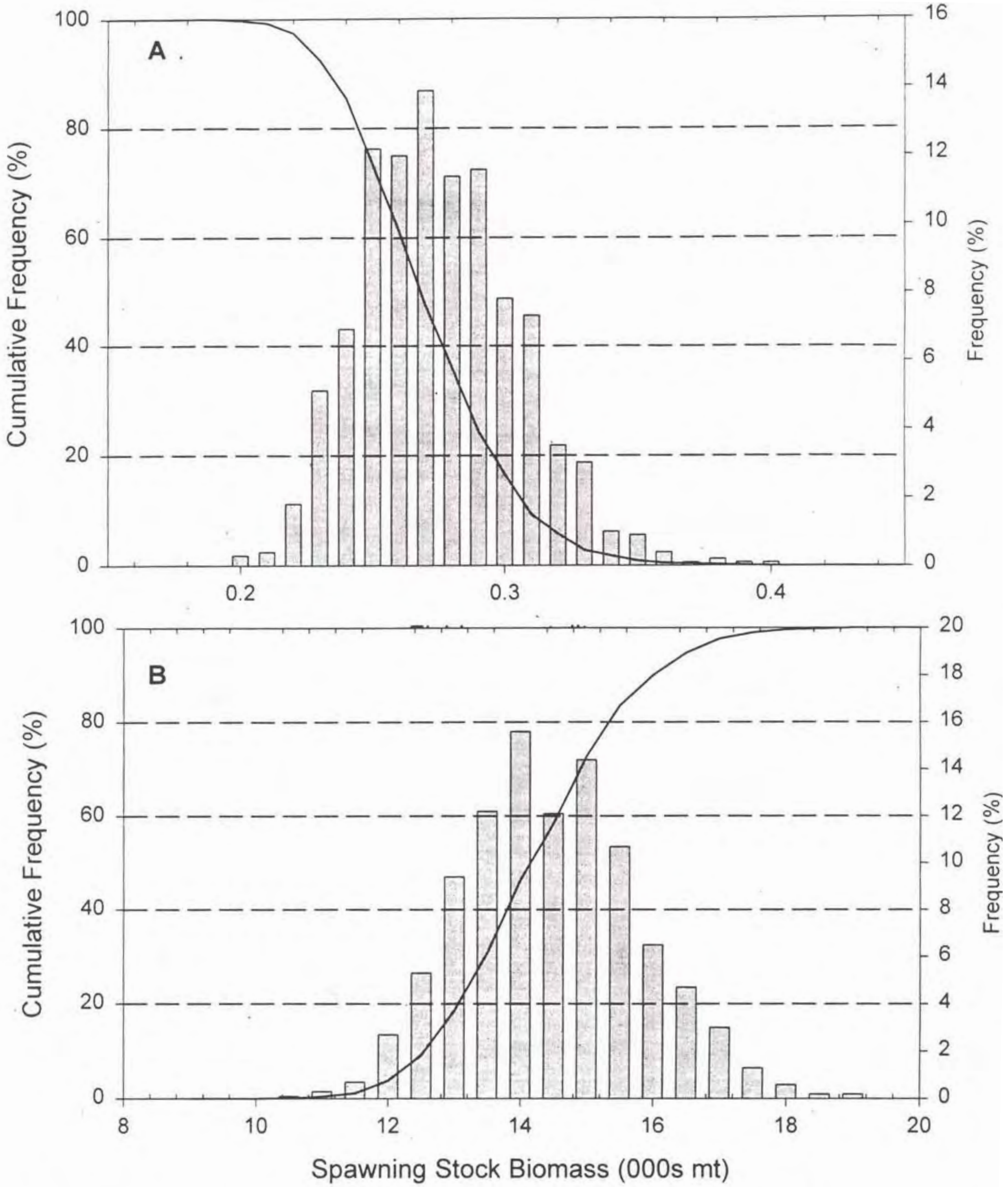


Figure A13. Precision of the estimates of the instantaneous rate of fishing (F) on teh fully recruited ages (5+) (Panel A) and spawning sotck biomass (Panel B) at the beginning of the spawning season for Gulf of Maine-Georges Bank American plaice, 1999. The bar height indicates the frequency of values within that range. The solid line gives the cumulative probability that F is greater than any selected value on the x-axis or the SSB is less than any selected value on the x-axis.

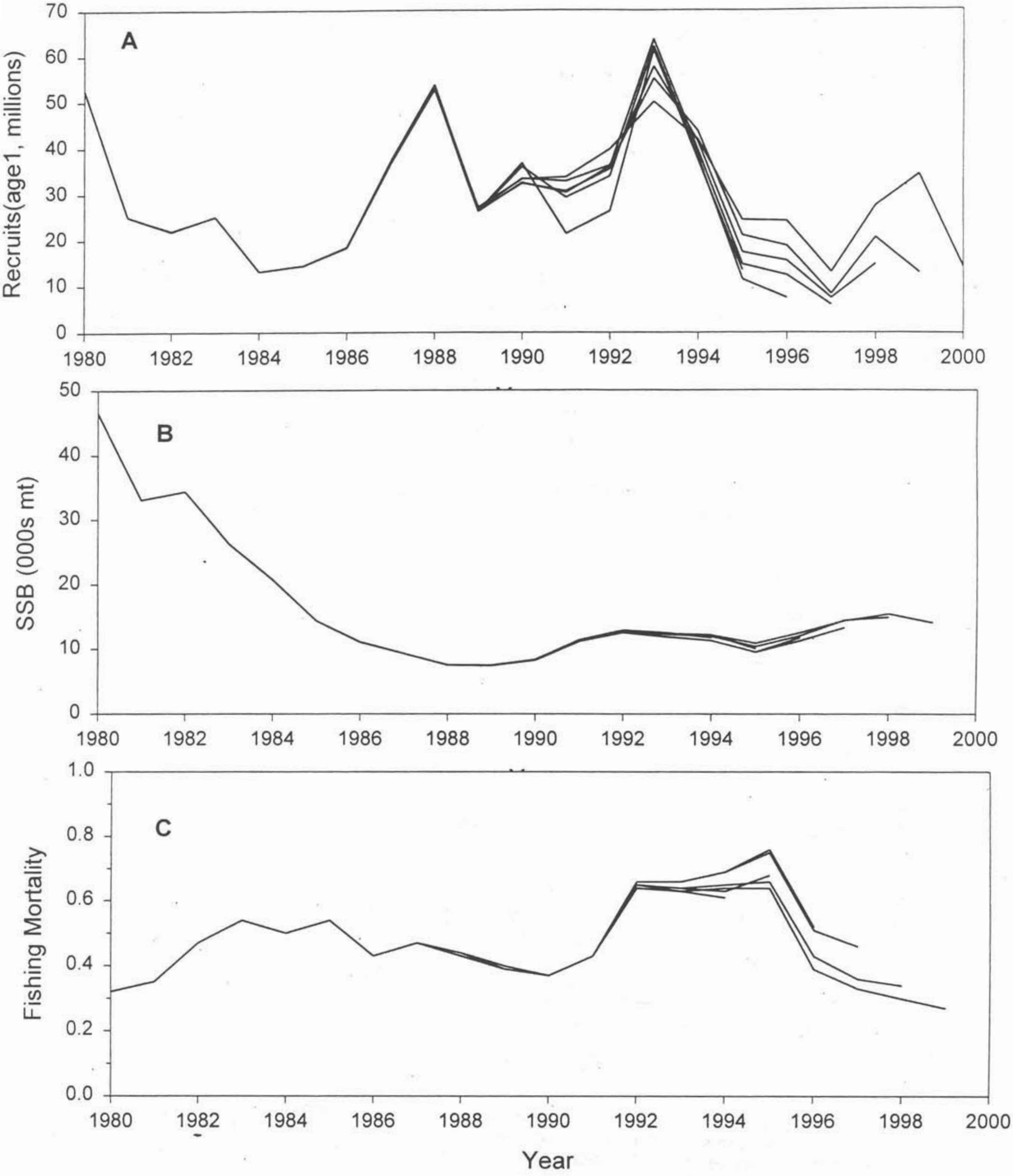


Figure A14. Retrospective analysis of Gulf of Maine-Georges Bank American plaice recruits at age 1 (A), spawning stock biomass (B), and fishing mortality (C, average F, aged 5-8, unweighted) based on the final ADAPT VPA formulation, 1999-1994.

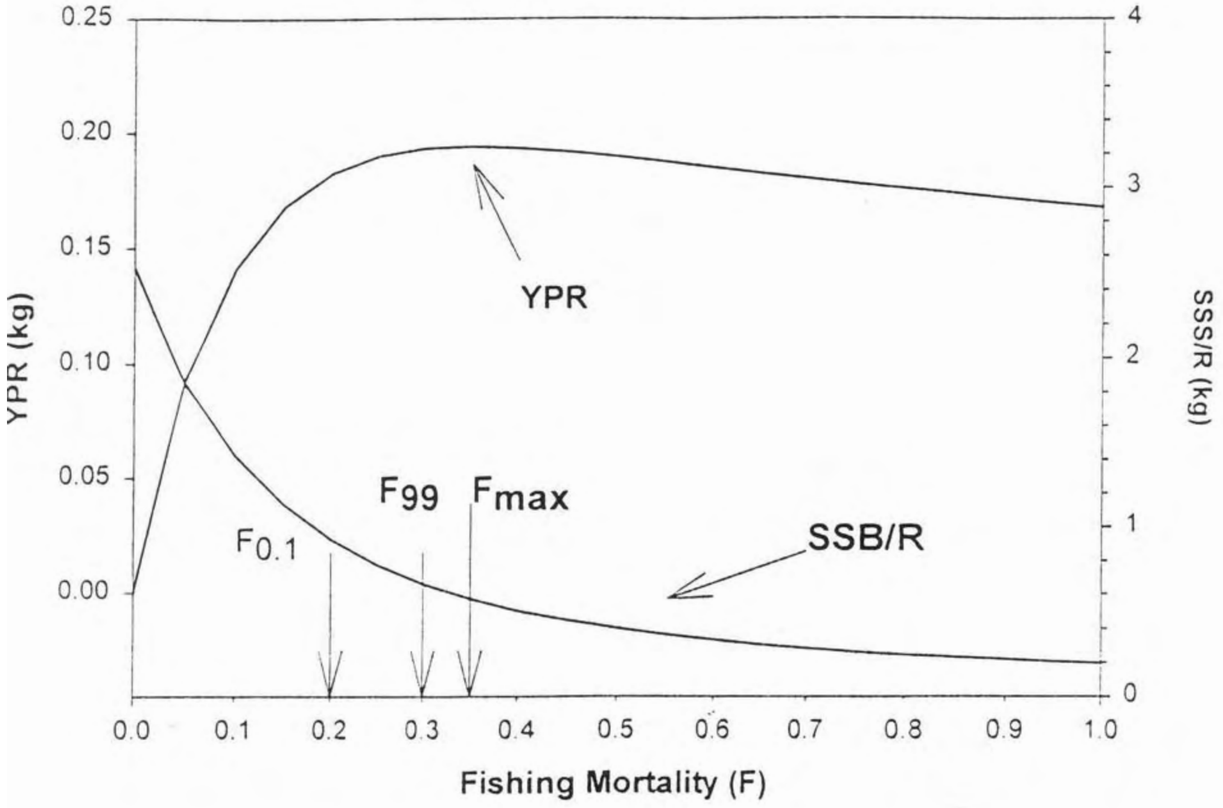


Figure A15. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for Gulf of Maine-Georges Bank American plaice, from O'Brien *et al.* (1998).

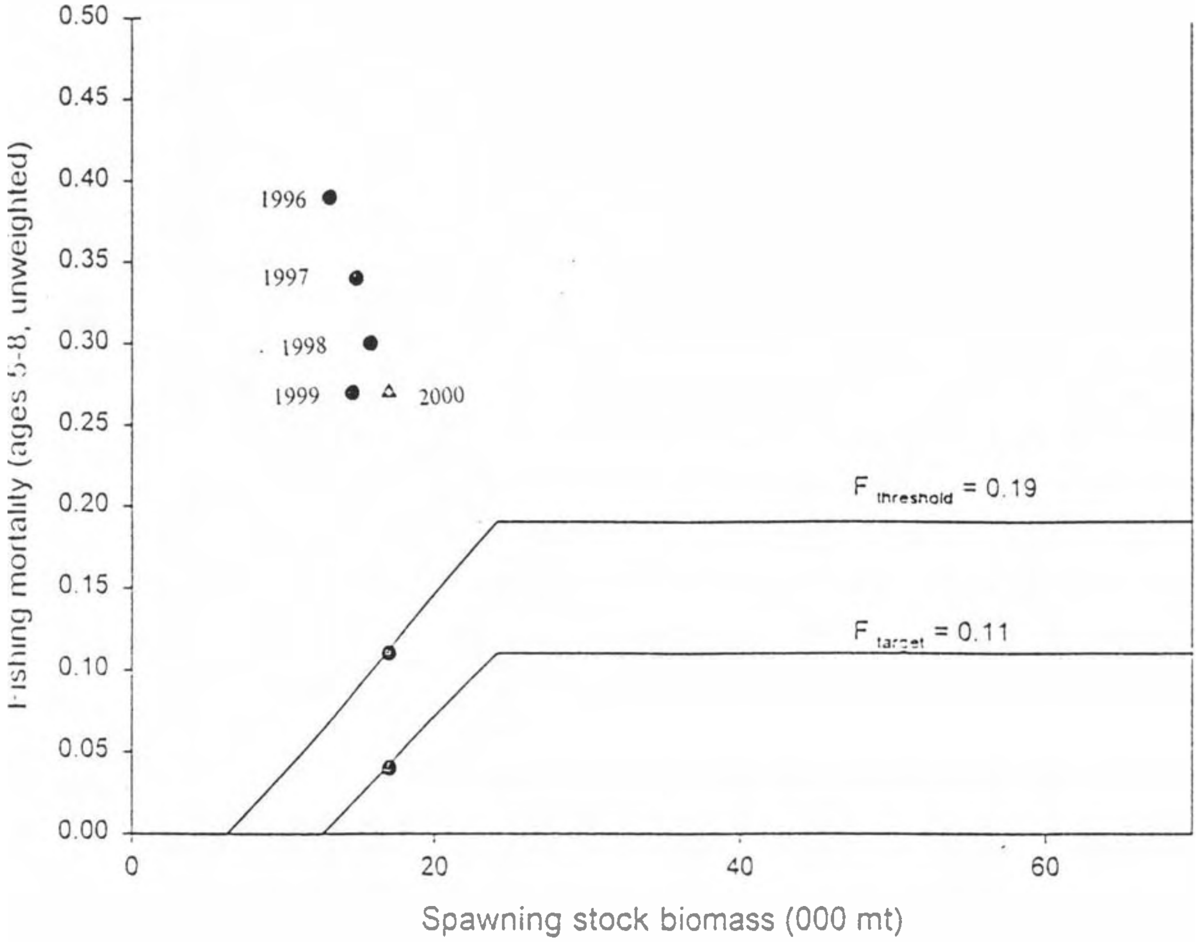


Figure A16. Proposed control rule and recent stock status for Gulf of Maine-Georges Bank American plaice. Triangle is the projected 2000 SSB and status quo F (0.27).

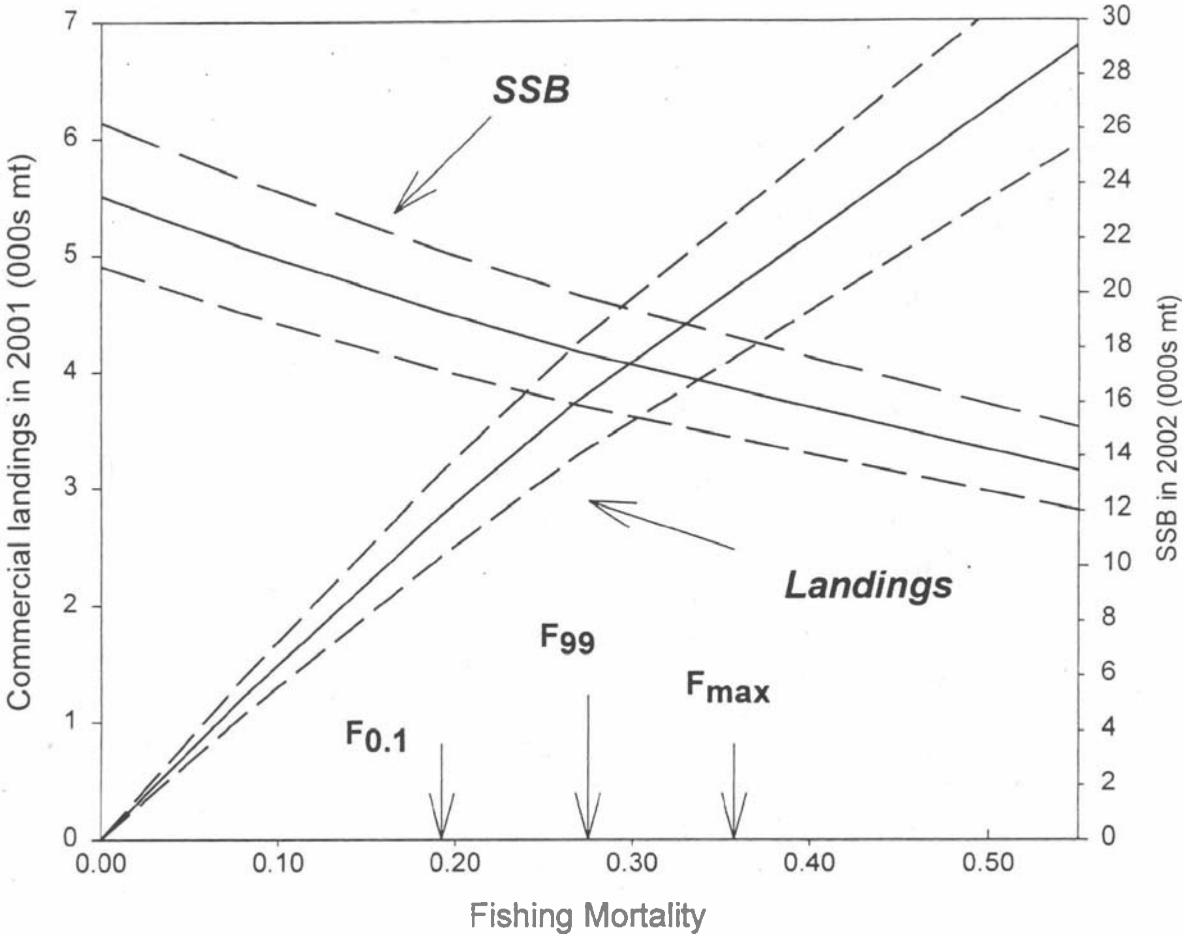


Figure A17. Predicted landings in 2000 and spawning stock biomass in 2001 with 80% confidence intervals for Gulf of Maine-Georges Bank American plaice as a function of fishing mortality in 2000.

B. SEA SCALLOPS

EXECUTIVE SUMMARY

Sea scallop biomass in both the Georges Bank and Mid-Atlantic stock areas increased considerably in recent years. Based on the 2000 NMFS scallop survey, biomasses in both regions are at record highs, and are above or near their target reference points. As indexed by the 2000 NMFS scallop survey, the biomass in 2000 was 9.1 kg/tow on Georges Bank, and 3.8 kg/tow in the Mid-Atlantic. Much of the biomass increase has occurred in the closed areas; these areas accounted for 80% of the biomass in Georges Bank and 50% in the Mid-Atlantic in the 2000 survey. Increases have also been observed in areas open to fishing, and biomass in the open areas of both Georges Bank and Mid-Atlantic are at record highs as well. Effects of area closures, above-average recruitment, and effort reduction have all contributed to the improved condition of the stocks. Neither the Georges Bank nor the Mid-Atlantic stocks are currently overfished as biomasses are above their respective biomass thresholds.

Fishing mortality on Georges Bank has declined significantly in recent years, due mainly to the effects of closed areas. Estimated fishing mortality (F) on Georges Bank during 1999 was 0.14 y^{-1}, up from 0.05 y^{-1} in 1998, but still well below the overfishing threshold of $F_{MAX} = 0.24$ y^{-1}. Overfishing was therefore not occurring in Georges Bank in 1999. The increase in fishing mortality on Georges Bank in 1999 was due to the reopening of a portion of Closed Area II.

Fishing mortality has been declining since 1996 in the Mid-Atlantic Bight, and was estimated to be 0.69 y^{-1} during 1998 and 0.43 y^{-1} in 1999. Closure of two areas in the Mid-Atlantic in 1998, combined with overall effort reduction measures, have contributed to the observed decline in fishing mortality. However, overfishing was still occurring during 1999 in the Mid-Atlantic stock since the estimated 1999 fishing mortality is above the reference point of $F_{MAX} = 0.24$ y^{-1}.

Total U.S. landings in 1999 were 10,146 mt (meats), the highest total since 1992, and an increase of over 80% from the 1998 total of 5,565 mt. Landings on Georges Bank rose from 2,064 mt in 1998 to 5,155 mt in 1999, mainly due to the reopening of a portion of Closed Area II. Mid-Atlantic landings also increased considerably, from 2,778 mt in 1998 to 4,653 mt in 1999. Landings in the Gulf of Maine declined from 455 mt in 1998 to 280 mt in 1999.

A new length-based yield-per-recruit model was developed for this assessment and reviewed by the SARC. The reference points given by this model are similar to age-based methods used previously. Current reference points were retained for management. Closed areas and rotational management require rethinking of the approach to fishing mortality reference points. In this assessment, it was proposed that in a rotational management system, fishing mortality should be calculated by time-averaging the fishing mortality of currently open areas over several years. This method would give an improved match to yield-per-recruit reference point calculations as compared to the current system of spatially averaging fishing mortality over open and closed areas in a single year.

A large number of depletion and photographic

studies were performed and analyzed for this assessment to estimate scallop dredge efficiency. These studies gave a wide range of efficiency estimates from 30%-80%. Efficiency in Georges Bank appeared to be somewhat lower (average estimate about 50%) than that of the Mid-Atlantic (average estimate about 70%). No single recommendation was made by the SARC on the value of the efficiency estimates to be used due to the high variability and uncertainty in these numbers. Evidence was presented that suggests that the NMFS survey dredge has a similar efficiency as commercial dredges.

TERMS OF REFERENCE

(A) Update the status of the Georges Bank, Mid-Atlantic and Gulf of Maine sea scallop resources through 2000, providing (where feasible) estimates of fishing mortality and stock size. Characterize uncertainty in estimates.

(B) Update estimates of F_{MSY}, F_{MAX}, B_{MAX} and other appropriate reference points or proxies for scallop stocks. Provide guidance on development of biological reference points relevant for rotational area management of scallop resources, accounting for current management measures that affect size selection by the fishery, new estimates of growth and scallop meat yield.

(C) Characterize the spatial distribution of fishing effort and fishing success and the size of the scallop resource (pre-recruits and harvestable sizes) based on research vessel and fishery data.

(D) Analyze results of recent surveys, depletion experiments and survey gear studies; provide recommendations for future gear-related research.

(E) Provide (to the extent practicable) short- and medium term projections of scallop biomass, and landings, accounting for spatial and temporal variation in the pattern and intensity of fishing.

INTRODUCTION

Sea scallops are one of the most important stocks in the northwest Atlantic. U. S. landings in 1999 exceeded 10,000 MT (meats), and the 1999 U.S. ex-vessel sea scallop revenues of about $120 million made it the second most valuable fishery in the northeastern United States.

Closed areas and limited openings allowing fishing in closed areas are the most important recent events in the sea scallop fishery. In December 1994, three large areas were closed to fishing in the U.S. portion of Georges Bank to protect groundfish (i.e., Closed Area I, Closed Area II and the Nantucket Lightship Closed Area, Fig. B3-1). Use of trawl gear and scallop dredges in closed areas was prohibited to reduce mortality of groundfish. These closings lead to a rapid buildup of sea scallop biomass in the closed areas, which were in a severely depleted state prior to the closures. In March 1998, two areas in the Mid-Atlantic Bight stock area were closed to scallop fishing for three years (i.e., the Virginia Beach and Hudson Canyon South closed areas, Fig. B3-2). These areas were closed to protect concentrations of juvenile sea scallop in order to increase scallop yield-per-recruit.

In June 1999, the southern portion of Closed

Area II on Georges Bank was reopened for limited fishing until mid-November that year. About 2700 MT of meats were landed in this area, more than all the landings from Georges Bank in 1998. Total catch of sea scallops in Closed Area II during 1999 was about 55% of the 5,000 mt total catch from the Georges Bank stock area and about 27% of the 10,000 mt total U.S. sea scallop catch during 1999 (Table B3-1).

Life History and Distribution

Sea scallops are found in the Northwest Atlantic Ocean from North Carolina to Newfoundland along the continental shelf, and are typically found on sand and gravel bottoms. They are harvested at depths between 40 and 200 m (22 and 110 fm) in the Georges Bank and Mid-Atlantic stock areas (NEFSC 1993).

In the U.S. EEZ, sea scallop are divided into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine stock areas based on survey distributions, fishery patterns, and other information (NEFSC 1995). Stock areas are defined in terms of NEFSC shellfish strata (Figs. B3-1 and B3-2). Scallops in NEFSC shellfish strata assigned to the Georges Bank and Mid-Atlantic stock areas are the main stock units treated in this assessment. Relatively small, but not precisely known, amounts of sea scallop stock biomass occur outside the survey strata used to stock areas for this assessment. Landings from stock areas other than Georges Bank and Mid-Atlantic stock areas have been relatively small (Table B3-1).

In this assessment, "areas" refer to stocks (e.g., the Georges Bank or Mid-Atlantic Stock areas). In contrast, "regions" are parts of stock areas (e.g., Closed Area II region in the Georges Bank stock area or the New York Bight region in the Mid-Atlantic Bight). Like stock areas, regions for sea scallop in this assessment (Fig. B3-1 and B3-2) are defined in terms of NEFSC shellfish strata and portions of strata that are open or closed to fishing (see below).

Age and growth

Sea scallops grow rapidly during the first few years of life with a 50-80% increase in shell height and quadrupling in meat weight between the ages of 3 and 5 years old (Fig. B3-3). The largest observed sea scallop shell height was about 23 cm (scallop size data are for shell heights in this assessment), but animals larger than 17 cm are rare in commercial and survey landings.

Sea scallop growth has been modeled using the von Bertalanffy growth equation. The parameters of this model were fit to shell heights and putative annual rings patterns in shell samples. Merill et al. (1966) reported problems with identification of annual rings on the external surface of the valve and proposed ring counts in the resilium (hinge ligament) to age scallops. Age determinations by ring counts conflicted with results from oxygen isotope studies by Krantz (1983) and Krantz et al. (1984). In contrast, Tan et al. (1988) found that isotope studies and ring counts gave consistent ages. All of the isotope studies were based on only a few samples, however.

Maturity and fecundity

Sexual maturity commences at age 2 but scallops younger than 4 years may contribute little to total egg production (MacDonald and Thompson 1985; NEFSC 1993). Spawning generally occurs in autumn. DuPaul et al. (1989) found evidence of spring, as well as autumn, spawning the Delmarva area and Almeida et al. (1994) found evidence of limited winter-early spring spawning in Georges Bank. Sea scallop eggs are buoyant after fertilization, and larvae remain in the water column for 4-7 weeks before settlement occurs. During this stage, water currents can transport larva considerable distances.

Shell height/meat weight relationships

Shell height-meat weight relationships for scallops in the Georges Bank and Mid-Atlantic regions are important in assessment work because survey data are in numbers of scallops by shell height while landings data are in meat weights. The relationship depends on area and season. Survey samples collected in 1997-8 (NEFSC 1999) suggested that mean meat weights are smaller than the estimates in Serchuk and Rak (1983) that were used in previous assessments. For this assessment, relationships in NEFSC (1999) and Serchuk and Rak (1983) are combined to obtain a single set of estimates based on all of the available data (see below). Fig. B3-3 gives the shell height and meat weight at age for Georges Bank and the Mid-Atlantic, based on the growth and shell height/meat weight models used in this assessment.

FISHERIES

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

FMP Amendment #4 (NEFMC 1993), implemented in 1994, changed the management strategy from primarily meat count regulation to effort control for the entire U.S. EEZ. These controls included incrementally increasing restrictions on days-at-sea (DAS), minimum ring size, and crew limits (Fig. B4-1). Currently, the scallop fishery is regulated by FMP Amendment #7 and Framework adjustments 12 and 13. These regulations presently allow 120 days-at-sea per year for full time scallop vessels, limit the crew to a maximum of seven persons, and require a 3½" minimum ring size. Framework 13 allowed for restricted limited access to portions of all three Georges Bank groundfish closed areas in 2000.

Framework 14, currently under consideration, specifies conditions for access to the Mid-Atlantic closed areas in 2001. A new FMP Amendment (#10), which proposes to implement a formal rotational management system, is under development.

Scallop dredges are the principal gear type in all regions (Table B3-1). However, trawl gear is of some importance in the Mid-Atlantic.

Landings and effort history

Major changes in collection of commercial fishing data for northeast U.S. fisheries occurred in June 1994. Prior to 1994, commercial fishing data were collected based on interviews and the "weigh-out" database. This was changed in 1994 to a new mandatory reporting system comprised of dealer reports (DR) and vessel trip reports (VTR). Dealer data contain total landings, and, since 1998, landings by market category (i.e., meat count ranges—10-20 meats/lb, 20-30 meats/lb etc.). VTR data contain information about area fished, fishing effort, and retained catches of sea scallops. Ability to link DR and VTR reports in data processing is problematic due to incomplete data reports and other problems, although there have been significant improvements since 1994 (Wigley et al. 1998). These problems make it difficult to precisely estimate catches and fishing effort for sea scallop, and to prorate catches and fishing effort among areas and gear types. Most importantly, the changes in 1994 (and introduction of closed areas) makes it difficult to compare trends in fishing effort and catch rates before and after 1994.

Commercial landings data for sea scallops in this assessment were based on port interviews and the weigh-out database prior to April 1994, and on the DR and VTR databases after April 1994. Proration of total commercial sea scallop landings into Georges Bank, Mid-Atlantic, Southern New England, and Gulf of Maine regions generally followed procedures in Wigley et al. (1998).

In future assessments, it is anticipated that vessel monitoring system (VMS) data, which provide real-time position information, will be linked fully with the dealer and vessel trip data. This will allow specification of spatial and temporal harvest patterns at much higher levels of resolution. Preliminary work on this methodology was considered by the Invertebrate Subcommittee but not reviewed by the SARC.

Sea scallop landings in the U.S. increased substantially after the mid-1940's (Fig. B4-2), with peaks occurring around 1960, 1978, and 1990. Maximum U.S. landings was 17174 mt in 1990. Canadian landings on Georges Bank have averaged about 4400 MT over the last 20 years.

Figure B4-3 gives U.S. landings in Georges Bank, Mid-Atlantic and the Gulf of Maine since 1962 (see also Table B3-1). U.S. Georges Bank landings show peaks in the early sixties, and around 1980 and 1990. Landings in the U.S. portion of Georges Bank declined precipitously in 1993 and remained low through 1998, before rebounding in 1999, due in part to the reopening of Closed Area II. The 1999 landings of 5155 mt are the highest seen in this region since 1992. Mid-Atlantic landings reached their peak of nearly 8000 mt in the mid-sixties and again in the late eighties and early nineties. Landings were less than 3000 mt in 1997-8, but increased to 4653 mt in 1999, due to good recruitment and to effort reduction measures which resulted in improved yield-per-recruit. Gulf of Maine landings peaked at about 800 mt in 1993, and in general made up only a small percentage of total landings. The 1999 landings of 280 mt comprised about 3% of total U.S. landings.

NEFSC (1999, their Fig. B4 and Table B8) tabulated fishing effort and CPUE for medium (51-150 GRT, ton-class 3) and large (151-500 GRT, ton-class 4) dredge vessels during 1982-1998, for scallop vessels 50-500 (GRT) in the Mid-Atlantic Bight and Georges Bank stock areas. The data seemed to suggest a general decreasing trend in CPUE during 1982-1998 in both the Georges Bank and Mid-Atlantic regions. However, trends were difficult to interpret due to the break in data collection procedures in 1994, onset of closed area management in 1995, and different trends in nominal fishing effort for the Mid-Atlantic Bight when effort was measured as either days fished or days absent.

Commercial shell height distributions

Size composition data for landed sea scallops are available from both port and sea samples (Burns and Schultz 1991; NEFSC 1999). Port sampling protocols required vessels to select

200 representative shells from the last tow of the trip. Depending on the duration of the trip and areas fished, this procedure may not have produced representative random samples. Factors affecting precision and accuracy of shell height distributions from port and sea sample data are summarized in NEFSC (1995; 1997). There was a significant reduction in port sampling after 1995, especially in the Georges Bank region, as port agents were directed to assist fishers in filling out VTR forms (Table B4-1).

The NEFSC Sea Sampling Program was fully implemented in 1992 (Table B4-2) and measures the size of scallops both landed and discarded portions of the catch. Discarded scallops had shell heights mostly less than 75-80 mm. Sea sample shell height data for discarded scallops are not reliable for some years (e.g., 1992) in both the Georges Bank and Mid-Atlantic regions due to small sample sizes.

Discards

The NEFSC sea sampling program collects hail weights of discarded and kept sea scallop catches from sampled tows. Estimates of discard rates, computed as the ratio of discard and kept catch, for the Georges Bank and Mid-Atlantic Bight stock areas (Table B4-2) are crude because discard and kept weight data were often not collected from the same tow. However, ratios of discard to kept weight indicate that discard rates for scallops in the Mid-Atlantic region peaked in 1993 at about 18% but were less than 2% after 1996 (after meat count regulations were abandoned).

SURVEYS

NEFSC sea scallop surveys were carried out in 1975 and then annually after 1977 to measure abundance, size composition, and recruitment of sea scallops in the Georges Bank (including the Canadian portion during some years), Mid-Atlantic and occasionally other regions as well. Survey data used in this assessment are for 1982-2000 because the time series beginning in 1982 is consistent and comparable.

The R/V Albatross IV was used for all NEFSC scallop surveys except during 1990-93, when the R/V Oregon was used instead. The surveys by the R/V Albatross IV during 1989 and 1999 were incomplete on Georges Bank. In 1989, the R/V Oregon was used to survey the northern part of the South Channel region, and the R/V Chapman was used to sample the southern part of the South Channel and a section of the Southeast Part. Serchuk and Wigley (1989) compared catch rates for the R/V Albatross IV, R/V Oregon and R/V Chapman based on a complete randomized block gear experiment (3 vessels x 13 stations=39 tows) in Stratum 34. No significant differences were detected by ANOVA (Serchuk and Wigley 1989). Therefore, as in previous assessments (e.g., NEFSC 1999), survey indices for the period 1990-93 based on data from the R/V Oregon were used without adjustment in database calculations. The Northern Edge and Peak Area of Georges Bank was not surveyed by any vessel in 1989. Abundances in this area in 1989 were estimated by averaging the 1988 and 1990 survey data. The 1989 Georges Bank survey data needs to be used cautiously because of the uncertainties and incompleteness of the survey that year.

The F/V Tradition was used to supplement sampling by the R/V Albatross IV during 1999 due to mechanical problems on the R/V Albatross IV. The F/V Tradition towed the standard NMFS scallop survey dredge as well as a New Bedford commercial scallop dredge side by side. For the purposes of the survey, only data from the (port) NMFS survey dredge was used. Scientists aboard the F/V Tradition used protocols similar to those on the R/V Albatross IV when sampling the catch. In addition to carrying out gear experiments, the F/V Tradition successfully sampled 103 stations, and re-sampled 21 of the R/V Albatross IV stations from the original survey plan. Log transformed catch rates for both vessels at 21 comparison stations (Table B5-1) did not differ statistically by a paired t-test ($p=0.59$). Therefore, data collected by the F/V Tradition with the NMFS survey dredge can be used to supplement data collected from the R/V Albatross in 1999.

As described above, there were 21 comparison stations occupied by both the F/V Tradition and the NOAA R/V Albatross IV. For survey database calculations, data collected by one vessel or the other at comparison stations was excluded, based on which vessel had sampled the complete set of stations in the stratum. Specifically, data from the R/V Albatross were used for strata 6460 and 6470 while data from the F/V Tradition were used for strata 6520, 6530, 6540, and 6550.

Stratum areas
Estimates of stratum areas for shellfish strata used for survey database calculations in NEFSC (1999) were estimated originally by hand using a planimeter. For this assessment, planimeter estimates were replaced by estimates from a GIS system (ARCInfo). The main advantage in using GIS areas is greater accuracy (planimeter estimates tend to be imprecise for strata with high perimeter/area ratios), and repeatability. Comparison of planimeter and GIS stratum areas (Table B5-2) show that planimeter and GIS estimates are similar in most cases. However, in some strata differences ranged from –211 to +39 nm^2 (-584% to +20%). For entire stock areas and most regions, differences were trivial (-1% to –3%, Table B5-3). However, the difference between planimeter and GIS area estimates for the relatively small Virginia-North Carolina region was –78 nm^2 (-265%).

Post-stratification
Relatively high abundance of sea scallops in closed areas makes it important in some instances to split NEFSC shellfish strata that cross open/closed area boundaries into new strata (i.e. post-stratify the data). For some calculations of interest, it is sometimes necessary to group strata into regions corresponding to open and closed regions, rather than regions traditionally used for sea scallop (Serchuk and Wigley 1989). Finally, in cases where the closed or open portion of an NEFSC survey stratum is very small, it is necessary to combine the small portion with an adjacent stratum to form a new stratum (NEFSC 1999).

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

Closed Area II were assigned to the new "Closed Area II (North)" region (Fig. B3-1).

In 1998-2000, some non-random tows were added to closed areas in an effort to reduce the variability introduced by area closures and post-stratification. With the exception of the Nantucket Lightship Area (where the choice of non-random stations may have been biased), these tows were used in all abundance calculations in this assessment.

In some years, no valid tows were performed in some strata. In these cases, the values from the two adjacent years (when available) were averaged to fill in the gap in the time series (see Table B5-5).

Survey and commercial dredge selectivity

Beginning in 1979, sea scallop surveys used a 2.44-m (8-ft) wide dredge equipped with 5.1-cm (2-in) rings and a 3.8-cm (1.5 in) polypropylene mesh liner. According to Serchuk and Smolowitz (1980), the liner reduces catchability of scallops greater than 75 mm in shell height. Based on data from Serchuk and Smolowitz' (1980) experiment with lined and unlined dredges towed for 15 minutes at 6.5 km/hr (3.5 knots) and with 3:1 wire scope, NEFSC (1995; 1997) estimated that the selectivity curve for an unlined survey dredge was:

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

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

$$w_h = \frac{0.7148e^{0.9180(0.7148(x-106309))} + e^{0.9180(x-106309)}}{e^{0.9180(0.7148(x-106309))} + e^{0.9180(x-106309)}}$$

where $x = 160 - h$ (Fig. B5-1).

Original survey catch data for each tow ($c_{h,t}$ for the number of scallops shell height h in tow t) were adjusted by applying the size-specific selectivity of the lined dredge (w_h) to estimate shell height distributions for the "population" of scallops sampled by the tow ($p_{h,t}$):

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

Population shell height estimates and distributions for each tow were partitioned into pre-recruit (not vulnerable to commercial dredges) and fully-recruited (completely vulnerable to commercial dredges) classes by applying a commercial dredge selectivity function developed by consensus (NEFSC 1995):

$$s_h = \begin{cases} 0 & \text{if } h \le h_{\min} \\ \dfrac{h - h_{\min}}{h_{full} - h_{\min}} & \text{if } h_{\min} < h < h_{full} \\ 1 & \text{if } h \ge h_{full} \end{cases}$$

where h_{min} = 65 mm and h_{full} = 88 mm (Fig. B5-1). [Note that terminology and definitions for prerecruit and recruit portions of sea scallop stocks in this assessment differ from terminology and definitions in previous stock assessments for sea scallop.]

Indices of relative abundance (stratified mean numbers per standard tow, adjusted for selectivity) for the whole population, pre-recruit, and recruit portions, were calculated for scallops greater than 40mm. Indices of relative biomass for the population, non-recruits, and recruits were calculated similarly by converting measured shell height to meat weight using stock-specific shell height-meat weight relationships (see below).

New information about dredge selectivity
In 1999, the NMFS scallop survey included tows completed by the *F/V Tradition*, which towed commercial and survey dredges side-by-side. This configuration allowed a direct estimate of the selectivity functions given above. Fig. B5-2 plots the ratio of the catches from the commercial dredge to those of the survey dredge at each 5 mm shell height class. This ratio were reduced by 8/15 to adjust for the different width of the two dredges, and the catches from the survey dredge were adjusted for its assumed selectivity pattern as discussed above. Fig. B5-2 plots the total catch of the commercial dredge as a function of that of the survey dredge, and compares this to the above commercial dredge selectivity curve (solid line). It is clear from this figure that the accepted selectivity curves are consistent with the data from the *F/V Tradition.*

Shell height/meat weight relationships
Shell height-meat weight parameters for the Georges Bank and Mid-Atlantic stock areas in this assessment were estimated as a function of the parameters from Serchuk and Rak (1983) and NEFSC (1999). The new parameters were estimated by calculating predicted meat weights using both sets of original parameters, averaging the predicted meat weights from each set of original parameters at each length, and then fitting the model $\ln(W)=\alpha+\beta\ln(L)$, where W is meat weight in grams and L is shell height in mm by linear regression (see the table following and Fig. B5-3).

	α	β
Georges Bank		
NEFSC (1999)	-11.4403	3.0734
Serchuk & Rak (1983)	-11.7656	3.1693
New "Average"	-11.6038	3.1221
Mid-Atlantic Bight		
NEFSC (1999)	-12.3405	3.2754
Serchuk & Rak (1983)	-12.1628	3.2539
New "Average"	-12.2484	3.2641

Nominal tow distance
Tow distance is critical in converting survey estimates of numbers or meat weight per standard tow to units of absolute population abundance or biomass (see below). Tow distance is less important, however, for estimating relative trends as long as the actual tow distance is consistent among tows and surveys.

In previous sea scallop assessments, the "nominal" tow distance assumed in abundance or biomass calculations was 3.5 nm h^{-1} x 0.25 h = 0.875 nm, where 3.5 nm h^{-1} was the target tow speed and 0.25 h was the duration of the time period (15 minutes) when the winch was locked and the dredge was assumed to be fishing. Average tow distances for sea scallop cruises during 1982-1994 (computed from bottom speed measured using an Ametek doppler sensor and times at which the winch was locked and unlocked) ranged 0.83-0.93 nm, averaged 0.88 nm, and were generally close to the 0.875 nm nominal value.

A new Raytheon doppler sensor was installed on the *R/V Albatross IV* in 1994 and tested against the Ametek instrument under survey conditions. Initial results indicated that velocities and distances measured using the Ametek doppler sensor were about 10% lower than velocities and distances measured with the Raytheon sensor. Additional comparisons to velocity and tow distances based on

LORAN and GPS equipment indicated an approximate -20% underestimation of tow distances with the original Ametek sensor (T. Azarovitz, NEFSC, Woods Hole, MA, personal communication[1]). Average tow distances for sea scallop cruises during 1994-2000 from the Raytheon doppler sensor ranged 0.90-0.98 nm, averaged 0.94 nm (about 7% larger than with the Ametek sensor). In addition, preliminary results from analysis of bottom sensor data collected during the 2000 survey (see below) suggest that scallop dredges may actively fish for a period of time longer than the period during which the winch is locked. Therefore, in this assessment, a nominal tow distance of 1 nm (about 6% larger than the mean doppler distance during 1994-2000) was assumed in swept area biomass estimates using NEFSC sea scallop survey data.

	Doppler Bottom Distance	
	1982-1991 (Ametek Sensor)	1994-2000 (Raytheon Sensor)
Mean	0.88	0.94
Minimum	0.83	0.9
Maximum	0.93	0.98

Survey Results in 2000 compared with 1994
Survey data maps showing the spatial distribution of prerecruit sea scallop (40+ mm) during 1994 (just before the Georges Bank closed areas were implemented) and the most recent survey during 2000 are shown in Figs. B5-4 through B5-7. Recruitment in Georges Bank in 2000 was at record levels, and strongly contrasted to 1994, when recruitment was poor (Fig. B5-4). Recruitment in 2000 was mainly concentrated in Closed Area II (especially the southern half) and in the South Channel region. Recruitment in Mid-Atlantic in both 1994 and 2000 was near long-term means (Fig. B5-5). Fig. B5-6 shows that the number of fully recruited scallops in Georges Bank had increased substantially in 2000 over 1994 levels. Much of this increase was in the closed areas, though the number of full recruits in open areas had also increased. More modest increases in fully recruited scallops in 2000 over that of 1994 was observed in the Mid-Atlantic (Fig. B5-7).

Abundance and biomass trends, 1982-2000
Biomass and abundance estimates from 1982-2000 (and in some cases 1979-1981) for Georges Bank and the Mid-Atlantic Bight are presented in Tables B5-6 and B5-7, and Figs. B5-8 to B5-11.

Database runs for survey trends and shell height calculations in this assessment used borrowing (see Table B5-5) and data from the *F/V Tradition* during 1999. Random and nonrandom (see above) tows during 1998-2000 were used to calculate mean numbers and meat weight per tow for closed areas other than the Nantucket Lightship. Relative biomass calculations (see below) were based on regions and used nonrandom tows during 1998-2000 for regions other than the Nantucket Lightship. Database variance calculations for survey data in this assessment included adjustments for borrowed data and strata with non-zero means but only one tow. Variances for strata with zero means were not used.

Assuming that mean survey values were log normally distributed, log scale standard errors

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[1] Memorandum dated January 31, 1996 from T. Azarovitz to B. L. Lake.

(σ) for mean numbers and meat weights per tow were calculated:

$$\sigma=\sqrt{\ln\left(CV^2+1\right)}$$

where CV was the arithmetic scale coefficient (Johnson et al. 1994 , Jacobson et al. 1994). The coefficient of variation (CV) was estimated as the ratio of the stratified survey estimate of the standard error to the mean.

Asymmetric bounds for approximate 95% confidence intervals were calculated by multiplying the original mean number or meat weight per tow by $e^{\pm 1.96\sigma}$. However, the coverage (probability) of the confidence interval is not known if the data are not log normally distributed.

In most regions of Georges Bank and the Mid-Atlantic Bight, and for the stock areas as a whole, abundance and biomass estimates were at record high levels in 2000 (Tables B5-6 and B5-7, Figs. B5-8 through B5-11). The biomass and abundance indices in the closed areas of both regions showed notable increases after closure. This increase was more rapid after the Mid-Atlantic closures because these areas were specifically closed to protect high densities of small scallops, whereas the decision to impose closures in Georges Bank was not related to scallop recruitment. Biomass and abundance of the open areas of both regions have increased recently, though not as quickly as the closed areas, and were at record levels for these areas in the 2000 survey. Increases in the open areas were due to a combination of effort reduction and good recruitment. Mean individual weights (computed as average meat weight per tow / average number per tow) generally increased in closed areas of Georges Bank after 1995 (column labeled "Mean Meat Wt (g)" in Table B5-7).

Prerecruit survey population abundance data for sea scallop (Tables B5-6 and B5-7) indicate that scallop recruitment was above the median in the Mid Atlantic in 1998 through 2000; on Georges Bank recruitment was above median levels in two of three years.

Recruit in 2000 on Georges Bank was the highest on record.

Minimum swept area biomass estimates for sea scallop from survey data (estimates of absolute abundance, assuming 100% dredge efficiency, Figs. B5-12 and B5-13) show that recent increases in biomass occurred primarily in the three closed areas, but have occurred in the open areas as well. In the Mid-Atlantic stock area, recent increases in biomass occurred in all areas, but especially in the Hudson Canyon closed area.

In 1998-2000, about 80% of the total scallop biomass in the Georges Bank stock area was in the three closed areas. Similarly, about 50% of total scallop biomass in the Mid-Atlantic Bight area during 1999-2000 was in the Mid-Atlantic closed areas.

Survey shell height distributions, 1982-2000

Population shell height distributions for sea scallops from survey data (by stock area and year in Figs. B5-14 and B5-15 and by region and year in appendices 1 and 2) were calculated using the same database options used for abundance trends except that means and CV's were calculated for each 5 mm size group above 40 mm.

Caution is required when interpreting shell height distributions and the progression of shell height modes for whole stock and relatively large areas because of differences among regions in recruitment patterns (Appendices 1 and 2; NEFSC 1999). In addition, the precision of shell height distributions depends on size and stock area. Precision of shell height distributions is best for intermediate size groups that are well sampled and poorest for very large and small shell height groups. Precision of shell height distributions is better for regions in the Mid-Atlantic Bight than for regions in the Georges Bank stock area. Precision for whole stock areas is better than for regions within stock areas.

Prior to 1994, when the entire Georges Bank stock area was open to fishing, modal shell heights were generally around 80 mm and seldom greater than 100 mm. Similar conditions prevailed after 1994 in stock areas open to fishing. In contrast, shell height distributions for closed areas in Georges Bank after 1994 include multiple modes with modal shell heights gradually exceeding 100 mm. Shell height distributions for the whole Georges Bank stock area had modes near 100 mm in most years after 1995 because most of the stock was in closed areas. However, in 2000 the modal shell height for Georges Bank decreased to about 60 mm due to strong recruitment in the southern part of Closed Area II and in the South Channel.

NEFSC (1999) reported that modes in shell height distributions from open and closed areas in the Mid-Atlantic region were generally less than 100 mm and that shell-height distributions were similar for open and closed areas of Georges Bank prior to 1994 (Appendix 2). Modal size increased to about 100 mm in both closed areas inside the Mid-Atlantic Bight (Appendix 2) and for the stock as a whole during 1999-2000. Apparently, the relatively recent closures in the Mid-Atlantic region are now affecting scallop size distributions.

Evidence for increased growth rates on Georges Bank

A qualitative analysis of survey shell height data from closed areas suggests the possibility of relatively rapid growth during 1995-2000 (Appendices 1 and 2). Shell height data from closed areas are particularly useful for evaluating growth because modes in shell height distributions can be tracked by survey data, and these modes are unaffected by fishing activity. In the Nantucket Lightship closed area, new recruits were observed at about 60-70 mm shell heights (about 2.8 years old) during most years since 1995. Based on current estimates of von Bertalanffy growth parameters (Serchuk et al. 1979), scallops 60-70 mm shell height should grow to about 84-92 mm by the time of the next survey. However, the second mode appears in most years (and particularly during 1996 and 1999) at over 100 mm. In the 1999 survey, recruits were observed in the survey data for Nantucket Lightship at about 45-55 mm. However, the mode in 1999 was strongly influenced by a single tow in a region where recruitment is usually poor. In the 2000 survey, a mode was observed at about 90-95mm shell height, presumably the year class observed at 45-55mm in 1999. Growth from 45-55 mm to 90-95mm is still greater than what would be predicted by the standard growth parameters. The growth pattern in Closed Area I is similar to that of the Nantucket Lightship Closed Area. Year classes are first observed at about 60-70 mm shell height, and appear the following year at modes of about 100 mm shell height, faster than what the standard parameters would predict.

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

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

To compare observed and expected growth for sea scallop in closed areas within the Georges Bank stock area, a population projection model used by NEFMC (2000) was initialized using mean numbers per tow at age in the 1995 survey data and estimates of numbers of recruits during 1996-2000. Assuming natural mortality M=0.1 y^{-1}, the model was used to predict shell height distributions observed in the 2000 survey based on the von Bertalanffy growth parameters of Serchuk et al. (1979) for the Georges Bank stock area. Observed and predicted survey length compositions did not match (Fig. B5-16) unless the von Bertalanffy growth parameter K was increased from the current best estimate of 0.34 to about 0.4 y^{-1} ($L_{¥}$ was kept fixed at the current best estimate of 152.5 mm).

A similar analysis in the Mid-Atlantic closed areas, initialized to the 1998 data, suggests the possibility that growth there may be slower than what the standard growth parameters predict. Figure B5-17 shows that a projection with K reduced to 0.23 (and using the standard L_{∞} = 151.8) fits the observed growth pattern better than the standard K of about 0.3. Future work, particularly the validation of scallop aging methods, is necessary to test the model analysis.

Recruitment

McGarvey et al. (1993) reported a stock-recruit relationship for sea scallop in Georges Bank, but that relationship was driven exclusively by two adjacent year classes (1978 and 1979). From 1982-1994, no relationship was observed between spawning stock biomass and recruits two or three years later, possibly because of the low contrast in spawning biomass. Since 1994, there has been a large increase in spawning-stock biomass in Georges Bank, primarily due to area closures. Two of the three year classes hatched since the closures (observed as recruits in 1998 and 2000) were strong and one appeared to be exceptional. A two-sample t-test on log transformed survey data was performed that compared the 1982-1997 recruitment data (40-70 mm) on Georges Bank to that of 1998-2000. This test indicated significant overall improvement in recruitment since 1998 (p = 0.034, one tailed test). Arithmetic and geometric mean recruitment observed during 1998-2000 were over three times larger than during 1982-1997.

Besides the increase in spawning stock biomass, it is possible that favorable environmental factors played a role in the recent good recruitment. Recent scallop surveys in a wide range of Canadian waters as well as in Georges Bank have shown good sea scallop recruitment (T. Kenchington, Gadus Associates, Ltd.); this suggests that environmental conditions have been good the last several years. More years of data, and combination of the U.S. and Canadian Georges Bank data are required to reach definitive conclusions about a stock-recruitment relationship on Georges Bank.

No relationship has been observed to date between Mid-Atlantic spawning stock biomass and recruits. Effects of the Mid-Atlantic closures on recruitment would not be observed until 2001 at the earliest.

Tests for effects of closed areas on recruitment

There are several possible mechanisms that might differentially affect recruitment in closed and open areas. High densities of adult scallops might increase the mortality rate of settling or newly settled spat due to various density-dependent mechanisms. It has been suggested that scallop dredging may increase settlement success by clearing the bottom of epibenthos. These factors would tend to reduce recruitment in closed areas only. In contrast, if small (pre-recruit) scallop suffer incidental fishing mortality, or if adult scallops or epibenthos enhance the survivability of juvenile scallops by providing good substrate, then observed recruitment might differentially increase in closed areas compared to open areas.

As discussed above, spawning stock biomasses in closed areas have increased considerably on Georges Bank. Area closures might also enhance fertilization success as scallops tend to aggregate into clumps (Stokesbury and Himmelman 1993). These high density areas tend to be heavily fished in the open areas, but will remain undisturbed in the closed areas. Because fertilization in sea scallops is external, there may be a higher rate of fertilization success in these high density patches.

Larval scallops probably travel long distances prior to settlement. Therefore, an increase in larval production within closed areas, due to increases in spawners and/or fertilization success, would likely result in improved recruitment within both open and closed areas.

To test whether closures have any effect on recruitment, recruitment (40-70 mm) in the Georges Bank closed areas (Closed Area I, Nantucket Lightship, and the northern part of Closed Area II) was compared to that in the open areas, both before and after the closures. The year 1989 was excluded because only a portion of the survey was completed that year. Data from the transitional 1995 year was also excluded. Since the southern portion of Closed Area II was fished prior to the 1999 and 2000 survey, it was excluded as well. A two-way ANOVA was performed on the log-transformed data, with the independent variables being "period" (i.e., either 1982-1994, or 1996-2000) and "region" (i.e., either currently open areas, or the closed areas). A stock-recruitment relationship caused by an increase in larvae released in the closed areas would be indicated by a "period" effect. Any of the proposed differential effects on post-larval survival between open and closed areas would appear as an interaction term between period and region.

Table (B5-8) displays yearly recruitment (40-70mm) as observed in the annual survey for the open areas, closed areas, the southern portion of Closed Area II, and the overall average, for the years 1982-2000. The log-transformed mean recruitment in the 1996-2000 period was modestly higher than that of the 1982-94 period in both the open and closed areas. These increases (i.e., the effect of the "period" variable) were not significant, however ($p = 0.41$; this lack of significance may be due to the limited number of years of data since the closures, and the exclusion of the southern portion of Closed Area II; see above). As recruitment rose after closure on average about the same amount in the open and closed areas, there was no evidence of any interaction term ($p = 0.99$). Thus, the data give no support to any of the above hypotheses that scallop dredging and trawling either enhances or decreases the survival rate of post-larval juvenile scallops.

Natural mortality estimates from survey "clapper" data

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

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

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

The average clapper ratio for 1982-2000 was 0.024 in Georges Bank stock area, and 0.005 for the Mid-Atlantic stock area. It is not clear whether there has been a real decrease in the clapper ratio since Merrill and Posgay (1964). Various gear may have differential selectivity for clappers as compared to live scallops, and Merrill and Posgay's study did not use the current gear configuration. In addition, it is possible that dredging may cause clappers to separate quicker so that lower clapper ratios during 1982-2000 may be due to increased fishing effort during the last twenty years. It is also difficult to interpret the lower clapper ratio in the Mid-Atlantic. Higher water temperatures in this region may increase the disintegration rate of clapper hinge ligaments and increase the separation rate S. However, despite all uncertainties, clapper ratios during 1982-2000 do suggest a low rate of natural mortality, of the order of $0.1\ y^{-1}$ or less. Comparison of year-to-year survey numbers in closed areas also indicates that natural mortality is low.

The current estimate of $M = 0.1$ is currently applied to all size categories >40mm, because Merrill and Posgay (1964) found no strong evidence of changes in M with size. Nonetheless, the possibility of an increase in natural mortality with age or size has been raised because scallops lose their ability to swim effectively above a shell height of about 110-120 mm. The reported paucity of ~~scallops greater than 20 years old is consistent~~ with the hypothesis of increased total mortality. Historically high rates of fishing mortality in USA waters make it impossible to infer an increase in natural mortality as the cause of low abundance of older animals. Data from MacDonald and Thompson (1986) suggest that natural mortality increases with shell height for scallops beyond 110 mm, and for very large scallops (>140mm), the natural mortality was relatively high ($\sim 0.2\ y^{-1}$).

To investigate the possibility of age-dependent natural mortality, clapper ratios were calculated in three size classes (40-80 mm, 80-120 mm, 120+ mm shell height) for the closed and open areas of Georges Bank for the periods 1982-1994 and 1996-2000 (see Table B5-9). If natural mortality is higher among very large scallops that have only been observed in large numbers in the past few years in the closed areas, then the clapper ratio should be highest in the largest size group, and there should be an increase in the clapper ratio in the largest size group after closure.

In the closed areas, the clapper ratio in the largest size group was about three times higher during the last four years than in previous years. This increase was mainly due to a high number of clappers observed in the Nantucket Lightship Area in 1999. Analysis of variance indicated that no effects were significant, however. In addition, clapper ratios are difficult to interpret because the separation rate may itself be size-dependent and may also be affected by dredging. Analysis of open area clapper ratios also failed to find any significant effects.

Age-dependent natural mortality was also investigated for the Mid-Atlantic (see Table B5-9). The clapper ratio was significantly higher in the largest size group compared to smaller ones. Again, this result is difficult to interpret because larger clappers may remain attached for a longer time, and large scallops were mostly found in areas of low fishing activity.

In conclusion, it appears that natural mortality is low, and the current estimate of $M = 0.1$ is reasonable. While there is some evidence that clapper ratios of large scallops is higher, the interpretation of this result is difficult. Thus, the evidence for age-dependent natural mortality is not definitive at this time.

Discard mortality

Discard mortality may have been important for sea scallop in some years and is potentially important in some calculations. Small sea scallop (less than about 75 mm shell height) are often discarded rather than shucked. Discarded sea scallop may suffer mortality on deck due to crushing, high temperatures, or desiccation. There may also be mortality after they are thrown back into the water from physiological stress and shock, or from increased predation due to shock and inability to swim or due to shell damage.

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

Incidental fishing mortality

It has long been suggested that scallop dredges can induce mortality on scallops in the track of the dredge, but not caught, primarily due to damage (e.g., crushing) caused to the shells by the dredge. Two studies have directly observed the condition of scallops remaining after a pass of a dredge from submersibles. Caddy (1973) estimated that 15-20% of the scallops remaining in the track of a dredge were killed. Murawski and Serchuk (1989) estimated that less than 5% of the scallops remaining in the track of a dredge suffered non-landed mortality. Caddy's study was done in a relatively hard bottom area in Canada, while the Murawski and Serchuk work was done in sandy bottom off the coast of New Jersey. It is possible that the different levels of indirect mortality observed in these two studies was due to different bottom types (Murawski and Serchuk 1989).

In order to use the above estimates to relate landed and non-landed fishing mortality, it is necessary to know the efficiency *e* of the dredge. Denote by *c* the fraction of scallops that suffer mortality among those which were in the path of the dredge but not caught. Thus, *c* was estimated at 0.15-0.2 by Caddy (1973), and less than 0.05 by Murawski and Serchuk (1989). The ratio *R* of scallops in the path of the dredge that were caught, to those killed but not caught is:

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

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

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

If, for example, the dredge efficiency *e* is 40% (NEFSC 1999), then $F_I = 1.5\, F_L\, c$. Assuming $c = 0.15$ to 0.2 (Caddy 1973) gives $F_I = 0.225\, F_L$ to $0.3\, F_L$. With $c < 0.05$ (Murawski and Serchuk 1989) $F_I < 0.075\, F_L$. In this example, the assumed 40% dredge efficiency, and two studies on incidental mortality give estimates of indirect mortality ranging from less than 7.5% to 30% of the landed mortality rate. Table B6-1 gives incidental mortality estimates for a range of assumed dredge efficiencies.

SMAST VIDEO SURVEY[2]

The School for Marine Science and Technology (SMAST) in collaboration with the scallop industry conducted a systematic video survey in the Nantucket Lightship Area, Closed Area I and Closed Area II of Georges Bank from May to September 1999. Scallop abundance, spatial distribution on several scales (cm, m, km), associated macroinvertebrate benthic community and substrate were identified and examined.

To sample scallop aggregations, a "pyramid" weighing approximately 318 kg was constructed with a square base 2.2 m per side (6 cm round iron) and 2.5 m sides (4.5 cm round iron). An underwater camera was attached to the center of the pyramid 157 cm above the pyramid base. Two 100 w lights were attached 50 cm above the pyramid on opposite arms.

In sampling, the pyramid was deployed from scallop fishing vessels using the large hydraulic winch normally used to deploy commercial scallop dredges. A video camera and lights were attached to the vessel using 200 m cables with cable tension controlled by hand. The video image was transmitted to the bridge of the ship where it was recorded on a standard VHS tape in real time. Along with each image the time, depth and latitude and longitude by differential GPS were recorded.

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[2] Project title: Examination of population biology and dynamics of the sea scallop, *Placopecten magellanicus*, in discrete areas of Georges Bank. Principal investigator: Kevin D. E. Stokesbury, Ph.D., School for Marine Science and Technology, University of Massachusetts Dartmouth, 706 South Rodney French Blvd., New Bedford, MA, 02744-1221

The base of the pyramid enclosed a 2.2 m^2 area of the ocean bottom.

Based on a systematic sampling design with stations separated by 1.57 km (0.85 nautical miles), a total of 798 stations were sampled in the Nantucket Lightship Area, Closed Area I and Closed Area II (Fig. B5-18). Once the vessel was on station, the pyramid was lowered to the sea floor and a clear image was obtained. Then, at the same station, the pyramid was raised so that the sea floor could no longer be viewed and lowered again to obtain a second image in a slightly different location. This procedure was repeated four times to provide four "quadrat" samples at each station. All scallops within the viewing field (including those those along the edge) were counted. The size of the viewing field was therefore increased in calculations to 2.36 m^2 to include edges and avoid bias.

After each cruise, videotapes were replayed and an image of each quadrat was digitized and saved (TIF file format). Scallop counts were verified, the substrate within each image was identified, and all macroinvertebrates were counted. After verification, raw counts were standardized to densities measured as number per m^2. The digitized images were loaded into UTHSCSA image tool software and shell heights of live scallops in each image were measured (Fig. B5-19).

Scallop and macroinvertebrate mean densities and standard errors were calculated using equations for a multistage sampling design (Cochran 1977, p. 277; Krebs 1989). Estimates of scallop densities within closed areas were calculated by multiplying the mean density of scallops times the area sampled. Estimates of scallop meat weight were calculated using shell height distributions and a shell height-weight regression ($\ln(W) = -4.416 + 2.8189\ln(L)$; $r^2 = 0.93$) estimated from 123 scallops collected in Closed Area II during October 1998.

For comparisons to NEFSC sea scallop survey results in this assessment, SMAST video survey data were tabulated for scallops with shell heights greater than 90 mm (see below). This adjustment reduced original estimates of scallop abundance by 15%, 27% and 28% for the Nantucket Lightship Area, Closed Area I and Closed Area II.

	Nantucket Lightship Area	*Closed Area 1*	*Closed Area 2*
Area sampled km^2	*507*	*1122*	*311*
Number of stations in area	*205*	*454*	*126*
Quadrats per station	*4*	*4*	*4*
Scallop density (number per m^{-2}) in sample area	*0.52*	*0.34*	*0.81*
Standard error	*0.08*	*0.03*	*0.1*
CV (SE/mean)	*0.154*	*0.088*	*0.123*
Total scallop abundance (millions, all sizes)	*264*	*381*	*252*
Scallop mean meat weight (g, all sizes)	*29.7*	*22.5*	*23.3*
Total scallop biomass (mt, all sizes)	*7,800*	*8,600*	*5,900*
Scallop >90 mm density (number per m^{-2})	*0.44*	*0.25*	*0.58*

During 1999, three NEFSC scallop dredge efficiency experiments were conducted to estimate scallop density at locations near SMAST video survey stations (see below). Density of scallops based on SMAST stations within 2 nm of the efficiency experiments are shown below.

	SMAST Stations	**Total SMAST Quadrats**	**Number Scallops Counted**	**Scallop Density (all sizes)**	**Scallop Density (> 90 mm)**
Nantucket Lightship	9	36	34	0.4	0.34
Closed Area 1 *(F/V Kathy Marie)*	11	56	96	0.73	0.53
Closed Area 1 *(F/V Santa Maria)*	14	44	30	0.29	0.21

VIMS-HUDSON CANYON CLOSED AREA SURVEY[3]

The Hudson Canyon and Virginia Beach closed areas in the Mid-Atlantic Bight stock area was surveyed by the Virginia Institute of Marine Science using two commercial dredges and the commercial F/V Alice Amanda during the summer and fall of 2000. The survey of the Hudson Canyon Closed Area from June 8-15, 2000 using a systematic grid design with survey stations located approximately 5 nm apart (Fig. B5-20). The survey of the Virginia Beach Closed Area (September 19-22, 2000) utilized a comparable sampling design (Fig. B2-21). Survey stations were located both inside and outside the boundaries of the closed areas. Additional stations were added along the western, northern and southern boundaries in an attempt to resolve the boundary effects on sea scallop abundance and size distribution. Survey tows were 10 minutes in duration at a speed of 4.5-5.0 kts. The sampling gear consisted of two standard 15 ft. New Bedford style sea scallop dredges with 8 inch twine tops, ring bags knit with 3.5" (88.9 mm) rings, and no tickler or rock chains. A NMFS inclinometer was attached to the frame of the starboard dredge to measure dredge angle and bottom contact time. The coefficients of the shell height-meat weight relationship were a=-12.1628 b=3.2539. A nominal tow length of 1 nm and an efficiency of 40% were used in the computation of total biomass.

Initial biomass estimates for the Hudson Canyon gave a total estimate of 18,818 mt with a coefficient of variation of 9% such that the approximate 95% confidence interval (+ 2 SE) was 15,292 to 22,346 mt. The biomass estimate for the Virginia Beach closed area was much smaller (1389 mt) and slightly less precise ~12%.

"Direct" Depletion Experiment Estimates of Commercial Dredge Efficiency

Depletion experiments were carried out during 1999 and 2000 using commercial vessels to estimate efficiency of commercial scallop dredges. Estimates of commercial dredge efficiency can also be used to develop indirect estimates of efficiency for the NEFSC sea scallop survey dredge. As shown above, catch rates from 193 comparative tows for a commercial dredge and the NEFSC survey dredge, fished at the same time from the *F/V Tradition* during 1999, were nearly identical after adjusting for differences in dredge width

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and dredge selectivity. Corrections for survey dredge and commercial dredge selectivity based on the results of Serchuk and Smolowitz (1980) result in comparable shell-height distributions. Finally, catch rates by the *F/V Tradition* using NMFS dredge at 21 stations previously sampled by the *R/V Albatross IV* were not statistically different (see above).

Estimators

Direct estimates of dredge efficiencies were obtained from depletion experiment data using the traditional Leslie and Davis (1939) model (LD) and the Patch model. In the LD model, catch per tow (C_i) is:

$$C_i = p\ (N - T_{i-1})$$

where T_{i-1} is the cumulative catch through the tow i-1, N is the initial population size and p is the catchability coefficient. The equivalent linear regression model is:

$$C_i = pN - pT_{i-1}$$

In the LD regression model, cumulative catches C_i are the dependent variable, pN is the intercept, p is the slope, and T_{i-1} is the independent variable.

Efficiency was estimated from LD regression results by multiplying the estimated slope $(\hat{p})$ by $A'/\hat{a}$, where A' is the estimated area swept at least once during the depletion experiment and $\hat{a}$ is the average area swept per tow. The LD model is biased for sea scallops (because the assumption of complete mixing between tows is violated) and the variance of statistical errors varies over the course of the experiment. Despite these problems, the LD model provides a simple check on estimates of density from other models. Specifically, the sum of the catches during the experiment divided by the area swept at least once (T_i/A', after the last tow) is a lower bound estimate for the true density N/A'.

The Patch model models catch and the spatial overlap of tows as a depletion experiment progresses. Taking into account the path of tow i as well as the paths of all previous tows, we compute the fraction of the cells during the tow sampled once, twice, etc. Explicitly, if the fraction of cells in tow i sampled j times is $frac_{i,j}$, then the catch equation can be written:

$$E(C_i) = e\, a_i D_0 \sum_{j=1}^{i} frac_{i,j} (1 - e\gamma)^{j-1}$$

where:

D_0 = Initial density (number/m^2)
C_i = Number caught in tow i
a_i = Area swept in tow i
e = Efficiency = Prob(Capture | Encounter)
w_{dredge} = width of dredge
Δx = Width of cell x
ε = factor related to unobserved mortality and indirect effects
$\gamma = (w_{dredge} / \Delta x) + \varepsilon$
$frac_{i,j}$ = Fraction of patches during tow i that was sampled j times

and for any tow:

$$\sum_{j=1} frac_{i,j} = 1.$$

The values of $frac_{i,j}$ are determined from the latitude and longitude coordinates $\{x_{ij}, y_{ij}\}$ that define each tow path.

The *"gamma"* parameter (g) is an important feature of the Patch model. If there are "indirect" effects of sampling during a depletion experiment, then catchability of the animals changes after sampling. Indirect effects may occur if the zone of influence of the dredge used in a depletion experiment is greater than the area swept, or because target animals (like scallops) are buried, killed without being caught, swim out of the area surveyed, fall out of the dredge outside of the experiment area during haulback, or become otherwise unavailable to the dredge for the duration of the experiment. With indirect effects, the population available for capture on subsequent passes will be less than expected based on Eq. 3. The *"gamma"* parameter (g) in the Patch model can be used to deal with this biologically and statistically important possibility because it can remove bias in abundance and efficiency estimates from depletion experiments.

The gamma parameter *ã* can have both physical and biological interpretations. In a physical sense, and ignoring possible biological effects, ã is simply the ratio of the dredge width and the cell width. In this simple circumstance, *ã* can be viewed as a parameter with a known value that does not require estimation in the Patch model. However, if the dredge has indirect effects beyond what it catches and brings to the deck of the ship, then the numbers of animals available to capture on subsequent passes will be lower than expected and it may be important to try and estimate ã in the Patch model, or by other means.

As described above, if there are no indirect effects, then g takes its nominal value which is equal to the area within a patch covered by the dredge divided by the area of the patch. Gamma will exceed its nominal value if animals become less available to the dredge with repeated passes over the same patch or if they are lost from the dredge and are not counted in the catch.

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Catch per tow was modeled as a negative binomially distributed random variable defined in terms of the parameters density D_o, efficiency *e*, gamma *ã*, and the dispersion parameter *K* as follows:

$$NB(C_i|a_i^*)=\left(\frac{K}{D_o a_i^*+K}\right)^K\left(\frac{D_o a_i^*}{D_o a_i^*+K}\right)^{C_i}\prod_{j=1}^{C_i}\left(\frac{K+j-1}{j}\right)$$

where a^*_i is the "effective" area swept per tow, such that:

$$a_i^* = e\, a_i \sum_{j=1}^{i} frac_{i,j}\,(1-e\gamma)^{j-1}$$

Given the above, and using the negative binomial distribution, the log likelihood of C_i for an experiment consisting of *I* tows is:

$$
\begin{aligned}
LL(C_I \mid K, D_o, a_I^{\bullet}) = {} & K\left(\sum_{i=1}^{I} \log(K) - \log(D_o a_i^{\bullet} + K)\right) + \\
& \sum_{i=1}^{I} C_i \left(\log(D_o a_i^{\bullet}) - \log(D_o a_i^{\bullet} + K)\right) + \\
& \sum_{i=1}^{I} \sum_{j=1}^{C_i} \log(K + j - 1) - \sum_{i=1}^{I} \log(C_i!)
\end{aligned}
$$

Note that the catch and depletion process is a function of the initial density D_o, the negative binomial dispersion parameter K, the efficiency parameter e, and $\tilde{a}$. The negative binomial model reduces to the Poisson distribution as the negative binomial parameter dispersion parameter K approaches infinity.

The Patch model was used to estimate an efficiency of 41% (SE 0.122) for scallop dredges (NEFSC 1999) based on results from twelve depletion experiments in Closed Area 2 during 1998 that had statistically significant declines in catch (NEFSC 1999). The 41% estimate was not used in the last assessment, however, because the "SARC felt that gear efficiencies in Closed Area 2, where depletion studies were conducted, were likely higher than elsewhere in the Georges Bank or Mid-Atlantic regions" (NEFSC 1999).

For this assessment, four fishing vessels carried out depletion experiments during 1999 and 2000 at a wider range of sites from the Virginia Beach Closed Area (Mid-Atlantic stock area) in the south, to Closed Area 1 (Georges Bank stock area in the north, Table B5-10 and Figs. B5-22, B5-23). The Patch model has also been used to estimate efficiency of NEFSC and clam dredges used for Atlantic surfclam and ocean quahog (NEFSC 1999; 2000).

The "gamma" parameter (γ) is important in analyzing depletion experiments and in interpreting results. All depletion experiments were analyzed in this assessment assuming a cell size of 60 ft x 60 ft and a dredge width of 30 ft (the sum of two 15 ft dredges towed side by side). If no indirect losses occur during the depletion experiment (i.e., no scallops are lost to the experiment without being caught), then the expected value of the gamma parameter is γ=30/60=0.5. If indirect losses occur, then the expected value of gamma is greater than 0.5. Therefore, each depletion experiment was analyzed assuming γ=0.5 and 0.75.

Natural variability and statistical estimation errors are both important in considering assumptions about indirect losses (γ) in depletion studies. The "true" value is uncertain, but gamma is at least as large as its expectation assuming no indirect losses (i.e., γ ³ 0.5). Gamma may vary among experiments or sampling areas due to differences in scallop density, size structure, fishing practices, bottom conditions, depth, water temperature, currents or other factors. Most of these factors likely effect dredge efficiency as well.

With the exception of the *F/V Kathy Marie*, fishing vessels used in depletion experiments were equipped with the same type of inclinometer used in the NEFSC sea scallop survey during 2000 (see above). Maximum (upper bound) estimates for tow distances in NEFSC sea scallop tows were based on inclinometer data and the "ski jump" (see above). The same approach was used to determine maximum tow distances in experiments by the *F/V Alice Amanda*, *F/V Courageous*, and *F/V Santa Maria*.

There was insufficient time to analyze all depletion experiments using minimum tow distance measurements based on bridge logs. Sensitivity analyses (see below) indicate that scallop density estimates were more sensitive than estimates of dredge efficiency to decisions about tow distances.

The *F/V Kathy Marie* used a different sensor package which was designed to record dredge depth, tilt and roll in addition to inclinometer data. However, this sensor package was less reliable and it failed to log data during much of the study. The *F/V Kathy Marie* carried out two experiments, but the second experiment could not be analyzed because all three sensors failed during most of the second experiment.

Fortunately, results from the first experiment by the *F/V Kathy Marie* could be analyzed using depth sensor, rather than inclinometer, data. Depth was the only variable logged successfully during most tows. The experiment took place in about 350 feet of water. The start and end of each tow was clearly indicated by a rapid change in depth measurements from 0 to 350 ft and *vice-versa*.

A "10 foot rule" was used to determine when a tow began and ended. In particular, the dredge was assumed to be on the bottom and fishing when depth was less than 10 feet from the bottom. Similarly, the dredge was assumed to be off the bottom and to have ceased fishing when the dredge was more than 10 feet from the bottom. To accommodate changes in bottom topography, noise and precision of sensor data, we used the average of the bottom depth during the most recent 16 seconds in applying the 10 foot rule. The dredge was assumed to be fishing during the entire time between the start and end points. Tows were at least 10 minutes long and carried out at speeds of at least 4 nm h^{-1}.

Conventions other than 10 feet could have been used, but the 10 foot rule was chosen to be certain that the dredge was actually off the bottom. Calculations showed that estimated tow distances would have changed very little if an "8 foot" or "6 foot" rule were used instead. At the start of a tow, the dredge falls rapidly through the water and switching to a different rule would have added only 1 or 3 seconds to the minimum 10 minute tow time. The *F/V Kathy Marie* was typically moving slowly at the end of each tow because power was diverted to the winch and because it is a relatively small vessel whose speed was quickly reduced by drag when power is reduced. Using an "8 foot" or "6 foot" rule would have added only 6 or 14 seconds to the end of the minimum 10 minute tow time.

Sensitivity analyses

Two analyses were done to determine the sensitivity of results from the Patch model to assumptions in the model. In the first analysis, data from the two experiments by the *F/V Santa Maria* were used to determine sensitivity to assumptions about tow distance and inclinometer data (see above). Specifically, the Patch model was fit to tow data to approximate minimum (lower bound) tow distances. Results with minimum tow distances were compared to results from the Patch model fit to maximum (upper bound) tow distances described above. Lower bound estimates were approximated by clipping the final 180 seconds from the end of each tow, prior to the ski-jump. Clipping reduced assumed tow paths to approximate the distances that would have been obtained if the tow ended shortly after the end of the timed-tow according to the bridge log.

The second sensitivity analysis measured sensitivity of predicted scallop catches from each tow to assumptions about the gamma parameter. Data from the first *F/V Santa Maria* experiment were used because estimated scallop density was relatively high. First, the model was run with $\gamma= 0.5$ to estimate parameters and predicted catches in each tow. The model was rerun with $\gamma= 0.75$ and all other parameters fixed at their solutions with $\gamma= 0.5$ to obtain another set of predicted catches. Predicted scallop catches in each tow from the two runs were then compared. Finally, to determine the effect of switching to from 0.75 to 0.5, the entire analysis was repeated with gamma fixed in the first run at $\gamma= 0.75$ and, in the second run, at $\gamma=0.5$.

Results

Of the 12 depletion experiments, nine were carried out in the Mid-Atlantic Bight stock area by the *F/V Alice Amanda* and *F/V Courageous.* The other three experiments with useable data were in Closed Area 1 and the Nantucket Lightship Closed Area (Georges Bank stock area) by the *F/V Kathy Marie* and *F/V Santa Maria*.

Mean efficiency estimates from the Patch model (with $\gamma= 0.5$ and 0.75) and LD model from all 12 experiments ranged 0.51-0.64 (Table B5-10). Standard errors were highest for the Patch model with $\gamma=0.5$. Median efficiency estimated by different models for all 12 experiments ranged from 0.48 (Patch model with $\gamma=0.75$) to 0.78 (Patch model with $\gamma=0.5$). Efficiency estimates from the Patch model with $\gamma=0.75$ were similar to LD estimates.

Efficiency estimates from the Patch model with $\gamma=0.5$ where often near the upper bound used in parameter estimation. The upper bound requires estimates of efficiency £ 0.95 and is used to avoid impossible solutions where estimated dredge efficiency is greater than one. Ninety-five percent confidence intervals from the Patch model for efficiency and density based on runs with $\gamma=0.5$ (Table B5-11) and 0.75 (Table B5-12) were more often very large or numerically unstable with $\gamma=0.5$. These results suggest that the assumption of no indirect losses (i.e., $\gamma=0.5$) is unrealistic (see above).

Efficiency estimates from southern experiments in the Mid-Atlantic Bight were higher than estimates from northern experiments in the Georges Bank stock area (Table B5-10). The Patch model with γ=0.75 and the LD model gave mean efficiencies of 0.59 and 0.58 in the southern Mid-Atlantic Bight stock area compared to 0.27 and 0.30 in the northern Georges Bank stock area.

Results of sensitivity analysis indicate that Patch model estimates of dredge efficiency are robust to assumptions about tow distances but that estimates of density are less robust. Shortening assumed tow distances by subtracting 180 seconds prior to the ski-jump (Table B5-13) had modest effects on efficiency estimates (0.13 vs. 0.10 in one depletion experiment, and 0.46 vs. 0.44 in the other), particularly at estimated efficiency levels (0.44-0.46) that appear typical in the fishery. However, reducing assumed tow distances gave higher density estimates (0.027 vs. 0.034 scallops ft^2 in one depletion experiment and 0.31 vs. 0.44 scallops ft^2 in the other).

Sensitivity analysis suggests that assumptions about the gamma parameter in the Patch model have relatively small effects on predicted catches (and probably abundance and density) when all other parameters in the negative binomial equation are fixed at their optimal solutions. When gamma was increased in sensitivity analysis from γ=0.5 to 0.75 (and other parameters were held constant at best estimates with γ=0.5), predicted catches declined by a small amount for most of the tows in the experiment (Fig. B5-24). Analogously, when gamma was reduced from γ=0.75 to 0.5 (and other parameters were held constant at best estimates with γ=0.75), predicted catch increased slightly, because fewer scallops were assumed to be lost due to indirect causes (Fig. B5-25).

Indirect Estimates of Efficiency

Field experiments like depletion studies (see above) give "direct" estimates of dredge efficiency for sea scallop. However, direct estimates from depletion are affected by uncertainty in measuring the position of the dredge, and the possibility that dredging repeatedly over same area reduces the ability of the dredge to sample from the original population. Indirect estimates are important because they supplement and complement direct estimates based on a wide variety of data and different assumptions. Three indirect approaches were used for sea scallop in this assessment: 1) the "catch ratio" method; 2) the "Patch model with density constraints"; and 3) ratios of catch-biomass to survey-based mortality rates. Most indirect efficiency estimates are based on ratios of relative abundance or mortality estimates from independent experiments.

Catch ratio method

The ratio of catch rates (usually density measured as numbers of scallops per m^2) for two different gears in the same area is equivalent to the ratio of their efficiencies. To see this, note that expected catches from one unit of sampling effort by two types of scallop dredge are $C_1=e_1a_1D$ and $C_2=e_2a_2D$, where D is the density of scallops, e_1 and e_2 are efficiencies (i.e., the probability of capture given encounter), and a_1 and a_2 are areas swept by each gear. Density is the same for both gears so that $(C_1/e_1a_1)/(C_2/e_2a_2)=1$ and the ratio of catch rates ($f_i=C_i/a_i$, catch per area swept) is the same as the ratio of efficiencies:

$$f_1/f_2=e_1/e_2 \qquad (5\text{-}1)$$

In the special and important case (see below) where the sampling efficiency of gear type 2 is near 100% (i.e., $e_2 \gg 1$), the ratio of catch rates measures the absolute efficiency of gear type 1. In other cases, estimates of the relative efficiency ratio e_1/e_2 can be multiplied by a direct efficiency estimate for one gear $e_{2,direct}$ to obtain an efficiency estimate for the other:

$$e_{1,direct} = (f_1 / f_2)\ e_{2,direct} = (e_1 / e_2)\ e_{2,direct} \quad (5\text{-}2)$$

The catch ratio method is applicable when the local population sampled by each gear is the same or, in statistical terms, the sampling frame is "equivalent". The assumption of an equivalent sampling frame means that the two gear types select scallops of the same sizes from the same spatial area at the same time.

For this analysis, scallop catches in dredge gear were restricted to a size range (shell heights ^{3} 90 mm) where size selectivity of the NEFSC research survey dredge and commercial dredges is equivalent .

The research dredge used in NEFSC scallop surveys is 8 ft wide with 2 inch rings lined internally with 1.5 inch mesh (see above and Appendix 3). In contrast, commercial dredges used in this study were 15 ft wide with 3.5 inch rings and no liner (Appendix 3). To compensate for the differences in selectivity between dredges, catch rates for scallops >90 mm in the NEFSC scallop dredge were adjusted upward by 1/0.713 to adjust for reduced catchability at large sizes (Fig. B5-1; Serchuk and Smolowitz 1980; NEFSC 1997) and then multiplied by 15/8 to adjust for differences in dredge width.

As described above, it is important to restrict the spatial domains for catch rates in the numerator and denominator of Eq. (5-1) to equivalent areas because scallop density can vary considerably over short distances depending on substrate characteristics, recent recruitment and fishing patterns. Data from research vessel, commercial fishing vessel, and photographic surveys used in this analysis were post-stratified (restricted spatially) to the same general area (see below).

Catch ratio variance estimation

The mean and variance of Eq. 5-1 can be approximated using first order error analysis (Taylor series expansion). Let $X = f_1$ and $Y = f_2$, and $m(X)$, $m(Y)$ represent the sample means of X and Y. Let $v(X)$, $v(Y)$ and $cov(X,Y)$ be the sample variances an covariance, then:

$$E[X/Y] = m(X)/m(Y) - 1/m(Y)^2\ cov(X,Y) + m(X)/m(Y)^3\ v(Y) \quad (5\text{-}3)$$

and

$$V[X/Y] = (m(X)/m(Y))^2\ \{v(X)/m(X)^2 + v(Y)/m(Y)^2 - 2\ cov(X,Y) / (m(X)\ m(Y))\} \quad (5\text{-}4)$$

It is possible to simplify calculation by assuming the covariance term cov(X,Y) is zero. We estimated the effect of this potential simplification using the correlation coefficient:

$$r = cov(X,Y) / (v(X)\ v(Y))^{1/2} \quad (5\text{-}5)$$

By rearranging Eq. 5-5 to solve for cov(X,Y) and substituting into Eq. 5-3 and 5-4, it is possible to evaluate the potential importance of the covariance term in estimating variances. The variance of NMFS research surveys, based on experience and theory (e.g., Gunderson 1993), increases with the mean. Therefore, it is unlikely that the covariance is negative. Effects on mean and variance were evaluated for levels of assumed correlation r=0, 0.25, 0.5, 1.0. Results (Tables B5-14 and B5-15) indicate that as r approaches 1.0 the sample variance estimates are reduced by about 50%.

To further assess the potential variation in ratios of catch rates, a parametric bootstrapping approach was implemented in Excel with 5000 iterations (each iteration using a new set of simulated catch rates). Mean catches were assumed to follow a normal distribution truncated to remove values with cumulative probability less than 10% and greater than 90%. Truncation reduces the probability of extreme ratios that tend to bias the mean well above its expected value, and reduces the variance as predicted by the Eq. 5-4 Bootstrap simulation results generally indicate that the sample standard deviation of the catch ratio was approximated by the predicted standard deviation from the Taylor series calculation when the assumed correlation coefficient was r=0.5 (Table B5-14).

Catch ratio results

Comparisons of efficiency ratios, catch rates and approximate sampling variances for the various research and fishing vessel experiments are summarized in Table B5-15.

After post-stratification, the spatial domain (area covered) by NEFSC survey data was generally smaller than the domain of the commercial fishing vessel survey. In these instances, stratification is designated "*R/V Strata*" in Table B5-15. The photographic video survey method conducted by SMAST (see above) aboard commercial fishing vessels was usually restricted to high concentrations of scallops in closed areas of Georges Bank and the stratification in Table B5-15 is "Photo Region".

Results suggest no significant differences between sampling efficiencies of NEFSC scallop survey and commercial scallop dredges (Fig. B5-26). Catch rate ratios were generally about one in the Nantucket Lightship Area, Hudson Canyon and Closed Area 1. Capture ratios in the Virginia Beach Closed Area were about 1.4 (NEFSC survey dredge catch rates exceeded commercial dredge catch rates) but this may have been due to difficulties in assigning fishing vessel sampling stations to the NMFS shellfish strata. Post-stratification is difficult because NEFSC shellfish survey strata are narrow in this region owing to steep bathymetry. Similar problems may have affected a catch rate ratio for Closed Area 1 during 1999.

The comparison of capture ratios for Closed Area II in 1998 illustrates influence of high variance on the capture ratio. Catch rates by commercial dredges were about half of catch rates in the NEFSC survey dredge, but the coefficient of variation for the commercial dredge was large (CV=3.7) indicating that the commercial catch rate estimates were imprecise. As in the Virginia Beach Closed Area, NEFSC shellfish survey strata in Area II are narrow and commercial dredge samples included in the comparison may have included deep tows outside the domain of the NEFSC survey data. The expected value of the ratio from the Taylor series expansion is dominated by the third term on the right hand side of Eq. 5-3 and the expected value of the ratio of catch rates $m(X/Y)$ exceeds the ratio of the mean catch rates $m(X)/m(Y)$ by a substantial amount (Table B5-16). Assuming that catch rates in the commercial dredge had a similar CV, and adjusting for variance in calculation of expected values based on Eq. 5-3, the expected value of the ratio of catch rates is dominated by terms with variances and covariances in Eq. 5-3, and exceeds two. The importance and statistical consequences of uncertainty in catch rates is also evident in the parametric bootstrap results.

Ratios based on "catch rates" in video photographic survey data and commercial (Fig. B5-27) and NEFSC survey dredge catch rates the *R/V Albatross* (Fig. B5-28) can be used to estimate absolute dredge efficiencies (Eq. 5-2) if the photographic survey identifies 100% of the scallops in its sampling quadrat (i.e., if it is 100% efficient). Estimated efficiencies of research and commercial dredges were nearly identical and about 0.84 in the Nantucket Lightship area closed area and about 0.32 in Closed Area 1. The apparent high efficiency of the dredges in the Lightship area may be due to patchiness of scallops. When the depletion experiment in the Nantucket Lightship was analyzed using the Patch model constrained to a local estimate of density (Table B5-17, and see below) estimated efficiency ranged 38% to 64%, depending on the value of gamma assumed and the number of tows included.

In Closed Area I the ratio of relative densities of NEFSC survey dredges and photo survey was about 0.34 (Table B5-16) but when the constrained estimate of density was applied to the depletion experiments by the *F/V Santa Maria* and *F/V Kathy Marie*, the efficiency estimates ranged from 0.5 to 0.9. Applying Eq. 2 to this range implies that the R/V efficiency would be about 0.45 to 0.81 (i.e., 0.5*0.9, 0.9 * 0.9).

Patch Model with Density Constraints

Results from the SMAST photo survey density estimates can be combined with the depletion experiment to derive a conditional efficiency estimate in the Patch model. In theory, the density estimates from a depletion experiment should equal the density derived from an unbiased measure of density. The photographic survey method does not have the same types of biases as dredge-based estimates of relative density, but visual detection limits and sampling intensity issues are potential problems in visual surveys. Additionally, depletion experiments were conducted near but not exactly in the same location as photographic survey stations. To compensate for lack of explicit overlap, data from 9 -15 photographic stations in the vicinity of the depletion experiment were used to compute a mean density.

Despite some possible problems, the constrained Patch model provides additional insights into the possible range of dredge efficiencies. The effect of the gamma parameter was examined fixing it to three alternative values (0.5, 0.75, and 1.0).

RESULTS

Results summarized in Table B5-17 show that photographic estimates of density scallop density were lower than unconstrained estimates from the Patch model. When Patch model to estimates of scallop density were constrained based on photographic survey density estimates, estimated efficiency estimates from the constrained Patch model to an average of 50% for the three experiments. Constraints on density resulted in an increase in the likelihood function suggesting that the constrained model did not fit the data as well.

Difficulties in combining results of photographic survey density estimates and depletion study estimates strongly suggest that experiments which apply both method simultaneously would be worthwhile.

Ratio of Catch-Biomass to Survey Based Mortality Rates

Whole stock indices of fishing mortality rates can be calculated as the ratio of total landings to minimum swept area biomass (see "catch-based" fishing mortality rates in Section 6 of this assessment). Minimum swept-area biomass is the expansion of stratified survey catch rates for a standard swept area per tow, to the total stock area. The expected value of the minimum swept area biomass estimate differs from the true biomass by the factor $1/e$ where e is the efficiency of the research dredge. This measure of fishing mortality is calculated:

$$F_{rel}(t) = L(t) / [B_{swept}(t)/e] = L(t) / [B_{true}(t) * e] \quad (5\text{-}6)$$

Where $L(t)$ is landings in year t, $B_{swept}(t)$ is minimum swept area biomass and $B_{true}(t)$ is the actual biomass of the stock.

Survey data can themselves be used to estimate total mortality by computing the ratio of abundances adjacent size groups in adjacent years (see "survey-based" fishing mortality rates in Section 6 of this assessment). If we define $N(t)$ as the average density of scallops exceeding some size limit h_c and $R(t)$ as the density of scallops between h_r and h_c, such that all of the survivors from $R(t)$ exceed a shell height of h_c in year t+1, then the total mortality rate can be estimated as

$$Z_{survey}(t) = -log_e\,(N(t+1) / (N(t) + R(t)) \quad (5\text{-}7)$$

and $F_{survey}(t) = Z_{survey}(t) - M$, where M=0.1 y^{-1} is the natural mortality rate. Thus, the ratio of $F_{survey}(t)$ to $F_{rel}(t)$ provides a measure of efficiency e.

RESULTS

The average catch-biomass fishing mortality estimate for Georges Bank during 1982-1994 based on minimum swept area biomass was 1.49 y^{-1} (Table B6-2). During the same period, the average survey-based fishing mortality was 1.13 y^{-1} (Table B6-4). The ratio $e = 1.13/1.49 = 0.76$ is an indirect estimate of survey gear efficiency during 1982-1994. The same calculation for sea scallops in the Georges Bank stock area during 1995-2000 gives $e = 0.16/0.24 = 0.64$. Indirect estimates of survey gear efficiency based on fishing mortality estimates for the Mid-Atlantic stock (Tables B6-3 and B6-5) were $e = 0.83/1.13 = 0.73$ for 1982-1994 and $e = 0.73/0.87 = 0.83$ for 1995-2000.

These estimates of efficiency are influenced by a variety of factors including estimation of landings, area swept per tow in the surveys, and growth rates of individual scallops. The influence of these factors can be evaluated by combining Eq. 5-6 and 5-7 to solve for efficiency. The resulting equation for efficiency can be expressed as:

$$e = \left[\left(\left(\frac{\overline{C}A}{a}\right)\right) \Big/ L_t\right]\left[-\ln\left(\frac{N_{t+1}}{N_t + R_t}\right) - M\right] \quad (5\text{-}8)$$

From the above equation it can be readily seen that an increase in landings will decrease the estimated efficiency. If historical landings have been underestimated the current estimate of efficiency is too high. Similarly, an increase in the estimated area swept per tow (i.e., *a*) would also decrease efficiency; if the actual tow distances are greater than the nominal distance, then the current estimate of efficiency is too high.

SUMMARY

Catch rates for sea scallop greater the 90 mm shell height were similar for NEFSC survey and commercial dredges (after adjustments for selectivity and differences in dredge width). Thus, results suggest that efficiencies of NEFSC survey and commercial dredges are comparable for larger scallops. Differences in catch rates by the two types of dredge (after an adjustment for NEFSC survey dredge selectivity) appear to be mostly due to differences in width. The consistency of capture rates after adjustment also suggests that the Serchuk-Smolowitz (1980) correction factor for survey dredge selectivity is appropriate (see above).

All of the indirect estimates suggest dredge efficiencies greater than 30%. Most estimates suggest dredge efficiencies greater than 60%. Substrate and depth are obvious factors influencing dredge efficiency. Indirect measures integrate over a range of these factors. More focused experiments with multiple methods (e.g., depletion experiment and photo survey at same site) will provide a more accurate estimate of efficiency at a single site. However, the problem of varying efficiency across areas will remain. Hence, the indirect methods may continue to provide a robust measure of dredge efficiency for some time to come.

BIOMASS, POPULATION SIZE, AND FISHING MORTALITY

Fishing mortality and biomass estimates from survey and landings data

Fishing mortality and biomass estimators based on catch and survey data for sea scallop include catch-biomass, survey-based, rescaled catch-biomass, and rescaled fishing effort-based approaches. Most were used for sea scallop by NEFSC (1999) but are used in this assessment with methodological and data refinements, and with greater spatial resolution (whole stocks and open areas not closed to fishing).

The catch-based approach gives relatively smooth trend information (has relatively low variance), but the average mortality rate (scale) is uncertain unless efficiency of the survey dredge is known precisely. Also, these estimates will underestimate fishing mortality if there have been significant underreporting of landings, or there has been non-landed fishing mortality (mortal discards or incidental fishing mortality). The survey-based approach has higher variance but may be more accurate on average (unbiased). The rescaled catch-biomass approach scales smooth trends estimated by the catch-survey model using the unbiased and relatively accurate average of survey-based estimates. It is similar to the method used in the last assessment (NEFSC 1999).

Of the various estimators based on landings and survey data, and assuming hypothetically that survey dredge efficiency estimates were too imprecise, rescaled catch-biomass and rescaled fishing effort methods based on long time series of data would probably be the best source of management advice for sea scallop. As pointed out above, the rescaled approaches have relatively low variance and are expected to be unbiased. However, when applied to short time periods (i.e., 1995-2000) and small regions with noisy survey data (i.e. open areas, see below), both rescaled methods suffer from imprecise estimates of average survey-based fishing mortality rates.

Variances and uncertainty

We used Demming (1960, p. 393) exact formula to compute CV's for fishing mortality rate estimators in this assessment, which are all based on ratio calculations (see below). In particular, if x, y and z are independent random variables (no covariances), then:

$$CV^2\left({}^{xy}\!/_{z}\right)=CV^2(x)+CV^2(y)+CV^2(z)$$

CV's for biomass estimates were computed from variances and stratified random means for survey data and estimated variances for efficiency estimates (if available but not always required, see below). In addition we assumed CV=5% for uncertainty in the size (nm^2) of stock areas and regions, and CV=10% for landings data.

In calculation of confidence intervals, fishing mortality rate estimates were assumed to be approximately log normally distributed so that

$\sigma=\sqrt{\ln(1+CV^2)}$ where CV was the arithmetic scale CV and σ was the long scale standard error. Bounds for 95% confidence intervals around arithmetic estimates were computed $Fe^{\pm1.96\sigma}$. The assumption of a lognormal distribution for survey data may not hold so that the coverage of confidence intervals is different than assumed.

Catch-biomass method

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

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

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

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

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

where C_y is the meat weight of scallops killed by fishing during the calendar year (Ricker 1975). Ideally, C_y includes reported landings, non-reported landings, mortal discard, and incidental mortality. However, reliable estimates of non-reported landings and discard were not available, so reported landings are used instead. The estimator is biased low and ${}^cF_y$ tends to be too small if non-reported landings and non-landed fishing mortality are substantial (see below).

Landings and survey data for sea scallops in the Georges Bank and Mid-Atlantic stock areas were used to calculate catch-survey fishing mortality estimates based on a range of values for survey dredge efficiency (Tables B6-2 and B6-3). However, as shown below, assumptions about survey dredge efficiency are irrelevant when catch-biomass fishing mortality estimates are used in rescaled-survey method calculations.

Figures B6-1 and B6-2 gives catch-biomass fishing mortality estimates for Georges Bank and the Mid-Atlantic with assumed 50% and 70% efficiencies, respectively. Catch-survey fishing mortality rates for scallops in the Georges Bank stock peaked in the early nineties and then declined. This decline was due first to an effort shift to the Mid-Atlantic, and then to area closures and effort reduction measures. Estimates for the Mid-Atlantic stock are less variable, peak slightly later than in Georges Bank, and have declined continuously after 1996. The large decline during 1998 and 1999 was due to closure of two areas to scallop fishing in April 1998, to effort reduction measures, and to the shift of effort to Georges Bank in 1999 because of the opening of Closed Area II.

Survey-based method

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

In this assessment, the first bin for Georges Bank consisted of scallops of 80-100 mm shell height (but see below) and the second bin consisted of all scallops larger than 100 mm. An 80 mm sea scallop is almost fully recruited to the fishery and will grow to 100 mm in one year, according to von Bertalanffy growth curves for scallops in the Georges Bank stock area. For the Mid-Atlantic stock, where growth is slightly slower, the first bin consisted of 80-98.5 mm scallops and the second bin consisted of scallops larger than 98.5 mm. Fishing mortalities were calculated:

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

where R_t was the mean population numbers of scallops per standard survey tow in the first bin (new recruits) during survey year t and P_t was the mean population number of scallops per standard survey tow in the second bin. Survey years are the annual period between NEFSC sea scallop surveys (summer to summer). Average stock biomass can be estimated from survey based fishing mortality rates as ${}^{s}B_t{}^{*}=C_t/{}^{s}F_t$. Three- and five- year moving averages were used to smooth trends in plots.

Trends in survey-based fishing mortality estimates (Table B6-4 and B6-5; Figs. B6-1 and B6-2) were qualitatively similar to catch-biomass method. In particular, fishing mortality estimates peaked in the early nineties and then declined.

The von Bertalanffy growth parameter K and growth rates for sea scallops on Georges Bank may be greater than the accepted value, at least in the last several years. If growth rates are faster, then bin sizes should be adjusted so that the first bin is larger. Based on a von Bertalanffy growth curve with $K = 0.38$ and other parameters unchanged, survey-based fishing mortality rates were re-computed for Georges Bank assuming that the first bin included scallops 75-100 mm (Table B6-6a). The alternative estimates are *ad-hoc* but may be more accurate. They are higher, on average, than estimates based on 80-100 mm bins but have a similar trend. If growth rates have increased during the last five years, for example, then "best" survey-based estimates for sea scallop in the Georges Bank during 1982-1995 would be from Table B6-4 and best estimates for 1996-1999 would be from Table B6-6a.

Similarly, there is evidence that the recent growth rate in the Mid-Atlantic is slower than what was predicted by the standard von Bertalanffy growth parameters (see above). Table B6-6b gives alternative survey estimates assuming a smaller value of K (0.23) than in Table B6-5.

Rescaled catch-biomass method
Following NEFSC (1999), rescaled survey-based estimates were computed:

$$^{R}F_{y} = {}^{c}F_{y}\left(\frac{^{s}\overline{F}_{t}}{^{c}\overline{F}_{y}}\right)$$

where average catch-biomass ${}^{c}\overline{F}_{y}$ and survey-based ${}^{s}\overline{F}_{t}$ fishing mortality rates were for a time period containing year y. Changes in the scallop fishery during the mid-1990's included a new fishery data collecting system based on logbooks instead of interviews. Fishery regulations changed from minimum average meat count requirements, to days at sea and ring size restrictions. There may have been incentives to avoid reporting landings for loads with low meat weights when minimum average meat-count regulations were in force. Three large areas of Georges Bank were closed to fishing in December 1994, followed by two areas of the Mid-Atlantic in April 1998. In view of these factors, it seems possible that the relationship between reported landings and fishery induced mortality for sea scallops may have changed over time. For these reasons, the possibility was considered to rescale the catch-biomass fishing mortality rates for 1982-1994 and 1995-2000 separately (i.e. ${}^{s}\overline{F}_{t}/{}^{c}\overline{F}_{y}$ was computed and used to scale ${}^{c}F_{y}$ values for each of the two time periods separately), as well as rescaling based on the entire 1982-1999 time series.

Trends in catch-biomass fishing mortality rates are independent of the assumed survey gear efficiency (NEFSC 1999) although scale and average values are very sensitive. Therefore, catch-biomass estimates ${}^{c}F_{y}$ used in rescaling were computed assuming a dredge efficiency of one. This convention had no effect on results.

As pointed out above, catch-biomass fishing mortality estimates were for calendar years while survey-based estimates were for survey years. Two conventions were therefore adopted in computing average survey-based values for 1982-1994 and 1995-1999. First, survey-based ${}^{s}F_{94}$, based on data from calendar years 1994 and 1995 was used in computing ${}^{s}\overline{F}_{t}$ for both periods, but given only half the weight of the other rescaled estimates. Similarly, ${}^{s}F_{99}$, based on survey data for 1999-2000, was given a weight of one half in computing means to account for the six month delay between the summer survey and the beginning and end of calendar years.

Rescaled catch-biomass fishing mortality estimates for scallops in the Georges Bank stock area (Table B6-7 and Fig. B6-1) declined during the early to mid-1980's but increased to a high level in the early 1990's. Fishing mortality declined sharply after 1993 due to a shift in fishing effort towards the Mid-Atlantic and increasing biomass in closed areas. Rescaled catch-biomass fishing mortality estimates for the Mid-Atlantic stock area (Table B6-8 and Fig. B6-2) showed no clear trend during 1982-1996 but declined after 1996.

Fishing mortality in open regions within stock areas

Landings used in calculating catch-biomass fishing mortality estimates for open areas in the Georges Bank stock area during 1995-2000 (Table B6-9a) exclude 2,720 mt of meats caught in Closed Area II during 1999.

Landings for open areas in the Mid-Atlantic stock area during 1995-1998 were difficult to estimate because closed area boundaries used to stratify survey data do not correspond with statistical areas used to report fishery data. As a crude first approximation, 20% and 7% of Mid-Atlantic landings were assumed to come from the currently closed areas within the Mid-Atlantic stock areas during 1995-1997 and 1998, respectively (Table B6-9b).

Regional catch-biomass fishing mortality rate estimates in Table B6-10 assume a dredge efficiency of 40% for the Georges Bank stock area and 60% for the Mid-Atlantic because dredge efficiencies are probably higher in the Mid-Atlantic (see above). Survey data for strata 6621 and 6610 were included in the Northern Edge and Peak, rather than the Southeast Part, to better correspond to the geographical stratification of landings data. Catch-biomass estimates indicate that fishing mortalities during recent years were highest in the South Channel region of the Georges Bank stock area, and in the Delmarva region of the Mid-Atlantic Bight stock area.

Survey based fishing mortality rates were computed for all open areas within the same stock area combined (Table B6-11). Two possible smoothing methods for the open area survey F mortalities were investigated. The first (DAS-trend F, Table B6-11) assumes that fishing mortality in the open areas is proportional to the number of days-at-sea used in the open areas (see DAS-adjusted column in Table B6-11, based on NEFMC 2000). The second is a rescaled catch-biomass F computed in the same way as the whole-stock F estimates for 1995-1999 (Table B6-12). Both these approaches give open area fishing mortalities of about 0.5-0.6 y^{-1} in both stocks. Considering that about 50% of the biomass in the Mid-Atlantic is in closed areas, this corresponds to a whole-stock fishing mortality of about 0.3 y^{-1} in the Mid-Atlantic.

BIOLOGICAL REFERENCE POINTS

For sea scallops, F_{MAX} from yield-per-recruit analysis and B_{MAX} are used as proxies for F_{MSY} and B_{MSY}. F_{MAX} is defined as the fishing mortality rate (in units y^{-1}) for fully recruited scallops that generates maximum yield-per-recruit. B_{MAX} for scallops is defined in survey units (meat weight in g tow^{-1}) and computed as the product of BPR_{MAX} (biomass per recruit at $F = F_{MAX}$, from yield-per-recruit analysis) and median numbers of recruits per tow based on NEFSC sea scallop survey data. Biological reference points, fishing mortality rates and biomass estimates used in status determination are for whole stocks, i.e., for the entire Georges Bank or Mid-Atlantic Bight.

From a technical point of view, the whole stock yield-per-recruit approach used to manage sea scallop stocks has the advantage of being relatively easy to apply. In the absence of a spawner-recruit relationship, and for fish stocks that mix throughout the year, yield-per-recruit reference points have a clear relationship to F_{MSY} and B_{MSY}.

Conventional age-based yield-per-recruit analysis

Applegate et al. (1998) used Thompson and Bell's (1934) method the set of yield-per-recruit references points (see below) which are currently used to manage both sea scallop stocks. In Applegate et al.'s (1998) yield-per-recruit analysis, scallops were "cohort" ages 3-11 (incremented by 0.75 y in size-at-age calculations to account for growth during January- October) and the last cohort age was a plus group. Selectivity at age 3 was assumed to be 0.5, and all scallops greater than age 3 were fully recruited. Size (shell height) at age was calculated using a von Bertalanffy growth curve (Serchuk et al. 1979) for the combined Georges Bank and Mid-Atlantic Bight stock areas. The shell-height meat weight relationship was for sea scallop on the Canadian side of Georges Bank (from an unpublished source). "Cohort" ages are incremented on January 1 of each year and are preferred for yield-per-recruit calculations (NEFSC 1999).

Given a range of assumptions about shell height-meat weight relationships and a range of increments to cohort ages (0, 0.5 and 0.75 y), NEFSC (1999) carried out a range of yield-per-recruit analyses for the Georges Bank and Mid-Atlantic stock areas that gave smaller F_{MAX} and larger B_{MAX} values (see below). NEFSC (1999) carried out extensive sensitivity analyses and concluded "F_{max} was more robust to assumptions abut growth than B_{max}".

NEW LENGTH-BASED YIELD-PER-RECRUIT MODEL

A new model for length-based yield-per-recruit analysis (LBYPR, implemented in Fortran-90) was developed for sea scallop in this assessment. As shown in sensitivity analyses below, LBYPR gives results that are similar to the conventional age-based approach when similar assumptions are made. However, LBYPR is more useful because it includes discard and incidental mortality and requires fewer assumptions. Parameters important in the LBYPR model (including the assumed rate of natural mortality, von Bertalanffy growth parameters, shell height-meat weight relationships, and fishery selectivity) were set at current best estimates (see above), unless otherwise specified.

As described above and in NEFSC (1999), the conventional age-based approach requires assumptions about fishery selectivity and mean weights at age. Selectivity actually depends on shell height rather than explicitly on age. Sea scallops grow quickly and there is likely a wide (but not quantified) range of sizes at each age. These factors complicate estimation of mean selectivity and meat weight at age for sea scallops. The new approach avoids some uncertainty by carrying out calculations based on length, rather than age.

In LBYPR, recruits start at a user specified starting shell height h_0 (usually the shell height at age 2, see below). Starting shell height is converted to an assumed starting age based on an inverted von Bertalanffy growth model; the results are independent of this assumed starting age. Age is increased in each time step as the model runs, and shell heights are calculated based on age and the von Bertalanffy growth model. Shell heights are converted to meat weights with shell height-meat weight relationships (see above).

Size-dependent fishing mortality rates for sea scallops in LBYPR were $F(h) = F_0 s_h$, where F_0 is the fully recruited fishing mortality rate, h is shell height, and s_h is the selectivity of a commercial scallop dredge (see above). As described above, sea scallop begin to recruit to commercial scallop dredges at shell height h_{min}=65 mm and are fully recruited to the gear at 88 mm. Scallop caught in commercial dredges in LBYPR are discarded if their shell height is less than a specified discard size h_d (if $h_{min} < h < h_d$). The mortality rate for discarded scallops is d. All individuals caught in the model with shell heights greater than h_d are assumed to be landed, and are included in total yield. $F_c(h)$ is the size-specific rate at which scallops are landed (i.e. caught and retained). Natural mortality $M(h)$ may depend on shell height.

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

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

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

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

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

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

where a_f is the ending age of the simulation, usually 30 + a_0. For convenience, a_0=2 years. The integrals were computed numerically with a time step of 0.01 years.

A number of simulations were done to test the sensitivity of biological reference points from ~~LBYPR to assumptions (Table B7-1).~~ Parameters for faster growth in the Georges Bank stock (see above) modestly increase F_{MAX}, Y_{MAX}, and B_{MAX}. Incidental fishing mortality lowers F_{MAX}, due to the assumption that incidental fishing mortality affects pre-recruit and partially recruited scallops. Changes in shell height-meat weight parameters had small effects on F_{MAX}, changed Y_{max} and B_{max} more substantially. A change in the final age group, a_f, had only modest effects.

Natural mortality may be age-dependent (see above). To explore this possibility, simulations were performed with M=0.08 y^{-1} for shell heights less than 120 mm, and 0.16 y^{-1} for larger sizes. In another run, M=0.1 y^{-1} for shell heights less that 120mm, and 0.15 y^{-1} for larger shell heights. These runs gave

F_{MAX}=0.24 y^{-1} for Georges Bank and F_{MAX}=0.23 y^{-1} for the Mid-Atlantic Bight, the largest F_{max} values in all sensitivity analysis runs.

In addition to the runs described above, LBYPR analyses were carried out with no incidental fishing mortality and with or without (h_d = 65mm) discards. Runs with no incidental fishing mortality and no discard gave reference points (F_{MAX}=0.21 y^{-1} for Georges Bank and F_{MAX}=0.19 y^{-1} for the Mid-Atlantic Bight) similar to reference points calculated using the traditional age-based model for sea scallop (NEFSC 1999).

STATUS DETERMINATION

According to the SFA control rule used by managers for sea scallop (Applegate et al. 1998), the sea scallop stock is overfished whenever survey biomass drops below ¼ B_{MAX}. When biomass is greater than B_{MAX}, overfishing occurs if fishing mortality exceeds F_{MSY}. For biomass levels less than B_{MAX} the overfishing threshold mortality rate decreases linearly to zero as biomass decreases to ¼ B_{MSY}. When standing biomass falls between ¼ B_{MSY} and B_{MSY}, fishing mortality should be reduced to rebuild the stock within 10 years.

As described above, managers use F_{MAX} from yield-per-recruit analysis and B_{MAX} as proxies for F_{MSY} and B_{MSY}. F_{MAX} is the fishing mortality rate for fully recruited scallops that generates maximum yield-per-recruit (see recent F and F_{MAX} estimates above). The target biomass level is B_{MAX}, a proxy for B_{MSY}.

B_{MAX} and data for status determinations are cast in the units of survey data, i.e. meat weight per tow. Specifically, the biomass reference point B_{MAX} is defined as:

$$B_{MAX} = \textit{Median recruitment} \cdot BPR_{MAX}$$

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

The current management reference points are based on a Thompson-Bell yield-per-recruit analysis and median recruitment estimated from the 1979-1997 survey data. The present reference points are F_{MAX} = 0.24 y^{-1} for both stocks and B_{MAX} = 8.16 kg/tow for Georges Bank and 3.90 kg/tow for the Mid-Atlantic.

On the basis of the 2000 NMFS scallop survey results, scallop biomass in Georges Bank appears to be above B_{MAX} while biomass in the Mid-Atlantic appears to be below B_{MAX}

There is a considerable amount of uncertainty about both of these statements, because biomass estimates of both stocks are within 15% of B_{MAX}, which is within the margin of error of the survey estimates. Biomass estimates for both stocks are well above ¼ B_{MAX}, indicating that the stocks are not currently overfished.

Fishing mortality in Georges Bank has been low in recent years, mainly due to the increases in biomass in the closed areas. All estimates of fishing mortality for 1999 (catch-biomass, survey-based, and rescaled catch-biomass) are below F_{MAX}. The best (rescaled catch-biomass) estimate of fishing mortality in 1999 is 0.14 y^{-1}. Therefore, overfishing is not occurring in the Georges Bank stock.

Fishing mortality in the Mid-Atlantic has been declining since 1996 due to effort reduction and area closures. However, all estimates of fishing mortality for 1999 are above F_{MAX}. The rescaled catch-biomass estimate of fishing mortality in 1999 is 0.43. It can be concluded that overfishing is occurring in the Mid-Atlantic.

Residual analysis comparing the rescaled catch-biomass estimates in Mid-Atlantic to the survey estimates suggest the possibility that there may have been considerably more unreported landings in the early 1990s than recently (see Fig B6-2). If so, then the 1999 rescaled catch-biomass estimate might be biased high by as much as 25%. Even if this is the case, however, the fishing mortality estimate would remain above F_{MAX}.

SARC COMMENTS

1. Previous assessments of sea scallops on Georges Bank and the Mid-Atlantic used population models to estimate population biomass and fishing mortality. SARC 29 decided not to use the model-based estimates because of uncertainties concerning assumptions and lack of fit. That SARC also recommended that further work be done on reconciling data and model assumptions. Robust empirical estimates of fishing mortality were accepted for use in the meantime and were used in the current assessment.

2. Three empirical estimators of annual fishing mortality were used in the current assessment. All were the same as used in SARC 29, i.e.,

$$^{C}F_{Y}=\frac{C_{y}}{B_{y}}$$

where C_y is the landed catch of meats in year y and B_y is total biomass in year y estimated from the survey using an estimate of dredge efficiency to convert survey biomass to population biomass.

The second estimate was based solely on the survey data,

$$^{S}F_{i}=-\ln\left(\frac{P_{i+1}}{R_{i}+P_{i}}\right)-M$$

where M is natural mortality (0.1), P_i and R_i are the mean numbers of fully-recruited and recruits, respectively from the survey in year i.

3. The third estimate scaled the first estimate by the ratio of the mean of the first two estimates, i.e.,

$$^{R}F_{y}={}^{C}F_{y}\times\left(\frac{^{S}\overline{F}_{y}}{^{C}\overline{F}_{y}}\right)$$

The reasoning behind this estimate was that while the first estimate may give an accurate estimate of trend in F, the actual level is highly dependent upon the dredge efficiency used to scale survey biomass. On the other hand, the survey-based estimate was assumed to be unbiased but was too variable from year-to-year to give a reliable estimate of trend. Also, scaling the first estimate by the ratio of the means cancels out the dredge efficiency estimate thus removing the need to estimate this difficult quantity.

4. The scaling described above implies a linear relationship between the fishing mortality estimates from the first two methods. Discussion ensued on possible problems with this assumption. The first estimate of fishing mortality is based on annual catches while the second estimate is

derived from changes over the survey year (July in year t to July in year t+1). Changes in the seasonal pattern of landings may result in changes in the relationship between the two estimates. Investigation of the seasonal pattern of landings in both Georges Bank and the Mid-Atlantic did not indicate any significant changes over time.

5. The definition of the shell height size ranges for P_i and R_i in the second estimate assumes an implicit growth model. The SARC questioned the sensitivity of this estimate to changes to these definitions. Results from a limited examination of this question did not appear to indicate any large changes in the fishing mortality estimates.

6. A comparison of a variety of estimates derived to reflect different dredge efficiency factors, different scaling using the whole time series or separate estimates for the periods of time before and after closed areas were introduced, all led to the same general conclusions about fishing mortality. That is, Georges Bank is just below F_{max} while the Mid-Atlantic is above F_{max}.

7. There was considerable discussion on whether or not any of these estimates of fishing mortality are comparable to F_{max} calculated from YPR. In particular, do these different methods include the same exploitation pattern as was used for the YPR? The survey based estimates of F are based on mostly fully-recruited scallops (shell heights of 80 mm and greater) the lower size limit of which roughly corresponds to age 3.5 years. There may have been recent changes in selectivity caused by opening parts of closed areas that could change the reference points but the exact partial recruitment that could be used is unknown. The decision was made to accept the comparison of the empirical estimates of F with F_{max} from YPR with the caveats about selectivity and growth changes.

8. The SARC discussed the effect of discards, unreported catch and incidental mortality on fishing mortality estimates. It was thought that discards may have been high early in the time series, but currently, discard mortality is unknown but probably low. The time of change in discarding cannot be pinpointed because changes in regulations had varying effects on discarding. However, the trends in fishing mortality were similar for the catch-based and the survey-based estimates.

9. The SARC reviewed a length-based (shell height) yield-per-recruit (LBYPR) method that was proposed to replace the previously used age-based yield-per-recruit to set F_{msy} (F_{max}) and B_{msy} (B_{max}) proxies. When parameter values were set to be similar to those used in an age-based YPR, the LBYPR gave similar results to the age-based model. However, it was not clear if differences in the results from the two methods for other parameter settings were due to the LBYPR having different assumptions or better assumptions than the age-based method. The SARC concluded that the LBYPR has potential and encouraged more work on this method. However, it was also noted that if this method is eventually used then assessments must be done on the same basis (e.g., using length-based VPA).

10. The SARC reviewed a paper (Hart 2000) on a new method for analyzing yield-per-recruit for rotational management plans. This method averaged fishing mortalities over time as the areas opened. The SARC believed that this approach was more appropriate than the current spatial averaging of fishing mortalities

over both open and closed areas within a time period. In practice, the actual results would depend upon the relative size and productivity of each area. The SARC endorsed further investigation of the method but could not evaluate results because there are no details on the particulars of candidate rotational plans.

11. Depletion studies have been pursued for the scallop surveys because the ability to convert biomass estimates from the survey to the population level using estimates of dredge efficiency is important for the assessment of these stocks. While significant progress has been made on estimating the efficiency of the dredge, the analyses of the experiments where both efficiency and density have to be estimated from the same data, has been problematic. The SARC considered preliminary results of depletion studies where independent density estimates were provided from photographic surveys in the same general area. This approach was seen to be an improvement in experimental design and the SARC recommended that further studies of this kind be done. In particular, the design should be such that the depletion studies must be in exactly the same area that the photographic survey was done.

12. At present, photographic/depletion experiments are only available for Georges Bank. The results of these experiments are preliminary and deficiencies in the design noted above need to be addressed. Therefore, the SARC could not recommend new efficiency factors for Georges Bank. We have no new information on efficiency estimates using this experimental design for the Mid-Atlantic area.

RESEARCH RECOMMENDATIONS

I. The current survey strata were defined before the implementation of closed areas. The adequacy of the current design to separately monitor open and closed areas should be investigated.

II. Further depletion studies should be conducted using coincident dredging/photographic experiments in Georges Bank and the Mid-Atlantic area. These studies should be done on areas with different bottom types, scallop density levels and size ranges. In addition, methods such as multi-beam sonar should be used to determine the spatial distribution of different bottom types on Georges Bank and the Mid-Atlantic area so that bottom type specific efficiencies can be used for the survey data.

III. Further development of the length-based yield-per-recruit should continue, especially in the context of evaluating the benefits of rotational management. In addition, it is important that this development is accompanied by further work on assessment methods that work on the same basis (i.e., length-based population models with the same exploitation patterns).

IV. As pointed out in SARC-29, lack of updated information on scallop growth continues to plague assessment and reference point calculation.

V. As pointed out in SARC-29, closed areas provide an opportunity to refine estimates of natural mortality and growth and to estimate non-yield mortality from fishing.

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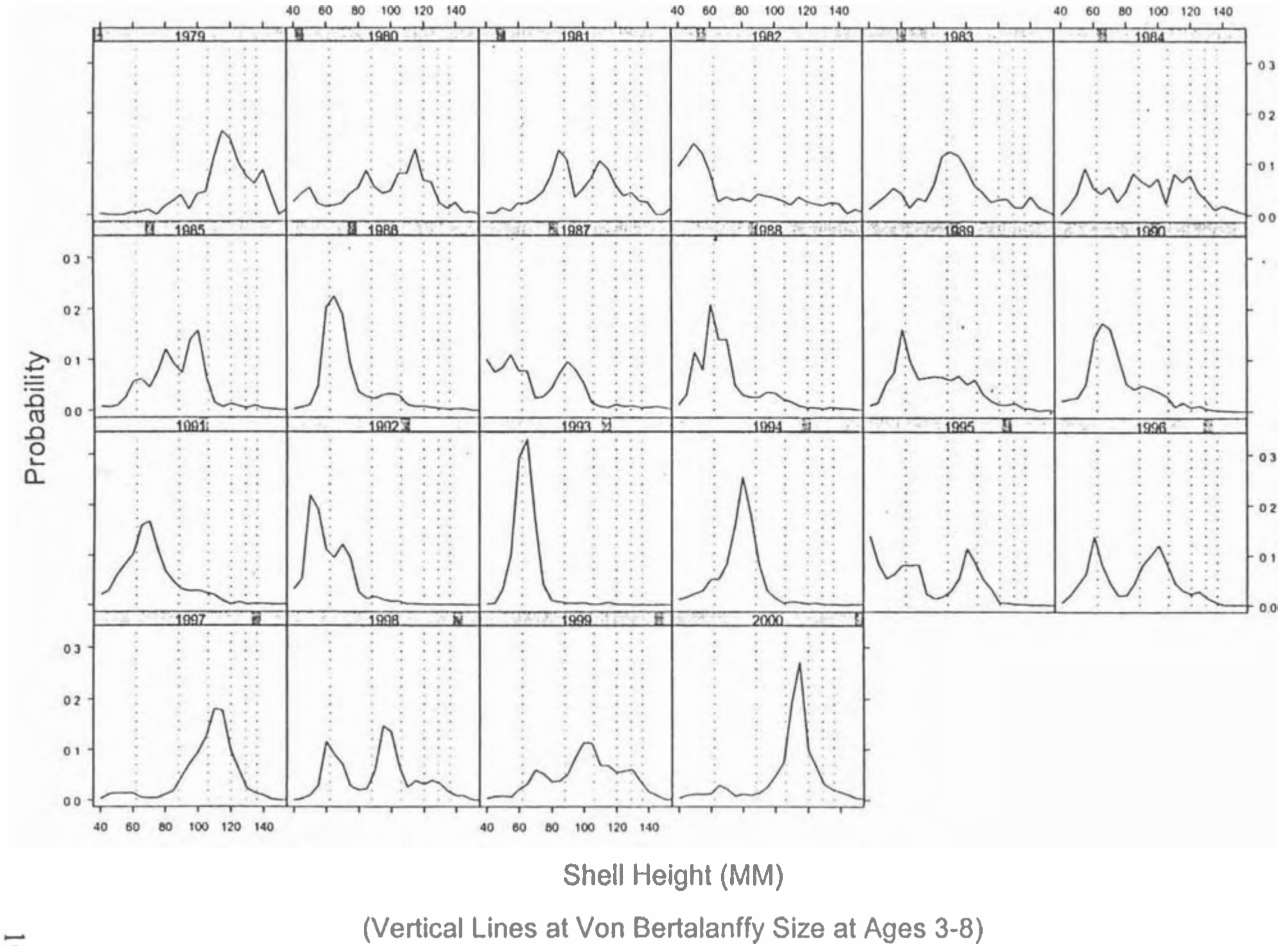
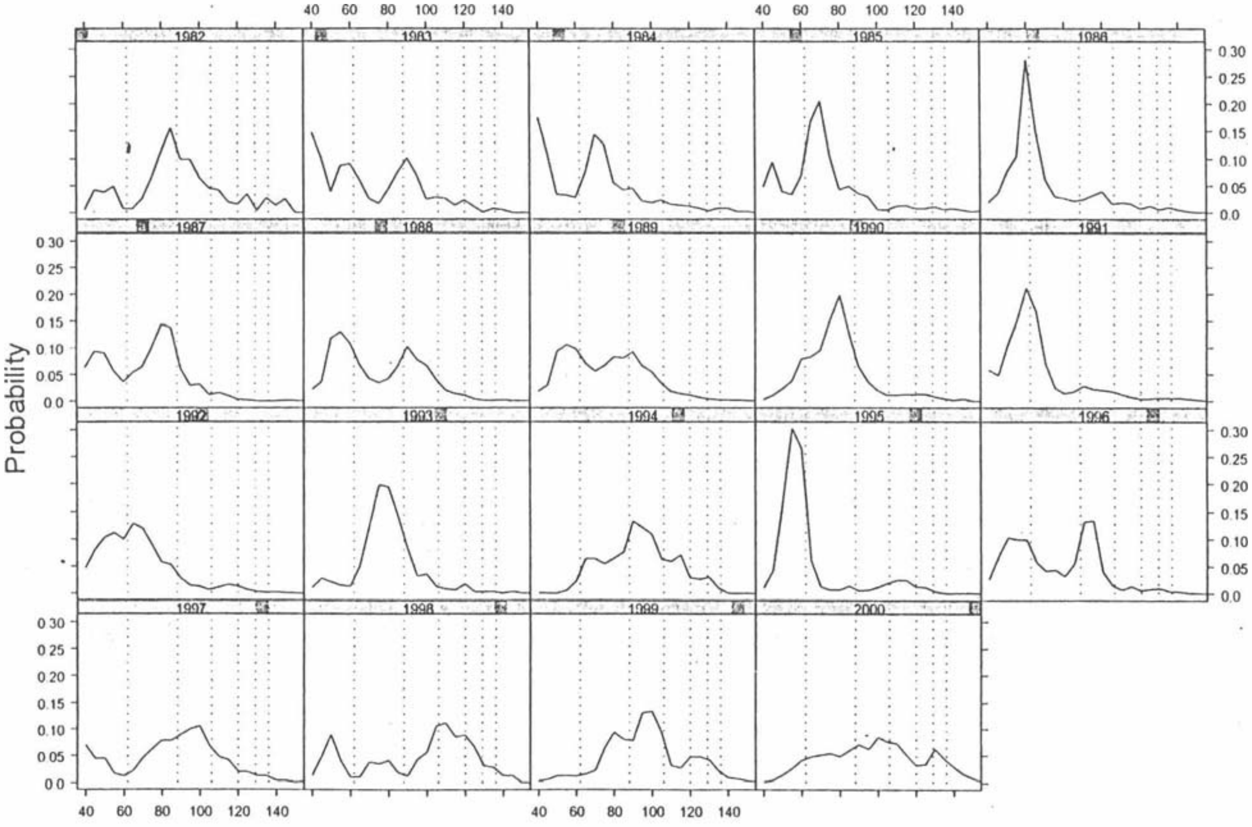
Appendix 1. Shell height composition data from NEFSC sea scallop surveys during 1982-2000 for open and closed regions in the Georges Bank Stock Area. Vertical lines show predicted lengths at the time of the survey based on von Bertalanffy growth model

Appendix 1. Scallop Survey-Closed Area 1 in the Georges Bank Stock Area



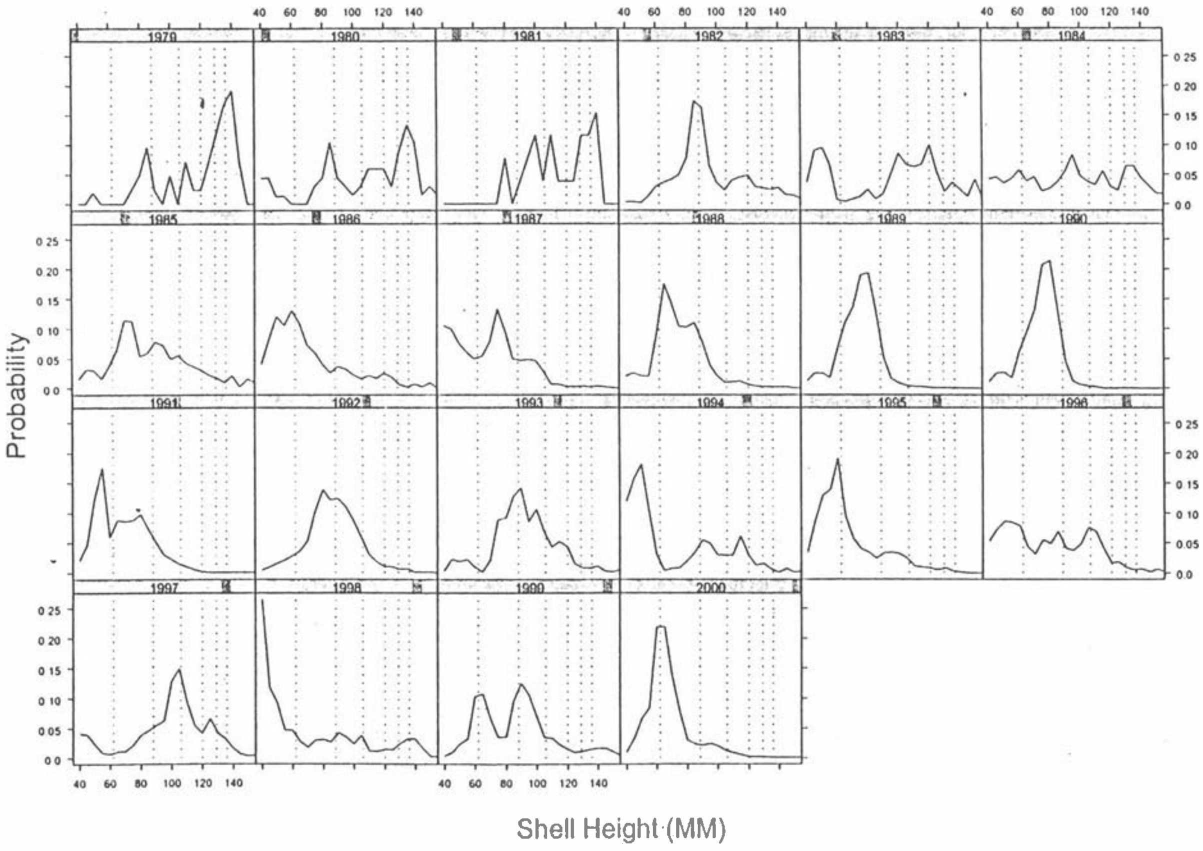
Appendix 1. Scallop Survey-Closed Area 2 (North) in the Georges Bank Stock Area



Shell Height (MM)

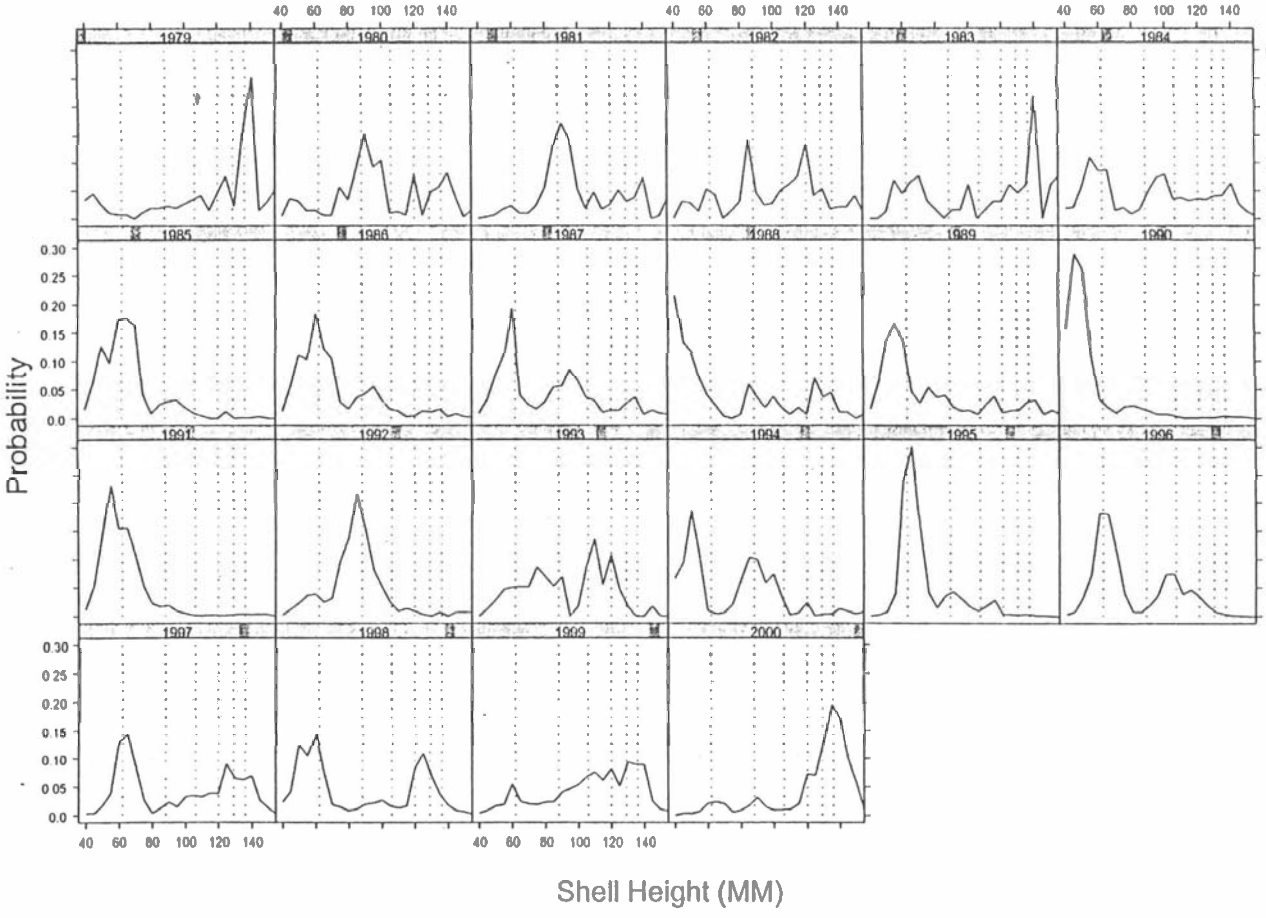
(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 1. Scallop Survey-Closed Area 2 (South) in the Georges Bank Stock Area



(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

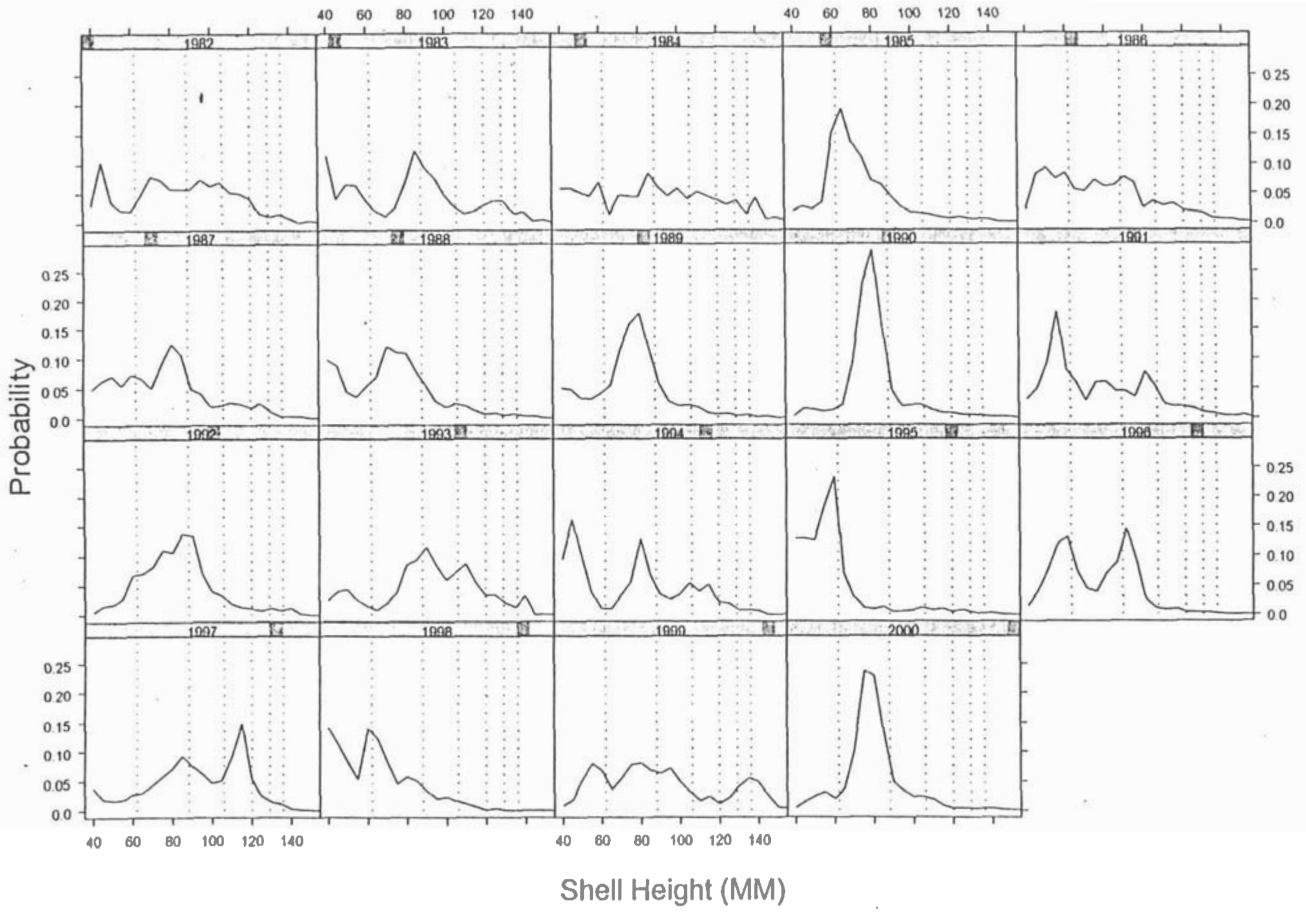
Appendix 1. Scallop Survey-Nantucket Lightship Closed Area in the Georges Bank Stock Area



Shell Height (MM)

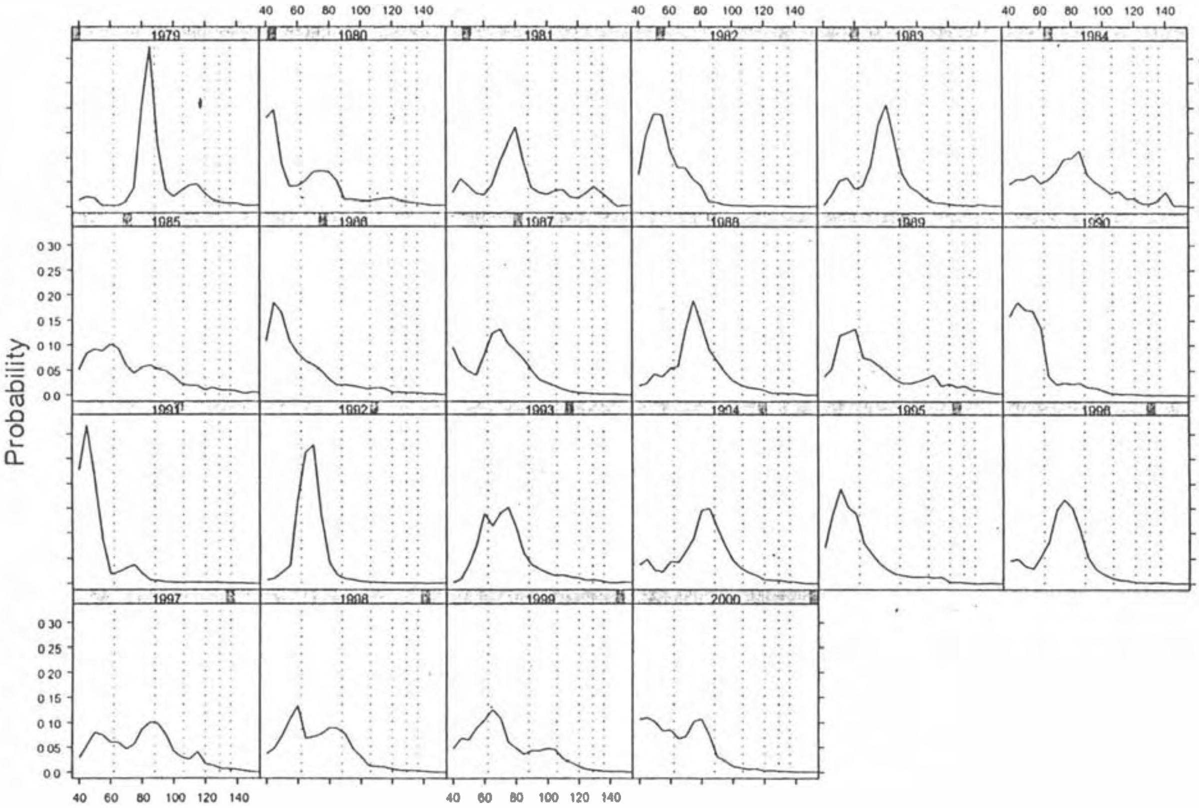
(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 1. Scallop Survey-North Edge & Peak Open Area in the Georges Bank Stock Area



(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

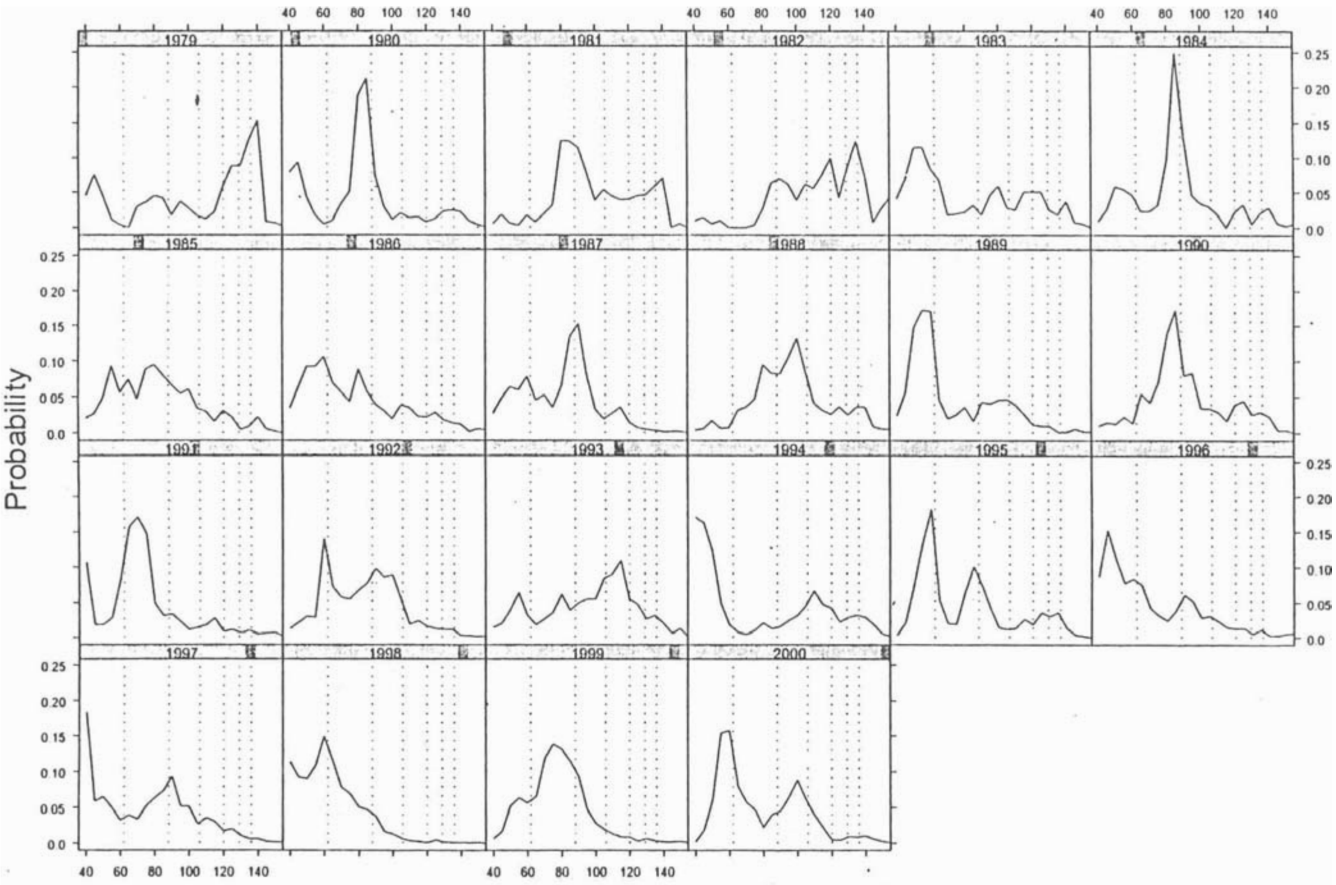
Appendix 1. Scallop Survey-South Channel Open Area in the Georges Bank Stock Area



Shell Height (MM)

(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 1. Scallop Survey-South East Part Open Area in the Georges Bank Stock Area

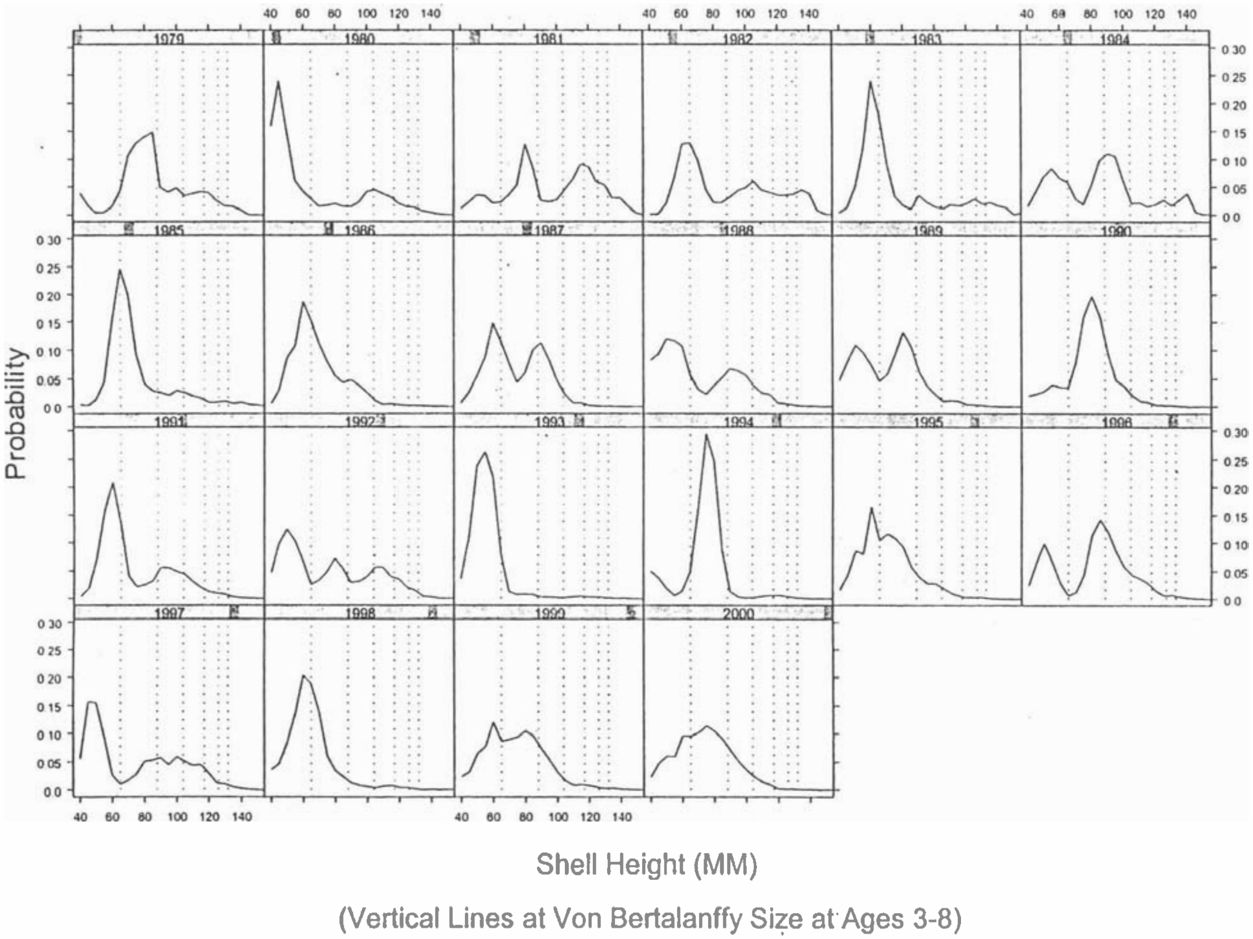


Shell Height (MM)

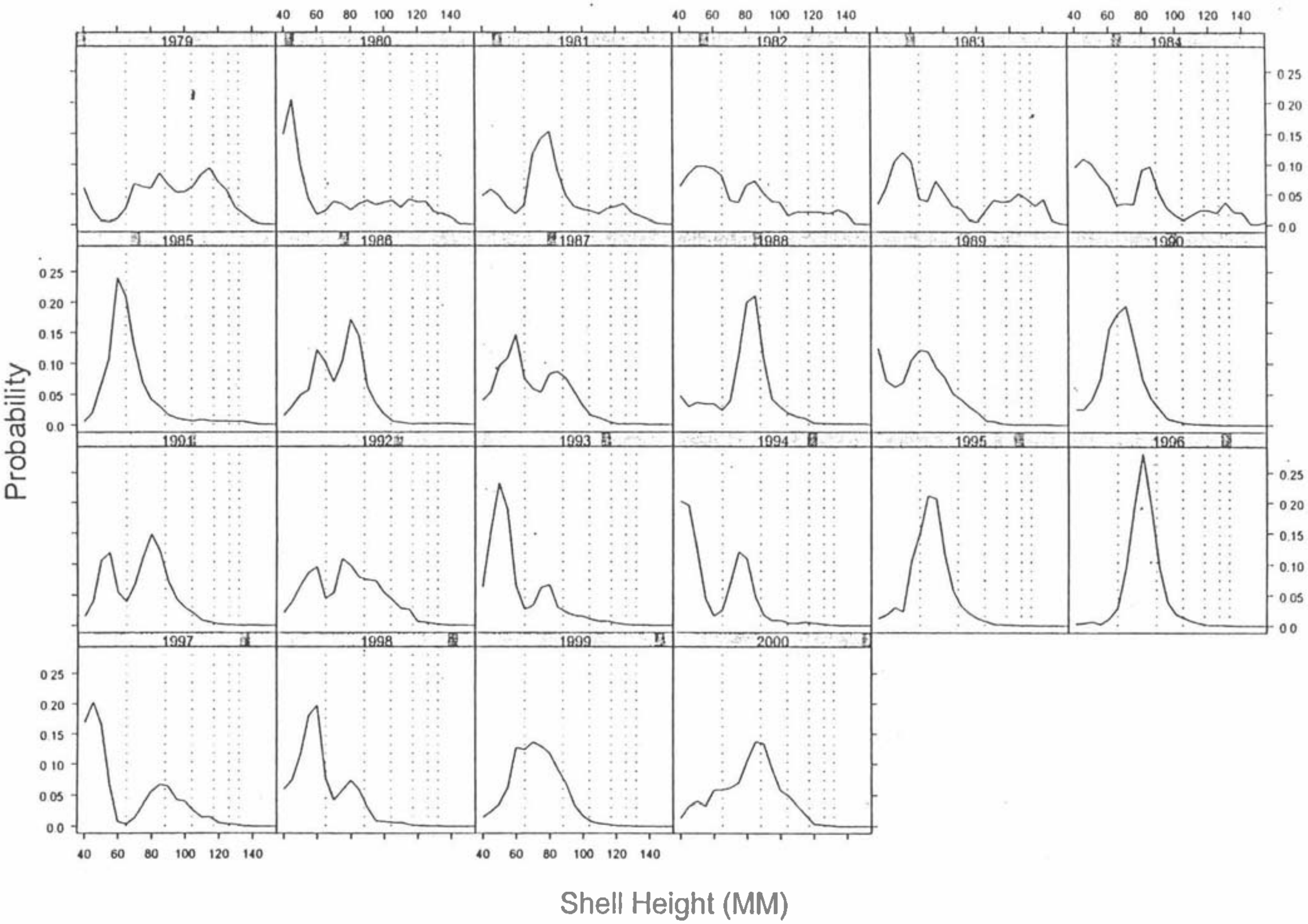
(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 2. Shell height composition data from NEFSC sea scallop surveys during 1982-2000 for open and closed regions in the Mid Atlantic Bight Stock Area. Vertical lines show predicted lengths at the time of the survey based on von Bertalanffy growth model.

Appendix 2. Scallop Survey-Delmarva Open Area in the Mid-Atlantic Bight Stock Area

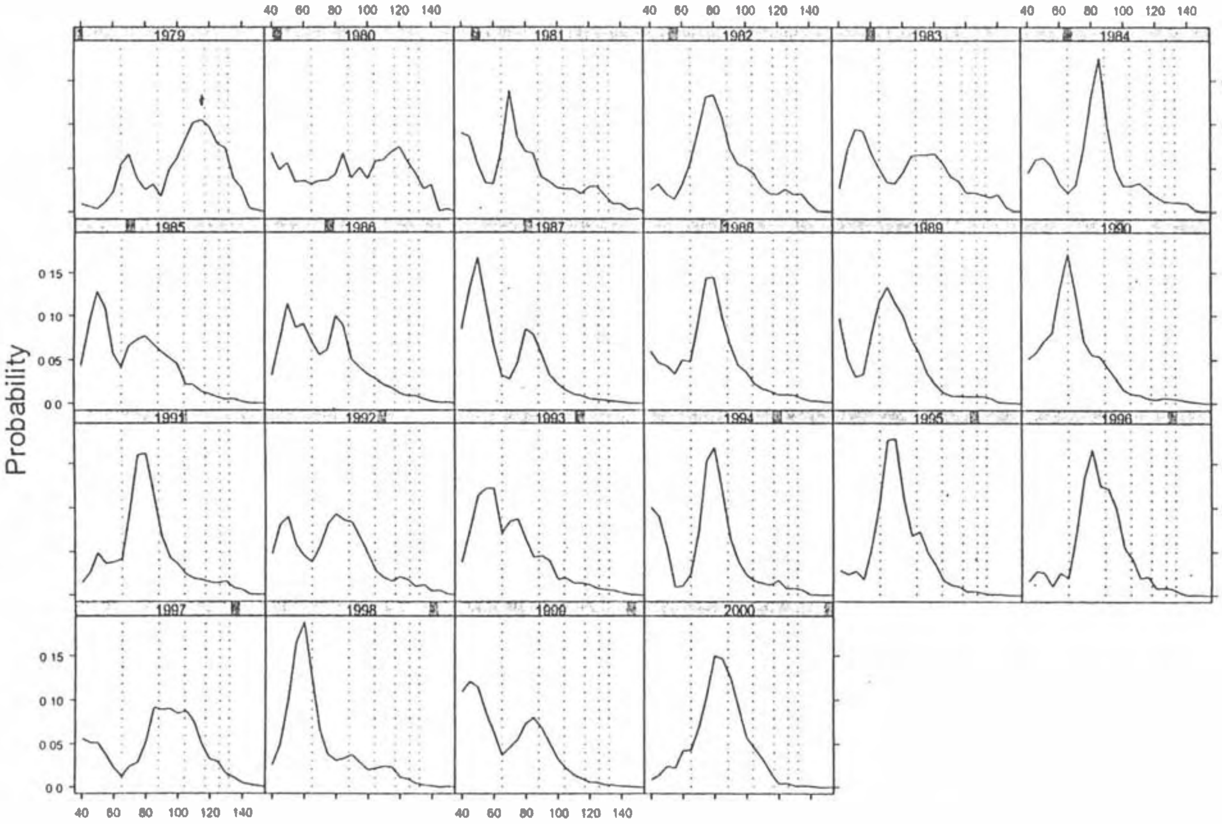


Appendix 2. Scallop Survey-Hudson Canyon S. Closed Area in the Mid-Atlantic Bight Stock Area



(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

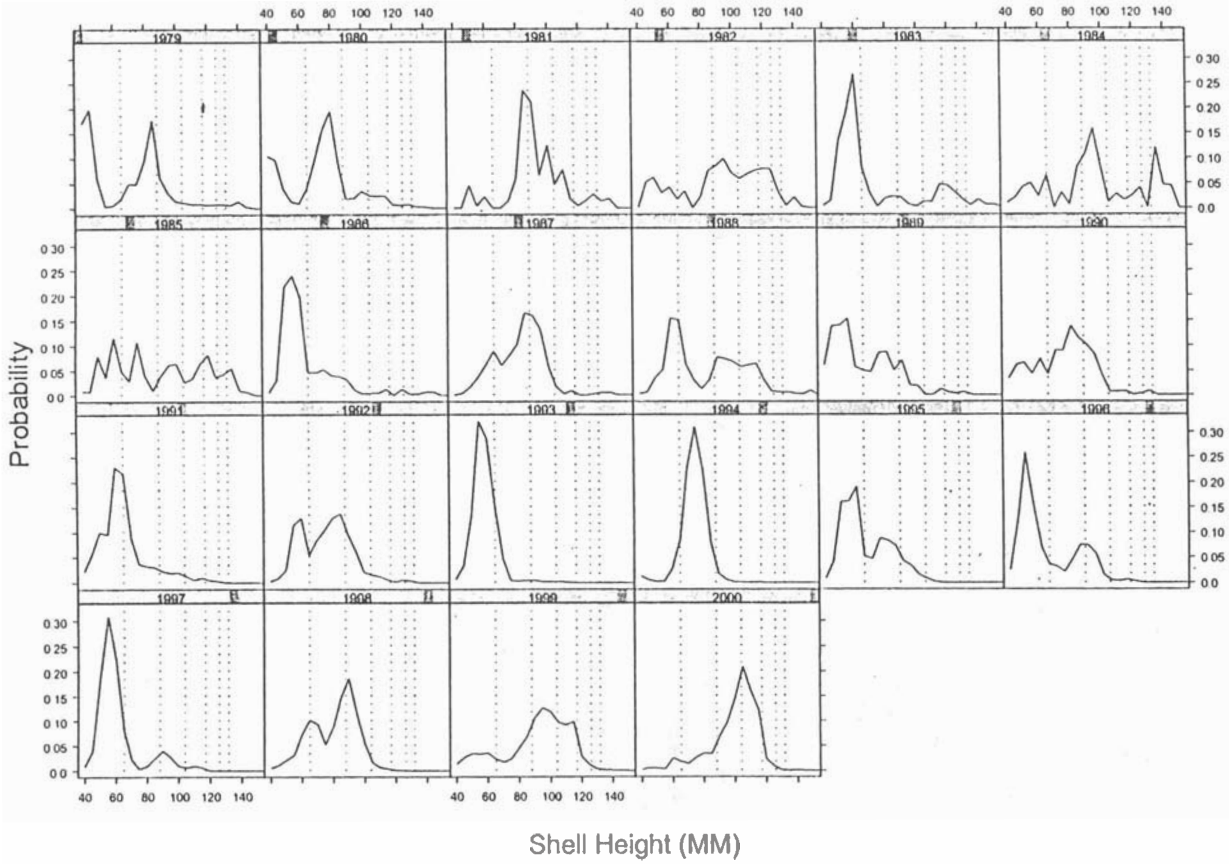
Appendix 2. Scallop Survey-New York Bight Open Area in the Mid-Atlantic Bight Stock Area



Shell Height (MM)

(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 2. Scallop Survey-Virginia Beach Closed Area in the Mid-Atlantic Bight Stock Area



(Vertical Lines at Von Bertalanffy Size at Ages 3-8)

Appendix 3. Summary of NEFSC survey and commercial scallop dredge gear used in depletion experiments for sea scallop during 1999 and 2000.

NEFSC Scallop Dredge (a New Bedford style scallop dredge)

Apron (top)	18 rings x 32 rings (Rings are 2" diagonal by 5/16" wide)
Bag (bottom)	15 rings x 32 rings
Front length	6' 3" long (from eye to bag attachment)
Front width	8' wide
Sweep chain	77 links of 5/8" casehardened steel
Top Twine	4" streched mesh nylon with 1½" poly - 63" deep hung on diamond
Liner	#21 polyethylene strech mesh 1½"
Rock chains	none
Pressure plate	3½" wide
Weight	1425 lbs.

F/V Tradition New Bedford Style Commercial Scallop Dredge

Apron (top)	7 rings x 42 rings (rings are 3½" dia by 3/8")
Bag (bottom)	25 rings (estimated) x 42 rings with chaffing gear
Front length	7'5" long (est.) - from eye to bag attachment
Front width	15' double bar frame with 2 solid rubber nosewheels 24" x 18" behind gooseneck
Sweep chain	120 links (est.)
Top twine	10" poly hung on diamond
Rock chains	13 up and downs & 7 tickler chains (3/8" chain)
Pressure plate	6" wide
Weight	4000 lbs. (est.)

F/V Santa Maria & F/V Kathy Marie New Bedford Style Scallop Dredges

Apron (top)	7 rings x 42 rings (rings are 3½" dia by 3/8")
Bag (bottom)	25 rings (est.) x 42 rings with chaffing gear
Front length	7'5" long (est.) (from eye to bag attachment)
Front width	15' double bar frame with 2 solid rubber nosewheels 24" x 18" behind gooseneck
Sweep chain	128 links (est.)
Top twine	8" poly 11 mesh x 39 mesh - hung on diamond
Rock chains	13 up and downs & 7 tickler chains (3/8" chain)
Pressure plate	7½" wide
Weight	4000 lbs. (est.)

F/V Courageous (1999) mid-Atlantic survey:
Dredge Width: 15ft.
Rollers: none
Ring Size: 3.5 inch
Links: double
Sweep:5/8 inch
Twine Top: 8 inch
Chains: none

F/V Alice Amanda (2000) mid-Atlantic survey:
Dredge Width: 15ft.
Rollers: none
Ring Size: 3.5 inch
Links: double
Sweep:5/8 inch
Twine Top: 8 inch
Chains: none

Table B3-1. Scallop landings (mt meats) by region, gear type, and year. Estimates for 1964-1988 from Serchuck and Wigley (1988). Estimates for 1989-1993 from NEFSC commercial weighout database (canvass data not included). Estimates for April, Estimates for 1994-1999 from Vessel Trip Reports and Dealer Logs. Prior to 1978, landings by dredges were included with landings by "other" gear.

	Gulf of Maine				Georges Bank				S. New England				Mid Atlantic Bight				Uncl.	Total			
Year	dredge	trawl	other	sum	dredge	trawl	other	sum	dredge	trawl	other	sum	dredge	trawl	other	sum	other	dredge	trawl	other	sum
1964		0	192	192		0	6,241	6,241		52	3	55					137		52	6,436	6,626
1965		0	115	115		3	1,480	1,483		2	24	26					3,974		5	1,619	5,598
1966		0	93	93		0	883	884		0	8	8					4,071		1	984	5,056
1967		0	80	80		4	1,217	1,221		0	8	8					1,873		4	1,305	3,182
1968		0	113	113		0	993	994		0	56	56		0	2,437	2,437			0	3,599	3,599
1969		1	122	123		8	1,316	1,324		0	18	19		5	846	851			14	2,302	2,317
1970		0	132	132		5	1,410	1,415		0	6	6		14	459	473			19	2,006	2,026
1971		4	358	362		18	1,311	1,329		0	7	7		0	274	274			22	1,949	1,971
1972		1	524	525		5	816	821		0	2	2		5	653	658			11	1,995	2,006
1973		0	460	460		15	1,065	1,080		0	3	3		4	245	249			19	1,773	1,792
1974		0	223	223		15	911	926		0	4	5		0	937	938			16	2,076	2,091
1975		6	741	746		13	844	857		8	42	50		52	1,506	1,558			80	3,132	3,212
1976		3	364	366		38	1,723	1,761		4	3	7		317	2,972	3,288			361	5,061	5,422
1977		4	254	258		27	4,709	4,736		1	10	11		27	2,564	2,591			58	7,536	7,595
1978	242	1	0	243	5,532	37	0	5,569	25	2	0	27	4,175	21	0	4,196		9,974	61	0	10,035
1979	401	5	1	407	6,253	25	7	6,285	61	5	0	66	2,857	29	1	2,888		9,572	64	9	9,645
1980	1,489	122	3	1,614	5,382	34	2	5,419	130	3	0	133	1,966	9	0	1,975	< 0.01	8,968	169	4	9,142
1981	1,225	73	7	1,305	7,787	56	0	7,843	68	1	0	69	726	5	0	731		9,806	135	7	9,948
1982	631	28	5	664	6,204	119	0	6,322	126	0	0	126	1,602	6	2	1,610		8,562	153	7	8,723
1983	815	72	7	895	4,247	32	4	4,284	243	1	0	243	3,081	18	10	3,109		8,386	124	21	8,530
1984	651	18	10	678	3,011	29	3	3,043	161	3	0	164	3,647	26	2	3,675		7,470	76	14	7,560
1985	408	3	10	421	2,860	34	0	2,894	77	4	0	82	3,227	47	1	3,276		6,572	88	11	6,672
1986	308	2	6	316	4,428	10	0	4,438	76	2	0	78	3,257	101	0	3,359		8,068	115	7	8,190
1987	373	0	9	382	4,821	30	0	4,851	67	1	0	68	7,488	315	1	7,803		12,749	346	10	13,104
1988	506	7	13	526	6,036	18	0	6,054	65	4	0	68	5,774	402	2	6,178		12,381	430	16	12,826
1989	600	0	44	644	5,637	25	0	5,661	127	11	0	138	7,549	422	2	7,973		13,913	458	45	14,416
1990	545	0	28	574	9,972	10	0	9,982	110	6	0	116	5,954	476	4	6,435		16,581	493	32	17,107
1991	527	3	75	605	9,235	77	0	9,311	55	16	0	71	6,195	808	9	7,011		16,012	903	84	16,999
1992	676	2	45	722	8,230	7	0	8,238	119	5	0	124	4,386	563	5	4,955		13,411	577	50	14,039
1993	763	2	32	797	3,637	18	0	3,655	65	1	0	66	2,382	392	3	2,778		6,848	413	36	7,296
1994	519	3	3	525	1,133	3	1	1,137	0	1	0	1	5,176	688	9	5,872		6,827	693	13	7,534
1995	424	4	238	665	967	15	0	982	35	1	0	36	5,408	744	166	6,318		6,799	762	404	7,965
1996	632	20	121	773	2,040	6	0	2,045	74	0	0	74	4,335	656	9	4,999		7,006	682	130	7,818
1997	581	21	98	699	2,317	10	0	2,326	69	0	0	69	2,442	357	111	2,910		5,339	387	209	5,936
1998	443	10	1	455	1,990	27	0	2,016	95	6	0	102	2,359	574	15	2,948	44	4,792	610	17	5,565
1999	277	3	0	280	5,151	4	0	5,155	46	5	3	54	3,646	958	50	4,653	4	9,074	965	50	10,146
1982-99																					
Mean	538	11	41	590	4,551	26	0	4,577	89	4	0	93	4,328	420	22	4,770		9,488	460	64	10,024
Min	277	0	0	280	967	3	0	982	0	0	0	1	1,602	6	0	1,610		4,792	76	7	5,565
Max	815	72	238	895	9,972	119	4	9,982	243	16	3	243	7,549	958	166	7,973		16,581	965	404	17,107

Table B4-1. Summary ofscallop shell samples collected from scallop vessels in the Georges Bank and Mid-Atlantic ports during 1982-1998.

Calender	Number of sampled trips			Number of shells sampled		
Year	Jan.-Jun.	Jul.-Dec	Sum	Jan.-Jun.	Jul.-Dec	Sum
Georges Bank						
1982	46	24	70	8,736	4,495	13,231
1983	22	16	38	4,601	3,116	7,717
1984	11	19	30	1,939	2,998	4,937
1985	13	22	35	2,525	4,781	7,306
1986	31	54	85	8,134	12,609	20,743
1987	15	49	64	3,732	12,687	16,419
1988	35	49	84	8,567	12,775	21,342
1989	17	54	71	4,272	12,799	17,071
1990	35	42	77	10,283	11,051	21,334
1991	53	47	100	15,441	13,628	29,069
1992	61	73	134	17,760	23,333	41,093
1993	57	75	132	17,613	19,972	37,585
1994	27	20	47	5,815	4,936	10,751
1995	0	1	1	0	273	273
1996	4	16	20	1,656	4,151	5,807
1997	2	5	7	440	884	1,324
1998	1	3	4	198	1,142	1,340
Mid-Atlantic						
1982	11	21	32	2,736	5,076	7,812
1983	42	26	68	11,180	5,951	17,131
1984	33	26	59	7,346	7,871	15,217
1985	33	34	67	8,501	8,156	16,657
1986	19	33	52	4,833	7,697	12,530
1987	61	65	126	15,470	16,004	31,474
1988	60	51	111	14,693	11,989	26,682
1989	67	49	116	16,652	10,613	27,265
1990	63	11	74	15,246	2,752	17,998
1991	23	24	47	5,190	4,774	9,964
1992	60	36	96	12,882	8,116	20,998
1993	40	25	65	9,201	5,566	14,767
1994	14	9	23	3,991	2,731	6,722
1995	8	17	25	1,600	3,246	4,846
1996	28	46	74	6,395	8,892	15,287
1997	23	18	41	4,542	3,399	7,941
1998	23	7	30	4,660	1,443	6,103

Table B4-2. Discard rates estimated as discard/kept weight ratios using sea sample data for sea scallop.

Georges Bank

Survey Year	lb-keep	lb-disc	ratio	std(r)	# tows
1992	227777	21538	9.46%	0.81%	902
1993	132525	2630	1.99%	0.33%	811
1994	100751	375	0.37%	0.07%	594
1995	348706	29689	8.51%	0.72%	948
1996	391426	5322	1.36%	0.14%	1138
1997	192546	3035	1.58%	0.28%	872
1998	28798	127	0.44%	0.08%	116

Mid-Atlantic

Survey Year	lb-keep	lb-disc	ratio	std(r)	# tows
1992	227572	3507	1.54%	0.20%	1407
1993	355832	65114	18.30%	1.87%	1269
1994	647824	32692	5.05%	0.33%	1982
1995	463617	7113	1.53%	0.19%	1504
1996	437131	1025	0.23%	0.14%	1883
1997	251280	3459	1.38%	0.29%	1093
1998	32027	81	0.25%	0.12%	151

Table B5-1. Duplicate stations sampled by both *R/V Albatross IV* and the *F/V Tradition* in 1999.

Stratum	Tradition Station	Albatross Station	Distance (nm)	Trd. Bms (g/tow)	Alb Bms. (g/tow)	Ln(Trd Bms)	Ln(Alb Bms)
46	167	281	1.37	9697	7760	9.18	8.96
46	169	274	1.16	238	297	5.47	5.69
46	173	279	1.42	64257	8033	11.07	8.99
47	166	282	0.54	113728	1528	11.64	7.33
47	168	287	0.45	17823	17671	9.79	9.78
47	170	275	1.18	528	508	6.27	6.23
47	171	276	0.81	5304	1296	8.58	7.17
47	172	278	0.46	17729	2365	9.78	7.77
52	145	396	0.09	2390	15397	7.78	9.64
52	127	398	1.33	1773	41644	7.48	10.64
53	150	388	0.89	121	1416	4.80	7.26
53	156	394	0.40	18638	17249	9.83	9.76
53	157	395	0.18	108	664	4.69	6.50
54	151	389	1.39	6588	43744	8.79	10.69
54	152	390	0.62	916	22	6.82	3.11
54	153	391	0.46	1086	7468	6.99	8.92
54	154	392	0.78	47948	77707	10.78	11.26
54	155	393	0.54	10685	33898	9.28	10.43
54	161	400	0.11	16883	177272	9.73	12.09
54	162	401	0.46	91	3162	4.51	8.06
55	164	403	0.62	442	93	6.09	4.53
Mean			0.73	16046	21866	8.06	8.32
Std Dev			0.43	27848	40786	2.19	2.29

Table B5-2. Areas (NM^2) of NEFSC shellfish strata in the Georges Bank (GBK) and Mid-Atlantic (MAB) stock areas estimated by planimeter and GIS. Regions (within stock areas, defined as in Serchuk and Wiggly 1989) in the Georges Bank stock area are: SCH=South Channel, SEP=Southeast Part, and NEP: Northern Edge and Peak. Regions in the Mid-Atlantic stock area are VNC: Virginia and North Carolina, DMV-Delmarva, and NYB=New York Bight.

Stratum	Stock Area	Region	Planimeter Area (NM^2)	GIS Area (NM^2)	Difference (NM^2)	Difference (%)
6460	GBK	SCH	416	205	-211	-102%
6470	GBK	SCH	871	875	4	0%
6490	GBK	SCH	244	223	-21	-9%
6500	GBK	SCH	150	156	6	4%
6510	GBK	SCH	139	115	-24	-21%
6520	GBK	SCH	307	346	39	11%
6530	GBK	SCH	268	270	2	1%
6540	GBK	SCH	278	296	18	6%
6550	GBK	SCH	364	387	23	6%
6580	GBK	SEP	300	304	4	1%
6590	GBK	SEP	538	513	-25	-5%
6600	GBK	SEP	816	803	-13	-2%
6610	GBK	NEP	576	589	13	2%
6621	GBK	NEP	551	576	25	4%
6631	GBK	NEP	345	311	-34	-11%
6651	GBK	NEP	115	107	-8	-8%
6661	GBK	NEP	122	117	-5	-4%
6710	GBK	NEP	146	169	23	14%
6720	GBK	NEP	504	474	-30	-6%
6740	GBK	NEP	433	444	11	3%
6060	MAB	VNC	62	23	-39	-171%
6070	MAB	VNC	46	7	-39	-584%
6100	MAB	DMV	152	191	39	20%
6110	MAB	DMV	229	247	18	7%
6140	MAB	DMV	219	206	-13	-6%
6150	MAB	DMV	394	388	-6	-2%
6180	MAB	DMV	249	241	-8	-3%
6190	MAB	DMV	274	266	-8	-3%
6220	MAB	NYB	312	306	-6	-2%
6230	MAB	NYB	714	725	11	2%
6240	MAB	NYB	476	455	-21	-5%
6250	MAB	NYB	648	649	1	0%
6260	MAB	NYB	188	190	2	1%
6270	MAB	NYB	451	443	-8	-2%
6280	MAB	NYB	149	152	3	2%
6290	MAB	NYB	1,096	1,080	-16	-2%
6300	MAB	NYB	669	669	0	0%
6310	MAB	NYB	932	934	2	0%
6330	MAB	NYB	363	362	-1	0%
6340	MAB	NYB	203	208	5	2%
6350	MAB	NYB	601	615	14	2%

Table B5-3. Areas (NM^2) of NEFSC the Georges Bank (GBK) and Mid-Atlantic (MAB) stock areas and regions estimated by planimeter and GIS. Regions (within stock areas, defined as in Serchuk and Wigley 1989) in the Georges Bank stock area are: SCH=South Channel, SEP=Southeast Part, and NEP: Northern Edge and Peak. Regions in the Mid-Atlantic stock area are VNC: Virginia and North Carolina, DMV-Delmarva, and NYB=New York Bight.

Stock Area	Region	Planimeter Area (NM^2)	GIS Area (NM^2)	Difference (NM^2)	Difference (%)
GBK	SEP	1,654	1,620	-34	-2%
	NEP	2,792	2,787	-5	0%
	SCH	3,037	2,874	-163	-6%
	Total	7,483	7,281	-202	-3%
MAB	DMV	1,517	1,540	23	2%
	NYB	6,802	6,789	-13	0%
	VNC	108	30	-78	-265%
	Total	8,427	8,359	-68	-1%

Table B5-4. Open and closed portions of NEFSC shellfish strata assigned to different strata or different closed areas in post-stratification to accommodate open and closed

Actual Stratum	Region	Stratum Assigned
6010	Virginia Beach	6010
6020	Virginia Beach	6020
6030	Virginia Beach	6030
6040	Virginia Beach	6040
6050	Virginia Beach	6050
6080	Virginia Beach	6080
6090	Virginia Beach	6090
6120	Virginia Beach	6120
6170	Hudson Canyon S.	6170
6180	Hudson Canyon S.	6220
6190	Hudson Canyon S.	6230
6200	Hudson Canyon S.	6200
6210	Hudson Canyon S.	6210
6250	Hudson Canyon S.	6220
6260	Hudson Canyon S.	6220
6280	Open Area	6270
6320	Hudson Canyon S.	6320
6410	Nantucket Lightship	6410
6420	Nantucket Lightship	6420
6430	Nantucket Lightship	6430
6440	Nantucket Lightship	6440
6450	Nantucket Lightship	6450
6460	Open Area	6470
6470	Closed Area I	6550
6480	Closed Area I	6480
6480	Nantucket Lightship	6480
6510	Closed Area I	6520
6590	Closed Area II (S)	6610
6610	Open Area	6621
6670	Closed Area I	6670
6700	Closed Area I	6700
6720	Closed Area II (N)	6710
6730	Closed Area II (N)	6730
6740	Open Area	6720

Table B5-5. List of NMFS shellfish strata and NMFS sea scallop cruise combinations with no tows (holes). Holes were filed by borrowing survey data for the same strata in adjacent years or by using NMFS survey data collected on the F/V Tradition (9907 cruise only). Holes for the Georges Bank stock area during 1979-1980 (cruises 7906 and 8003) were not filled because there were no survey data for the same strata during adjacent years. Instead, survey results for the Georges Bank stock area during 1979-1980 were not not included in plots and tables.

Stock Area	Stratum	Year	Cruise	Filled By
Georges Bank	6460	1980	8003	Borrowing
	6470	1986	8605	Borrowing
	6490	1999	9907	Borrowing (1-sided)
	6500	1999	9907	F/V Tradition
	6500 (north of 41°45')	2000	2004	Borrowing (1-sided)
	6510	1999	9907	F/V Tradition
	6510 (north of 41°45')	2000	2004	Borrowing (1-sided)
	6520	1999	9907	F/V Tradition
	6520 (north of 41°45')	2000	2004	Borrowing (1-sided)
	6530	1980	8003	Borrowing
	6540	1999	9907	F/V Tradition
	6610	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
	6621	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
	6631	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
	6651	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
	6661	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
		1999	9907	F/V Tradition
	6710	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
		1999	9907	F/V Tradition
	6720	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
		1990	9003	Borrowing (1-sided)
		1999	9907	F/V Tradition
		2000	2004	Borrowing (1-sided)
	6740	1979	7906	Not filled
		1980	8003	Not filled
		1981	8111	Borrowing (1-sided)
		1989	8902	Borrowing
		1999	9907	F/V Tradition
Mid-Atlantic	6290	1998	9803	Borrowing

Table B5-6. NMFS sea scallop survey trend data Georges Bank and Mid-Atlantic Bight stock areas during 1982-200. Trend data are stratified mean numbers or meat weights per standard tow for scallops 40+ mm shell height. "Survey" values are without correction for survey dredge selectivity. "Population" values include corrections for survey dredge selectivity (NEFSC 1997). Population values were split into recruited and not recruited portions using a commercial dredge selectivity function (NEFSC 1992). Area surveyed is the sum of strata areas with at least one tow (after borrowing and including F/V Tradition tows). Survey results in this table are meant to reflect stock trends and may not be suitable for calculation of mortality rates or for overfishing status determinations. Stratum areas estimated by GIS.

Year	Survey N/Tow	CV	Population N/Tow	Population N/Tow Not Recruited	Population N/Tow Fully Recruited	Survey Kg/Tow	CV	Population Kg/Tow	Population Not Recruited Kg/Tow	Population Fully Recruited Kg/Tow	Mean Meat Weight (G)	Area Surveyed (NM^2)
Georges Bank												
1981	33	20%	45	10	34	0.582	17%	0.812	0.048	0.764	18.2	4,931
1982	107	39%	134	101	33	0.663	19%	0.895	0.304	0.591	6.7	7,250
1983	45	20%	60	23	37	0.518	15%	0.719	0.097	0.621	11.9	7,216
1984	29	12%	39	15	23	0.387	10%	0.538	0.054	0.483	14.0	7,172
1985	56	15%	75	39	36	0.547	13%	0.758	0.155	0.603	10.1	7,281
1986	91	14%	114	76	38	0.675	9%	0.924	0.271	0.652	8.1	7,029
1987	98	15%	127	68	59	0.791	13%	1.089	0.247	0.842	8.6	7,281
1988	74	16%	99	51	48	0.645	12%	0.892	0.209	0.684	9.0	7,281
1989	81	36%	109	55	54	0.673	17%	0.932	0.243	0.688	8.5	7,281
1990	159	23%	205	128	77	0.974	20%	1.330	0.470	0.859	6.5	7,281
1991	216	32%	262	209	53	0.978	16%	1.297	0.585	0.712	5.0	7,281
1992	201	38%	267	189	79	1.202	29%	1.649	0.797	0.851	6.2	7,281
1993	52	28%	70	47	23	0.386	17%	0.534	0.205	0.329	7.6	7,281
1994	34	16%	44	19	25	0.330	13%	0.456	0.068	0.389	10.3	7,281
1995	103	20%	130	101	29	0.591	16%	0.799	0.316	0.482	6.1	7,281
1996	119	23%	158	79	78	1.094	22%	1.513	0.299	1.213	9.6	7,281
1997	82	15%	111	29	81	1.302	18%	1.814	0.104	1.709	16.4	7,281
1998	242	30%	348	143	205	3.601	36%	4.999	0.520	4.479	14.4	7,281
1999	180	17%	251	69	183	3.212	25%	4.481	0.296	4.185	17.8	7,281
2000	688	30%	914	549	364	6.551	28%	9.077	1.984	7.093	9.9	7,281
Mid-Atlantic Bight												
1979	32	10%	43	11	32	0.529	10%	0.738	0.046	0.692	17.1	8,174
1980	41	12%	52	27	25	0.457	7%	0.630	0.063	0.568	12.2	8,174
1981	28	18%	37	17	20	0.316	12%	0.438	0.061	0.377	11.9	8,325
1982	29	11%	39	15	24	0.366	8%	0.509	0.063	0.446	12.9	8,220
1983	30	9%	39	20	19	0.350	8%	0.485	0.066	0.419	12.3	8,035
1984	30	10%	39	15	24	0.330	9%	0.458	0.049	0.409	11.8	8,035
1985	72	13%	94	59	36	0.538	8%	0.740	0.209	0.530	7.8	8,220
1986	116	9%	153	89	64	0.866	7%	1.193	0.324	0.869	7.8	8,359
1987	118	9%	150	92	57	0.757	6%	1.032	0.271	0.761	6.9	8,359
1988	139	10%	184	79	105	1.254	8%	1.737	0.310	1.428	9.4	8,174
1989	168	9%	218	130	88	1.120	7%	1.540	0.467	1.073	7.1	8,359
1990	198	22%	264	173	91	1.213	17%	1.669	0.702	0.967	6.3	8,359
1991	79	10%	106	49	57	0.717	10%	0.994	0.202	0.792	9.4	8,035
1992	42	11%	55	25	29	0.406	7%	0.561	0.084	0.477	10.3	8,035
1993	131	11%	163	137	26	0.568	8%	0.756	0.389	0.367	4.6	8,174
1994	121	12%	153	86	67	0.752	9%	1.030	0.311	0.719	6.7	8,174
1995	155	12%	209	117	92	1.087	10%	1.506	0.534	0.972	7.2	8,035
1996	56	8%	77	23	54	0.556	7%	0.775	0.117	0.658	10.1	8,220
1997	43	13%	54	28	26	0.387	6%	0.532	0.064	0.468	9.9	8,174
1998	143	17%	184	137	47	0.768	14%	1.043	0.448	0.595	5.7	8,220
1999	223	22%	293	164	129	1.574	18%	2.168	0.603	1.565	7.4	8,220
2000	272	14%	369	129	239	2.715	12%	3.776	0.557	3.219	10.2	8,359

Table B5-7. NMFS sea scallop survey trend data for 1982-2000 for open and closed regions in the Georges Bank and Mid-Atlantic Bight stock areas. Trend data are stratified nean numbers or mean meat weights per standard tow for scallops 40+ mm shell height. "Survey" values are without correction for survey dredge selectivity. "Population" values nclude corrections for survey dredge selectivity. Population values were split into recruited and not recruited portions using a commercial dredge selectivity function. The number of ows includes tows borrowed and tows by the F/V Tradition in 1999. Area surveyed is the sum of strata areas with at least one tow (after borrowing and including F/V Tradition tows). Total area is the area of the entire region. CV (standard error / mean) for survey values can be applied to population (recruited and not recruited) values. Non-random tows were used for closed areas except the Nantucket Lightship closed area during 1998-2000 but not in other years or for open areas. Survey results in this table are meant to reflect stock trends only; they may not be suitable for calculation of mortality rates or for overfishing status determinations. Stratum areas estimated by GIS.

Region	Year	Survey N/Tow	CV	Population N/Tow	Population N/Tow Not Recruited	Population N/Tow Fully Recruited	Survey G/Tow	CV	Population KG/Tow	Population KG/Tow Not Recruited	Population KG/Tow Fully Recruited	Mean Meat Weight (G)	Number Tows	Number Positive Tows	Area Surveyed (NM^2)
Georges Bank															
CL-1 (Closed Area I)															
	1979	30	58%	42	1	41	0.918	63%	1.284	0.005	1.279	30.3	7	7	673
	1980	34	37%	46	10	36	0.613	31%	0.855	0.035	0.820	17.8	14	13	673
	1981	39	46%	54	7	47	0.757	48%	1.058	0.037	1.021	19.4	8	8	536
	1982	73	36%	91	56	36	0.732	17%	1.004	0.148	0.856	10.0	14	14	673
	1983	37	32%	51	11	39	0.586	26%	0.817	0.042	0.775	15.8	17	16	673
	1984	38	30%	51	15	36	0.612	24%	0.853	0.059	0.795	16.3	9	9	564
	1985	120	37%	165	42	123	1.520	42%	2.122	0.211	1.911	12.7	18	18	673
	1986	204	32%	279	180	99	1.604	26%	2.225	0.831	1.394	7.9	15	15	673
	1987	62	34%	78	44	35	0.519	29%	0.713	0.127	0.586	8.4	18	18	673
	1988	126	56%	167	115	52	0.913	43%	1.255	0.445	0.810	7.2	16	15	673
	1989	40	18%	55	26	28	0.407	18%	0.565	0.107	0.458	10.1	16	14	673
	1990	213	24%	289	169	120	1.682	19%	2.330	0.756	1.574	7.9	16	16	673
	1991	144	28%	193	119	74	1.068	26%	1.474	0.511	0.962	7.4	18	18	673
	1992	682	93%	863	708	155	2.951	82%	3.930	2.405	1.525	4.3	16	16	673
	1993	352	43%	476	407	70	1.686	40%	2.308	1.729	0.578	4.8	13	12	673
	1994	120	40%	165	60	105	1.030	37%	1.434	0.327	1.107	8.6	18	15	673
	1995	73	48%	93	51	42	0.640	36%	0.880	0.150	0.730	8.7	19	17	673
	1996	135	24%	184	70	114	1.696	21%	2.359	0.263	2.095	12.5	20	20	673
	1997	137	20%	189	13	176	3.015	16%	4.214	0.042	4.173	22.1	21	18	673
	1998	1,184	63%	1,638	494	1,144	18.491	61%	25.810	2.176	23.633	15.6	19	17	673
	1999	404	27%	561	83	478	8.142	29%	11.381	0.422	10.959	20.2	39	39	673
	2000	470	43%	652	61	591	11.291	44%	15.783	0.244	15.539	24.0	23	23	673
CL-2(N) (Closed Area II - Northern Part)															
	1982	16	40%	22	5	17	0.238	44%	0.331	0.021	0.310	14.5	10	5	832
	1983	27	55%	34	19	15	0.223	56%	0.305	0.052	0.254	8.2	14	9	863
	1984	51	29%	64	39	25	0.365	30%	0.500	0.131	0.370	7.2	14	9	863
	1985	68	37%	89	56	33	0.518	29%	0.714	0.231	0.483	7.6	18	11	863
	1986	71	34%	94	67	27	0.537	30%	0.738	0.246	0.493	7.5	21	13	863
	1987	49	29%	63	32	31	0.348	32%	0.478	0.116	0.361	7.1	20	11	863
	1988	112	23%	147	78	70	0.951	20%	1.309	0.259	1.050	8.5	22	18	863
	1989	81	45%	107	53	54	0.707	20%	0.976	0.199	0.778	8.7	42	33	863
	1990	47	30%	64	26	38	0.443	30%	0.617	0.137	0.481	9.5	20	15	863

1991	153	38%	196	153	43	0.929	27%	1.264	0.522	0.742	6.1	23	20	863
1992	126	31%	162	112	50	0.778	29%	1.061	0.408	0.653	6.2	21	12	863
1993	17	22%	23	8	15	0.159	22%	0.222	0.046	0.176	9.4	21	13	863
1994	5	22%	7	1	6	0.079	23%	0.110	0.007	0.104	15.7	23	13	863
1995	120	59%	153	130	23	0.655	42%	0.881	0.397	0.483	5.5	21	13	863
1996	238	59%	311	157	154	2.050	59%	2.822	0.508	2.314	8.6	24	20	863
1997	117	27%	156	44	111	1.517	32%	2.109	0.154	1.956	12.9	29	21	863
1998	389	60%	521	136	384	7.115	70%	9.908	0.434	9.474	18.3	40	35	863
1999	153	39%	213	27	185	2.737	37%	3.825	0.149	3.676	17.9	23	21	863
2000	164	27%	227	46	181	3.203	28%	4.475	0.219	4.256	19.6	21	15	863
L-2(S) (Closed Area II - Southern Part)														
1981	26	46%	36	1	36	0.819	46%	1.146	0.006	1.140	31.5	1	1	633
1982	35	51%	49	8	41	0.636	28%	0.888	0.041	0.847	18.1	12	11	994
1983	20	35%	26	8	18	0.386	27%	0.536	0.020	0.517	19.2	13	10	994
1984	25	21%	34	10	24	0.512	22%	0.713	0.034	0.679	20.1	13	12	994
1985	26	17%	35	11	23	0.380	13%	0.529	0.053	0.476	14.9	19	18	994
1986	73	26%	93	61	32	0.588	17%	0.806	0.209	0.598	8.1	16	12	994
1987	161	27%	205	117	88	1.179	21%	1.616	0.403	1.214	7.3	18	14	994
1988	130	37%	176	88	88	1.087	29%	1.510	0.416	1.094	8.4	17	12	994
1989	295	70%	403	191	212	2.226	36%	3.092	0.994	2.098	7.5	33	27	994
1990	414	40%	565	263	302	3.061	42%	4.252	1.398	2.854	7.4	20	19	994
1991	313	42%	408	255	153	2.040	26%	2.788	0.937	1.851	6.5	17	17	994
1992	62	13%	86	20	66	0.773	11%	1.080	0.106	0.974	12.4	17	16	994
1993	23	16%	32	5	27	0.355	15%	0.496	0.025	0.471	15.2	18	17	994
1994	50	28%	61	37	24	0.451	16%	0.615	0.079	0.536	8.9	16	16	994
1995	64	26%	81	59	22	0.398	22%	0.541	0.194	0.347	6.3	16	16	994
1996	79	28%	103	49	54	0.859	17%	1.188	0.153	1.034	10.9	17	17	994
1997	93	46%	126	19	106	1.795	37%	2.505	0.057	2.448	19.3	15	14	994
1998	260	28%	312	195	117	2.478	29%	3.391	0.416	2.975	9.5	23	23	994
1999	187	38%	257	87	170	2.580	28%	3.597	0.376	3.221	13.8	30	30	994
2000	2,596	43%	3,460	2,569	891	15.378	35%	21.090	10.512	10.578	5.9	21	21	994
NLS (Nantucket Light Ship Closed Area)														
1979	15	47%	21	3	18	0.518	52%	0.723	0.007	0.716	33.8	11	9	828
1980	10	83%	14	2	12	0.228	32%	0.318	0.008	0.311	21.9	9	8	828
1981	16	65%	22	2	20	0.349	49%	0.488	0.010	0.479	22.1	9	7	828
1982	13	51%	18	3	15	0.308	53%	0.430	0.012	0.418	23.4	11	6	828
1983	9	42%	12	3	9	0.264	33%	0.368	0.013	0.355	30.4	11	7	828
1984	19	44%	26	10	16	0.343	29%	0.478	0.033	0.445	18.0	12	9	828
1985	70	58%	92	70	22	0.411	51%	0.559	0.260	0.300	5.8	10	5	828
1986	37	97%	48	32	16	0.307	40%	0.422	0.113	0.308	8.4	19	14	828
1987	25	66%	34	16	17	0.322	53%	0.447	0.055	0.392	12.8	14	10	828
1988	14	70%	16	10	7	0.149	48%	0.204	0.019	0.185	11.0	14	8	828
1989	12	69%	15	9	6	0.153	38%	0.211	0.030	0.181	12.9	16	11	828
1990	126	79%	143	128	15	0.422	56%	0.535	0.268	0.267	3.4	13	9	828
1991	205	59%	263	218	45	1.034	49%	1.394	0.768	0.626	5.1	13	9	828
1992	12	73%	16	4	13	0.147	55%	0.205	0.020	0.185	12.3	15	8	828
1993	7	41%	9	2	7	0.108	35%	0.151	0.011	0.139	16.4	12	7	828
1994	20	63%	25	12	13	0.190	52%	0.260	0.031	0.230	9.5	16	9	828

1995	94	96%	130	89	41	0.697	88%	0.966	0.397	0.569	7.4	11	5	828
1996	166	92%	226	125	101	1.769	84%	2.457	0.521	1.936	10.7	13	6	828
1997	63	51%	87	34	53	1.291	56%	1.803	0.145	1.657	20.5	12	8	828
1998	225	34%	295	154	141	3.418	58%	4.739	0.482	4.257	15.2	29	22	828
1999	396	51%	547	82	464	10.351	61%	14.465	0.327	14.138	26.2	15	12	828
2000	404	80%	563	40	523	15.282	89%	21.374	0.178	21.196	37.9	14	12	828
IEP (North Edge and Peak Open Area)														
1982	32	31%	43	15	27	0.413	30%	0.573	0.056	0.517	12.8	25	22	989
1983	40	27%	51	20	32	0.495	20%	0.685	0.053	0.632	12.4	25	23	989
1984	29	24%	39	14	25	0.443	23%	0.616	0.044	0.571	15.1	24	23	989
1985	64	38%	87	51	36	0.525	22%	0.728	0.230	0.498	8.2	31	28	989
1986	50	21%	65	32	34	0.514	22%	0.710	0.110	0.600	10.3	35	30	989
1987	86	21%	113	54	59	0.810	23%	1.120	0.205	0.915	9.4	34	32	989
1988	105	31%	136	73	62	0.810	23%	1.115	0.274	0.841	7.7	31	27	989
1989	84	43%	112	50	62	0.714	19%	0.989	0.229	0.760	8.5	59	55	989
1990	72	38%	100	31	68	0.704	34%	0.983	0.198	0.785	9.8	34	33	989
1991	40	31%	52	28	23	0.372	23%	0.513	0.093	0.419	9.4	33	30	989
1992	46	22%	63	21	42	0.506	19%	0.705	0.103	0.603	11.1	34	34	989
1993	17	27%	23	5	18	0.269	34%	0.375	0.017	0.358	15.8	30	26	989
1994	21	45%	26	13	13	0.198	34%	0.273	0.036	0.237	9.4	34	27	989
1995	84	56%	102	91	11	0.351	47%	0.464	0.252	0.212	4.2	35	31	989
1996	119	65%	157	81	77	0.952	62%	1.312	0.290	1.022	8.0	31	27	989
1997	120	52%	163	36	127	1.890	69%	2.637	0.151	2.486	15.8	34	29	989
1998	127	23%	159	115	43	0.675	25%	0.912	0.363	0.549	5.3	30	25	989
1999	110	40%	150	52	98	1.774	61%	2.470	0.213	2.258	16.1	22	22	989
2000	515	46%	708	254	454	4.895	39%	6.820	1.469	5.351	9.5	27	24	989
SCH (South Channel Open Area)														
1979	196	69%	269	36	233	2.645	55%	3.694	0.207	3.487	13.5	29	23	1,373
1980	141	47%	170	118	53	0.905	30%	1.225	0.318	0.907	6.4	34	26	1,300
1981	57	34%	77	29	48	0.726	31%	1.010	0.130	0.880	12.7	40	29	1,373
1982	456	49%	559	481	77	1.760	36%	2.309	1.449	0.860	3.9	36	28	1,373
1983	134	35%	182	72	110	1.218	32%	1.691	0.358	1.333	9.1	40	36	1,308
1984	32	24%	43	19	24	0.347	15%	0.482	0.071	0.410	10.7	48	38	1,373
1985	68	23%	88	50	38	0.669	16%	0.922	0.167	0.755	9.8	48	41	1,373
1986	180	28%	218	170	48	0.969	17%	1.297	0.465	0.832	5.4	57	50	1,121
1987	190	32%	247	146	101	1.327	26%	1.825	0.566	1.259	7.0	56	50	1,373
1988	68	37%	93	40	53	0.612	32%	0.850	0.198	0.651	8.9	61	43	1,373
1989	44	37%	57	35	22	0.407	25%	0.560	0.120	0.440	9.3	56	45	1,373
1990	273	48%	323	285	38	0.933	40%	1.202	0.705	0.497	3.4	62	41	1,373
1991	576	60%	644	596	48	1.479	42%	1.812	1.227	0.586	2.6	60	52	1,373
1992	532	50%	727	532	195	3.006	46%	4.155	2.554	1.601	5.6	58	52	1,373
1993	45	26%	61	34	27	0.367	21%	0.509	0.158	0.351	8.2	58	47	1,373
1994	33	21%	44	15	29	0.343	17%	0.476	0.065	0.411	10.4	57	51	1,373
1995	243	30%	299	247	53	1.099	20%	1.458	0.722	0.736	4.5	60	54	1,373
1996	140	26%	187	94	93	1.040	24%	1.439	0.432	1.006	7.4	53	46	1,373
1997	77	25%	102	43	58	0.786	33%	1.088	0.156	0.932	10.2	64	57	1,373
1998	101	23%	133	75	58	0.752	20%	1.035	0.278	0.756	7.5	61	51	1,373
1999	127	29%	165	99	66	1.001	22%	1.378	0.365	1.013	7.9	51	45	1,373

2000	475	39%	597	398	199	2.632	33%	3.566	1.313	2.253	5.5	51	47	1,373

SEP (Southeast Part Open Area)

1979	27	27%	36	8	28	0.680	27%	0.948	0.024	0.924	24.9	18	14	1,562
1980	62	39%	81	28	53	0.703	32%	0.975	0.095	0.880	11.4	18	13	1,562
1981	21	23%	28	3	25	0.422	20%	0.589	0.018	0.572	20.5	18	17	1,562
1982	9	29%	12	1	12	0.267	24%	0.373	0.002	0.371	29.6	21	17	1,562
1983	20	36%	26	13	13	0.269	29%	0.373	0.040	0.333	13.2	18	16	1,562
1984	18	41%	25	7	18	0.246	35%	0.342	0.026	0.316	13.4	18	14	1,562
1985	19	23%	25	10	15	0.229	22%	0.319	0.041	0.277	12.3	26	23	1,562
1986	41	31%	54	29	25	0.444	18%	0.614	0.100	0.514	10.8	31	30	1,562
1987	64	43%	86	33	52	0.669	41%	0.928	0.118	0.810	10.4	30	21	1,562
1988	14	22%	20	3	17	0.267	20%	0.374	0.015	0.359	18.9	31	27	1,562
1989	31	36%	40	26	14	0.265	22%	0.363	0.080	0.282	8.4	32	24	1,562
1990	9	27%	12	3	9	0.132	25%	0.185	0.013	0.172	15.5	29	22	1,562
1991	23	23%	30	18	12	0.202	20%	0.280	0.076	0.204	8.8	30	24	1,562
1992	32	28%	43	16	27	0.369	17%	0.513	0.068	0.445	11.7	30	27	1,562
1993	11	20%	15	4	12	0.208	19%	0.290	0.013	0.277	18.4	30	28	1,562
1994	19	31%	23	13	11	0.238	21%	0.328	0.024	0.303	12.5	30	25	1,562
1995	27	21%	36	18	18	0.308	13%	0.426	0.064	0.362	11.5	31	28	1,562
1996	29	24%	37	23	14	0.236	15%	0.322	0.065	0.258	8.0	31	28	1,562
1997	23	21%	29	14	15	0.216	17%	0.298	0.038	0.260	9.4	31	28	1,562
1998	82	25%	103	77	26	0.410	20%	0.553	0.252	0.301	5.0	29	25	1,562
1999	90	32%	122	52	70	0.822	24%	1.141	0.248	0.893	9.1	30	29	1,562
2000	59	37%	79	42	38	0.608	31%	0.841	0.154	0.688	10.3	29	24	1,562

Atlantic Bight
(Hudson Canyon South Closed Area)

1979	38	21%	51	11	40	0.640	19%	0.893	0.044	0.849	16.9	41	38	1,461
1980	41	21%	50	29	21	0.394	14%	0.540	0.059	0.481	9.6	39	37	1,461
1981	30	29%	40	16	24	0.333	18%	0.462	0.069	0.393	11.0	43	40	1,461
1982	33	30%	43	24	19	0.321	17%	0.442	0.072	0.370	9.6	44	41	1,461
1983	16	24%	21	11	10	0.221	14%	0.306	0.036	0.270	13.4	41	37	1,461
1984	30	23%	38	20	18	0.305	17%	0.421	0.055	0.365	10.1	40	37	1,461
1985	113	29%	151	113	38	0.700	22%	0.963	0.440	0.522	6.2	39	36	1,461
1986	135	14%	182	91	91	1.015	15%	1.405	0.386	1.019	7.5	47	44	1,461
1987	135	13%	176	105	71	0.917	9%	1.258	0.350	0.908	6.8	44	38	1,461
1988	198	16%	267	89	178	1.832	16%	2.545	0.382	2.163	9.2	47	38	1,461
1989	300	16%	382	260	121	1.600	12%	2.181	0.879	1.301	5.3	47	44	1,461
1990	627	36%	840	583	257	3.422	32%	4.709	2.474	2.235	5.5	42	36	1,461
1991	119	16%	158	79	79	0.878	11%	1.210	0.297	0.913	7.4	48	40	1,461
1992	42	17%	57	26	31	0.386	12%	0.535	0.097	0.438	9.1	47	39	1,461
1993	121	11%	147	116	31	0.517	10%	0.684	0.299	0.385	4.3	46	44	1,461
1994	280	21%	333	243	90	1.169	14%	1.555	0.624	0.931	4.2	49	45	1,461
1995	380	23%	519	303	216	2.476	22%	3.434	1.470	1.964	6.5	50	48	1,461
1996	141	12%	197	54	142	1.309	11%	1.829	0.352	1.477	9.3	44	40	1,461
1997	97	29%	115	75	40	0.550	12%	0.740	0.149	0.590	5.7	46	41	1,461
1998	424	31%	539	414	125	1.957	30%	2.635	1.282	1.354	4.6	52	49	1,461
1999	637	35%	860	478	382	4.369	30%	6.047	2.085	3.962	6.9	54	48	1,461
2000	672	26%	911	301	610	6.884	24%	9.577	1.249	8.328	10.2	53	43	1,461

BC (Virginia Beach Closed Area)														
1979	182	39%	223	119	104	1.297	41%	1.773	0.278	1.494	7.1	6	6	130
1980	194	55%	251	120	131	1.556	38%	2.149	0.455	1.694	8.0	6	6	130
1981	25	55%	35	3	32	0.393	33%	0.550	0.014	0.536	15.5	5	5	97
1982	21	41%	28	6	22	0.369	32%	0.514	0.019	0.495	17.6	11	10	130
1983	43	4%	57	40	16	0.416	32%	0.572	0.126	0.447	9.6	13	13	130
1984	13	20%	18	4	14	0.262	24%	0.366	0.013	0.353	20.2	14	14	130
1985	14	28%	18	7	12	0.222	19%	0.309	0.026	0.283	16.3	14	12	130
1986	142	42%	182	144	38	0.775	41%	1.045	0.438	0.607	5.4	13	11	130
1987	52	36%	72	22	51	0.544	34%	0.758	0.103	0.655	10.4	15	11	130
1988	49	36%	67	29	37	0.614	25%	0.854	0.115	0.740	12.6	16	13	130
1989	140	68%	175	120	55	0.757	57%	1.023	0.346	0.677	5.4	13	11	130
1990	92	15%	122	55	68	0.746	12%	1.032	0.210	0.822	8.1	11	11	130
1991	225	35%	294	229	64	1.174	29%	1.599	0.807	0.793	5.2	14	14	130
1992	67	25%	91	42	49	0.547	17%	0.759	0.181	0.578	8.2	15	15	130
1993	783	17%	1,004	953	51	2.586	17%	3.402	2.985	0.417	3.3	15	15	130
1994	327	43%	453	214	239	2.311	45%	3.223	1.269	1.954	7.1	14	14	130
1995	184	27%	239	167	72	0.974	21%	1.322	0.556	0.766	5.3	16	16	130
1996	156	24%	194	137	57	0.787	17%	1.054	0.349	0.705	5.0	14	10	130
1997	215	33%	273	234	38	0.894	30%	1.188	0.676	0.512	4.2	14	14	130
1998	251	18%	345	117	227	2.366	17%	3.296	0.531	2.765	9.4	20	20	130
1999	357	16%	486	95	392	5.402	15%	7.534	0.323	7.211	15.1	20	20	130
2000	403	37%	561	47	514	7.428	38%	10.386	0.220	10.166	18.4	16	11	130
DMV (Delmarva Open Area)														
1979	67	17%	92	26	66	0.877	15%	1.225	0.133	1.092	13.1	37	36	1,411
1980	98	24%	116	81	35	0.683	11%	0.926	0.159	0.767	7.0	39	38	1,411
1981	15	14%	21	5	16	0.295	11%	0,412	0.020	0.392	19.5	36	36	1,411
1982	28	23%	38	16	22	0.452	13%	0.630	0.067	0.563	16.2	40	38	1,411
1983	46	22%	62	41	21	0.482	14%	0.668	0.154	0.514	10.4	42	40	1,411
1984	29	16%	39	14	24	0.388	11%	0.540	0.046	0.494	13.5	45	44	1,411
1985	57	30%	78	48	30	0.495	19%	0.688	0.219	0.469	8.7	48	47	1,411
1986	204	18%	272	184	87	1.283	12%	1.763	0.699	1.064	6.3	56	56	1,411
1987	112	11%	151	77	73	0.892	9%	1.234	0.292	0.942	8.0	52	52	1,411
1988	104	14%	131	80	51	0.758	10%	1.037	0.214	0.823	7.3	55	53	1,411
1989	190	18%	245	137	108	1.287	17%	1.765	0.461	1.304	6.8	54	54	1,411
1990	96	14%	131	46	85	0.865	11%	1.204	0.226	0.978	9.0	53	50	1,411
1991	67	18%	90	56	34	0.561	10%	0.774	0.191	0.583	8.3	55	55	1,411
1992	35	20%	44	23	21	0.343	9%	0.473	0.066	0.408	9.9	53	50	1,411
1993	372	22%	456	432	24	1.167	19%	1.505	1.151	0.353	3.1	50	50	1,411
1994	203	20%	273	128	145	1.447	18%	2.010	0.677	1.333	7.1	55	55	1,411
1995	197	15%	261	165	96	1.280	12%	1.761	0.639	1.122	6.5	52	52	1,411
1996	56	11%	73	25	48	0.577	7%	0.800	0.078	0.722	10.4	52	52	1,411
1997	50	16%	62	33	29	0.455	10%	0.624	0.077	0.547	9.1	53	52	1,411
1998	155	20%	202	162	40	0.755	17%	1.026	0.582	0.445	4.9	53	52	1,411
1999	149	18%	198	104	94	1.165	18%	1.611	0.407	1.204	7.8	56	56	1,411
2000	367	15%	489	253	236	2.784	12%	3.849	1.014	2.835	7.6	55	55	1,411

NYB *(New York Bight Open Area)*

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1979	17	13%	24	4	20	0.388	17%	0.543	0.019	0.524	22.6	82	72	5,171
1980	23	15%	31	10	21	0.388	11%	0.540	0.029	0.511	16.7	83	76	5,171
1981	31	23%	40	20	20	0.315	18%	0.436	0.071	0.365	10.1	83	71	5,356
1982	29	13%	39	13	26	0.355	11%	0.495	0.060	0.435	12.4	90	79	5,217
1983	29	11%	38	17	21	0.349	11%	0.484	0.050	0.434	12.1	97	81	5,032
1984	30	14%	40	14	26	0.324	13%	0.449	0.049	0.400	10.7	105	91	5,032
1985	66	16%	85	48	37	0.512	10%	0.703	0.148	0.555	7.7	100	93	5,217
1986	87	13%	113	62	51	0.718	11%	0.989	0.206	0.783	8.2	110	99	5,356
1987	116	12%	144	95	50	0.683	10%	0.924	0.248	0.677	5.9	115	110	5,356
1988	134	15%	178	78	100	1.242	10%	1.723	0.320	1.403	9.3	109	102	5,171
1989	128	12%	167	93	74	0.955	10%	1.319	0.359	0.960	7.5	130	117	5,356
1990	111	25%	145	98	47	0.713	17%	0.978	0.356	0.622	6.4	110	95	5,356
1991	68	16%	92	35	57	0.703	16%	0.977	0.163	0.814	10.4	111	101	5,032
1992	43	16%	56	25	31	0.424	10%	0.586	0.083	0.504	9.9	114	96	5,032
1993	54	12%	70	45	25	0.375	10%	0.514	0.149	0.365	6.9	103	96	5,171
1994	51	19%	66	29	36	0.417	13%	0.576	0.107	0.469	8.2	109	100	5,171
1995	81	16%	110	52	58	0.660	13%	0.917	0.250	0.667	8.1	109	101	5,032
1996	31	16%	42	11	31	0.340	13%	0.474	0.058	0.416	11.0	101	86	5,217
1997	22	12%	29	8	21	0.312	8%	0.434	0.022	0.412	14.2	112	102	5,171
1998	60	18%	78	55	23	0.408	11%	0.558	0.183	0.375	6.8	112	98	5,217
1999	127	18%	158	95	63	0.826	15%	1.126	0.257	0.868	6.5	108	96	5,217
2000	134	14%	184	52	133	1.444	14%	2.014	0.257	1.757	10.8	114	100	5,356

Table B5-8. Effect of closed areas on recruitment in Georges Bank

Year	Recruits/tow Clsd areas	ln(recruits) Clsd areas	Recruits/tow Open areas	ln(recruits) Open areas	Recruits/tow CLII-S	ln(recruits) CLII-S	Recruits/tow TOTAL	ln(recruits) TOTAL
AREA (sqnm)	2361.2		3926.0		993.8		7281.0	
1982	17.31	2.84	155.45	5.05	4.32	1.46	90.33	4.50
1983	9.87	2.29	22.89	3.14	7.86	2.06	16.56	2.81
1984	17.58	2.85	9.79	2.23	8.90	2.19	12.12	2.49
1985	43.30	3.77	28.58	3.36	6.68	1.90	30.36	3.41
1986	71.59	4.27	65.38	4.26	54.55	4.00	65.94	4.19
1987	26.08	3.26	60.38	4.09	90.61	4.51	53.38	3.98
1988	56.55	4.04	21.33	3.18	61.37	4.12	38.22	3.64
1990	85.03	4.44	99.19	4.60	134.99	4.91	99.48	4.60
1991	146.32	4.99	210.83	5.35	208.76	5.34	189.63	5.25
1992	206.46	5.33	136.25	4.91	9.89	2.29	141.77	4.95
1993	104.41	4.65	10.06	2.32	2.53	0.93	39.63	3.68
1994	12.66	2.54	11.00	2.32	36.42	3.60	15.01	2.71
1995	86.97	4.47	109.38	4.71	54.90	4.01	94.67	4.55
1996	107.45	4.68	45.92	3.88	42.97	3.76	65.47	4.18
1997	25.22	3.23	23.79	3.16	16.04	2.78	23.20	3.14
1998	197.94	5.29	74.90	4.26	147.38	4.99	124.69	4.83
1999	38.31	3.65	51.35	3.92	77.61	4.35	50.70	3.93
2000	35.62	3.57	153.33	5.03	2598.06	7.86	448.85	6.11
Mean 82-94	66.43	3.77	69.26	3.73	52.24	3.11	66.04	3.85
Mean 96-00	80.91	4.08	69.86	4.05	576.41	4.75	142.58	4.44
Mean 82-00	71.59	3.90	71.65	3.88	197.99	3.61	88.89	4.05
G.Mean 82-94	43.56		41.54		22.37		47.05	
G.Mean 95-00	59.27		57.78		115.42		84.51	
G.Mean 82-00	49.31		48.05		37.09		57.56	
Stdev 82-94	61.02	1.01	67.07	1.13	64.42	1.47	55.25	0.89
Stdev 96-00	73.09	0.86	50.08	0.68	1131.21	1.92	175.19	1.11
Stdev 82-00	61.03	0.93	59.91	1.00	601.74	1.68	102.05	0.95

Table B5-9. Clapper Ratio Analysis

Closed Areas, Georges Bank

	40-80mm	80-120mm	120+mm	TOTAL
82-94	0.0054	0.016	0.012	0.009
96-00	0.0047	0.011	0.036	0.017

ANOVA	F	p
Size	1.70	0.19
Period	0.11	0.74
Interaction	1.17	0.32

Open Areas, Georges Bank

	40-80mm	80-120mm	120+mm	TOTAL
82-94	0.031	0.021	0.022	0.023
96-00	0.004	0.005	0.016	0.004

ANOVA	F	p
Size	0.12	0.89
Period	2.25	0.14
Interaction	0.26	0.77

Mid-Atlantic

	40-80	80-120	120+	TOTAL
82-00	0.005	0.008	0.022	0.006

ANOVA	F	p
Size	10.8	0.0001

Table B5-10. Comparison of dredge efficiency and scallop density (ft^2 and meters^2) estimates from depletion experiments conducted in 1999 and 2000. Regions: "South" includes Virginia Beach and Hudson Canyon (MidAtlantic). "North" includes Georges Bank and Nantucket Lightship.

Experiment sm21: tow #205 omitted.

						Patch Model (cell size = 60x60 ft)						Leslie Davis Model		
						gamma = 0.5			gamma = 0.75					
Fishing Vessel	Experiment	Code	Location	Depth (fathoms)	Number of Tows	Efficiency	Density (#/ft^2)	Density (#/m^2)	Efficiency	Density (#/ft^2)	Density (#/m^2)	Efficiency	Density (#/ft^2)	Density (#/m^2)
Alice Amanda	1	vb1	Virginia Beach		6	**0.74**	0.028	0.301	**0.49**	0.043	0.463	**0.56**	0.044	0.474
	2	vb2			5	**0.95**	0.013	0.140	**0.95**	0.016	0.172	**0.83**	0.021	0.226
Courageous	1	hc1	Hudson Canyon		12	**0.95**	0.021	0.226	**0.64**	0.032	0.344	**0.55**	0.034	0.366
	2	hc2			11	**0.10**	0.149	1.604	**0.37**	0.056	0.603	**0.64**	0.043	0.463
	3	hc3			8	**0.95**	0.020	0.215	**0.68**	0.030	0.323	**0.57**	0.036	0.388
	4	vb3	Virginia Beach		7	**0.95**	0.017	0.183	**0.65**	0.026	0.280	**0.73**	0.028	0.301
	5	vb4			9	**0.81**	0.031	0.334	**0.44**	0.048	0.517	**0.45**	0.050	0.538
	6	vb5			4	**0.92**	0.010	0.108	**0.79**	0.011	0.118	**0.60**	0.014	0.151
	7	vb6			8	**0.39**	0.022	0.237	**0.26**	0.034	0.366	**0.32**	0.030	0.323
Kathy Marie	1	km1	Cl. Area I	55	28	**0.06**	0.235	2.530	**0.22**	0.083	0.893	**0.24**	0.077	0.829
Santa Maria	1	sm11	Cl. Area I	40	29	**0.19**	0.209	2.250	**0.13**	0.307	3.305	**0.24**	0.183	1.970
	2	sm21	Nantucket Lightship	40	18	**0.69**	0.018	0.194	**0.46**	0.027	0.291	**0.42**	0.029	0.312

Region	Efficiency Stats:			
All	Mean	***0.64***	***0.51***	***0.51***
	Std Error (of Mean)	0.103	0.070	0.053
	Median	0.78	0.48	0.56
	Count	12	12	12
South	Mean	***0.75***	***0.59***	***0.58***
	Std Error (of Mean)	0.102	0.072	0.049
	Median	0.92	0.64	0.57
	Count	9	9	9
North	Mean	***0.31***	***0.27***	***0.30***
	Std Error (of Mean)	0.192	0.098	0.060
	Median	0.19	0.22	0.24
	Count	3	3	3

Table B5-11. Comparison of dredge efficiency and scallop density (ft^2) estimates from depletion experiments conducted in 1999 and 2000. Confidence intervals (LL= lower limit, U=upper) are from the profile likelihood method (see Appendix A). For density, a Lower Limit of "--" implies a value <0.02. All runs of the Patch model used a gamma = 0.50.

						Patch Model (cell size = 60x60 ft.; gamma = 0.5)						***Leslie Davis Model***	
Fishing Vessel	***Experiment***	***Code***	***Location***	***Depth (fathoms)***	***Number of Tows***	***efficiency***	***LL***	***UL***	***density (#/ft^2)***	***LL***	***UL***	***efficiency***	***density (#/ft^2)***
Alice Amanda	1	vb1	Virginia Beach		6	0.74	--	--	0.028	--	--	0.56	0.044
	2	vb2	Virginia Beach		5	0.95	--	--	0.013	--	--	0.83	0.021
Courageous	1	hc1	Hudson Canyon		12	0.95	0.66	--	0.021	--	0.027	0.55	0.034
	2	hc2			11	0.10	--	--	0.149	--	--	0.64	0.043
	3	hc3			8	0.95	0.77	--	0.020	--	0.023	0.57	0.036
	4	vb3	Virginia Beach		7	0.95	--	--	0.017	--	0.032	0.73	0.028
	5	vb4			9	0.81	--	--	0.031	0.024	0.042	0.45	0.050
	6	vb5			4	0.92	--	--	0.010	--	--	0.60	0.014
	7	vb6			8	0.39	--	--	0.022	--	--	0.32	0.030
Kathy Marie	1	km1	Area I	55	28	0.06	--	--	0.235	--	0.39	0.24	0.077
Santa Maria	1	sm11	Area I	40	29	0.19	0.07	0.35	0.209	0.14	--	0.24	0.183
	2	sm21 (w/out Tow 205)	Nantucket Lightship	40	18	0.70	0.40	0.90	0.018	--	0.024	0.40	0.029

Table B5-12. Comparison of dredge efficiency and scallop density (ft^2) estimates from depletion experiments conducted in 1999 and 2000. Confidence intervals (LL= lower limit, U=upper) are from the profile likelihood method (see Appendix A).
For density, a Lower Limit of "--" implies a value <0.02. All runs of the Patch model used a gamma = 0.75.

						Patch Model (cell size = 60x60 ft.; gamma = 0.75)						***Leslie Davis Model***	
Fishing Vessel	***Experiment***	***Code***	***Location***	***Depth (fathoms)***	***Number of Tows***	***efficiency***	***LL***	***UL***	***density (#/ft^2)***	***LL***	***UL***	***efficiency***	***density (#/ft^2)***
Alice Amanda	1	vb1	Virginia Beach		6	0.49	0.10	--	0.043	0.029	--	0.56	0.044
	2	vb2	Virginia Beach		5	0.95	--	--	0.016	--	0.02	0.83	0.021
Courageous	1	hc1	Hudson Canyon		12	0.64	0.44	0.81	0.032	0.026	0.041	0.55	0.034
	2	hc2			11	0.37	0.19	0.55	0.056	0.04	0.086	0.64	0.043
	3	hc3			8	0.68	0.55	0.82	0.029	0.03	0.033	0.57	0.036
	4	vb3	Virginia Beach		7	0.65	0.23	--	0.026	--	0.049	0.73	0.028
	5	vb4			9	0.44	0.25	0.66	0.047	0.038	0.060	0.45	0.050
	6	vb5			4	0.79	0.53	--	0.011	--	0.013	0.60	0.014
	7	vb6			8	0.26	--	0.54	0.034	0.02	--	0.32	0.030
Kathy Marie	1	km1	Area I	55	28	0.22	--	0.40	0.083	0.052	--	0.24	0.077
Santa Maria	1	sm11	Area I	40	29	0.13	0.05	0.24	0.307	0.2	--	0.24	0.183
	2	sm21 (w/out Tow 205)	Nantucket Lightship	40	18	0.46	0.28	0.65	0.027	0.021	0.035	0.40	0.029

Table B5-13. Model results examining the effect of the tow path endpoint for two scallop depletion experiments.
The "whole Tow" includes the ski-jump feature in the inclinometer plot.
The "clipped Tow" omits 180 seconds from the end of the tow path (i.e. most of the ski jump).
Confidence intervals are from the profile likelihood method (see Appendix A). All runs of the Patch model used a gamma = 0.75.

								Patch Model (cell size = 60x60 ft.; gamma = 0.75)					
Fishing Vessel	*Experiment*	*Code*	*Location*	*Depth (fathoms)*	*Number of Tows*	*Tow Path*	*Mean Distance (nmi)*	*efficiency*	*LL*	*UL*	*density (#/ft^2)*	*LL*	*UL*
Santa Maria	1	sm11	Cl. Area I	40	29	**Whole**	0.972	0.13	0.05	0.24	0.307	0.2	--
						Clipped	0.855	0.10	0.05	0.16	0.441	0.32	0.99
	2	sm21	Nantucket Lightship	40	18	**Whole**	0.971	0.46	0.28	0.65	0.027	0.021	0.035
						Clipped	0.866	0.44	0.30	0.55	0.034	0.027	0.043

Table B5-14. Approximate error estimates for dredge efficiency estimates based on ratio of reseach and commercial dredge efficiencies to photo-based estimates of average density. Standard deviation estimates are approximated from first order Taylor Series expansion.

						Assumed Correlation between X and Y			
Descriptor	Area	Year	StrataType	Comparsion Type	Statistic	0	0.25	0.5	1
NLSA, FV to Photo 1999, photo strata	*NLSA*	*1999*	*PHOTO*	*FV_PH*	Cov(x,y)	0.000	0.002	0.003	0.007
					E(x/y)	0.861	0.852	0.843	0.826
					V(x/y)	0.068	0.054	0.039	0.010
					SD(x/y)	0.261	0.232	0.197	0.098
					CV(x/y)	0.304	0.272	0.234	0.118
NLSA, RV to Photo 1999, photo strata	*NLSA*	*1999*	*PHOTO*	*RV_PH*	Cov(x,y)	0.000	0.003	0.005	0.011
					E(x/y)	0.866	0.852	0.838	0.810
					V(x/y)	0.147	0.123	0.100	0.053
					SD(x/y)	0.383	0.351	0.316	0.230
					CV(x/y)	0.442	0.412	0.377	0.284
Closed Area 2 Far North, RV to photo 1	*CA2_FN*	*1999*	*PHOTO*	*RV_PH*	Cov(x,y)	0.000	0.005	0.010	0.020
					E(x/y)	0.817	0.802	0.787	0.757
					V(x/y)	0.251	0.227	0.202	0.154
					SD(x/y)	0.501	0.476	0.450	0.392
					CV(x/y)	0.613	0.594	0.572	0.518
Closed Area 1, FV to Photo 1999, phot	*CA1*	*1999*	*PHOTO*	*FV_PH*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	0.347	0.345	0.343	0.340
					V(x/y)	0.006	0.005	0.004	0.002
					SD(x/y)	0.078	0.071	0.063	0.042
					CV(x/y)	0.226	0.206	0.183	0.123
Closed Area 1, RV to Photo 1999, phot	*CA1*	*1999*	*PHOTO*	*RV_PH*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	0.318	0.317	0.315	0.311
					V(x/y)	0.008	0.007	0.005	0.003
					SD(x/y)	0.088	0.081	0.073	0.055
					CV(x/y)	0.275	0.255	0.233	0.178

Table B5-15. Approximate error estimates for catch ratios between reseach and commercial dredges.
Standard deviation estimates are approximated from first order Taylor Series expansion.

						Assumed Correlation between X and Y			
Descriptor	AreaS	year	StrataType	CompTypeS	Statistic	0	0.25	0.5	1
NLSA, RV to FV 1999, nmfs strata	*NLSA*	*1999*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.001	0.002
					E(x/y)	0.992	0.955	0.919	0.846
					V(x/y)	0.300	0.234	0.168	0.036
					SD(x/y)	0.548	0.484	0.410	0.190
					CV(x/y)	0.552	0.506	0.446	0.225
NLSA, RV to FV 1999, photo strata	*NLSA*	*1999*	*PHOTO*	*RV_FV*	Cov(x,y)	0.000	0.004	0.008	0.016
					E(x/y)	1.079	1.050	1.021	0.963
					V(x/y)	0.257	0.199	0.141	0.025
					SD(x/y)	0.507	0.446	0.375	0.157
					CV(x/y)	0.470	0.425	0.368	0.163
Virginia Beach , RV to FV 2000, NMFS strat	*VAB*	*2000*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	1.518	1.482	1.446	1.374
					V(x/y)	0.444	0.342	0.239	0.034
					SD(x/y)	0.667	0.585	0.489	0.185
					CV(x/y)	0.439	0.394	0.338	0.135
Virginia Beach , RV to FV 1999, NMFS strat	*VAB*	*1999*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	1.483	1.464	1.446	1.409
					V(x/y)	0.208	0.156	0.105	0.003
					SD(x/y)	0.456	0.396	0.325	0.056
					CV(x/y)	0.307	0.270	0.224	0.040
Hudson Canyon, RV to FV, 2000, NMFS strat	*HC*	*2000*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	1.050	1.044	1.038	1.025
					V(x/y)	0.073	0.060	0.047	0.021
					SD(x/y)	0.270	0.245	0.217	0.146
					CV(x/y)	0.257	0.235	0.209	0.142
Closed Area II All, RV to FV 1998, NMFS str	*CA2_ALL*	*1998*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	1.445	1.428	1.410	1.375
					V(x/y)	0.616	0.566	0.516	0.416
					SD(x/y)	0.785	0.752	0.718	0.645
					CV(x/y)	0.543	0.527	0.509	0.469
Closed Area II North, RV to FV 1998, NMFS	*CA2_N_alt*	*1998*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.001	0.001
					E(x/y)	3.129	2.862	2.595	2.061
					V(x/y)	4.402	3.302	2.201	0.000
					SD(x/y)	2.098	1.817	1.484	0.000
					CV(x/y)	0.671	0.635	0.572	0.000
Closed Area II North, RV to FV 1998, NMFS	*CA2_N*	*1998*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.001	0.003	0.006
					E(x/y)	30.423	29.047	27.671	24.919
					V(x/y)	60.645	54.974	49.303	37.961
					SD(x/y)	7.787	7.414	7.022	6.161
					CV(x/y)	0.256	0.255	0.254	0.247
Closed Area II South, RV to FV 1998, NMFS	*CA2_S*	*1998*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	0.725	0.723	0.722	0.719
					V(x/y)	0.042	0.039	0.037	0.033
					SD(x/y)	0.204	0.198	0.193	0.181
					CV(x/y)	0.281	0.274	0.267	0.252
Closed Area I, RV to FV 1999, photo strata	*CA1*	*1999*	*PHOTO*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.000
					E(x/y)	0.959	0.946	0.934	0.908
					V(x/y)	0.096	0.072	0.049	0.002
					SD(x/y)	0.309	0.269	0.221	0.049
					CV(x/y)	0.322	0.284	0.237	0.054
Closed Area I, RV to FV 1999, nmfs strata	*CA1*	*1999*	*NMFS*	*RV_FV*	Cov(x,y)	0.000	0.000	0.000	0.001
					E(x/y)	1.459	1.428	1.398	1.336
					V(x/y)	0.327	0.245	0.164	0.002
					SD(x/y)	0.572	0.495	0.405	0.040
					CV(x/y)	0.392	0.347	0.290	0.030

Table B5-16. Comparison of catch rates (#/m^2) of scallops >90 mm shell height between fishing vessels and R/V Albatross for various fishery surveys in 1998-2000

			Density Estimates (numbers of scallops >90 mm per sqr m)								Efficiency compared to Photo Estimate			
			R/V Albatross		Commercial F/V			Photographic Method			1.49 m^2 quadrat		2.2 m^2 quadrat	
Area	Year	Stratification	RV Density	Coef of Variation	F/V Density	Coef of Variation	Names of Fishing Vessels	1.49 m^2 quadrat	2.2 m^2 quadrat	Relative Efficiency RV to FV	RV Effic	FV Effic	RV Effic	FV Effic
NLSA	1999	F/V strata			0.054	0.24								
		R/V strata	0.095	0.52	0.105					0.90				
		Photo Reg	0.372		0.370	0.27	KM, SM	0.503	0.44	1.01	0.740	0.736	0.845	0.841
Closed Area I	1999	F/V strata			0.059	0.2								
		R/V strata	0.09	0.29	0.068	0.32				1.32				
		Photo Reg	0.079		0.086	0.21		0.207	0.25	0.92	0.382	0.415	0.316	0.344
Closed Area II (South)	1998	F/V strata			0.019		CA,CE,TH							
		R/V strata	0.021	0.28	0.029	0.03	GN,GU,EM			0.74				
Closed Area II (North)	1998	F/V strata			0.021		CA,CE,TH							
		R/V strata	0.068	0.72	0.033	3.71	GN,GU,EM			2.08				
Closed Area II (Far North)	1999	north of 42	0.459	0.61				0.49	0.57		0.937		0.805	
Area II All	1998	F/V strata			0.024		CA,CE,TH							
		R/V strata	0.043	0.54	0.030	0.09	GN,GU,EM			1.45				
Hudson Canyon Closed Area	1999	R/V strata	0.0259	0.21	0.026		CR			1.00				
	2000	R/V strata	0.078	0.24	0.075	0.1	AA			1.04				
Virginia Beach Closed Area	1999	F/V strata			0.036		CR							
		R/V strata	0.06	0.21	0.043	0.25				1.40				
	2000	F/V strata			0.022		AA							
		R/V strata	0.064	0.39	0.045	0.26				1.42				
	1	2	3	4	5.000	6	7	8	9					
Column	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Computation										C/E	C/H	E/H	C/I	E/I

Commercial Fishing Vessel Names: CA = Christian Alexa, CE= Celtic, TH= Thor, GN= Good News, GU= Guidance, EM=Eileen Marie, KM= Kathy Marie, SM = Santa Maria, CR=Courageous, AA= Alice Amanc

Table B5-17. Summary of Patch model efficiency estimates for depletion experiments conducted in Closed Area I and Nantucket Lightship in 1999 in which the density estimates were constrained to equal those derived from SMAST photographic survey.
Size range of scallops restricted to >90 mm.

					Efficiency Estimates						
Fishing Vessel	Location	Code	Photo Estimate of Density /m^2 (SE)	Fixed Level of Gamma	Mean Efficiency	Lower Limit	Upper Limit	- Log Likelihood Value	Density Constraint	Uncon-strained Density	Comment
Kathy Mari	Area I	km1	0.183	0.5	0.896	0.65	>1	255.23	Y		
			(0.86)	0.75	0.654	0.46	0.9	266.53	Y		
				1	0.513	0.35	0.7	275.65	Y		
				0.5	0.06	--	--	239.6	N	2.53	
				0.75	0.22	--	--	240.3	N	0.893	
Santa Mari	Area I	sm11	0.37	0.5	0.95	0.46	0.9	301.92	Y		efficiency at upper li
			(0.09)	0.75	0.719	0.43	0.95	318.39	Y		
				1	0.556	0.37	0.7	335.36	Y		
				0.5	0.19	0.07	0.35	256.5	N	2.25	
				0.75	0.13	0.05	0.26	256.5	N	3.305	
Santa Mari (with Tow 205)	NLSA	sm21	0.28	0.5	0.577	0.38	0.87	140.46	Y		
			(0.105)	0.75	0.477	0.3	0.67	143.14	Y		
				1	0.378	0.25	0.57	149.39	Y		
				0.5	0.64	0.35	0.9	140.1	N	0.196	
				0.75	0.42	0.25	0.6	145.1	N	0.300	
Santa Mari (without Tow 205)	NLSA	sm21	0.28	0.5	0.638	0.34	0.93	132.65	Y		
			(0.105)	0.75	0.515	0.35	0.709	134.33	Y		
				1	0.4036	0.28	0.55	140.48	Y		
				0.5	0.69	0.4	0.95	132.1	N	0.194	
				0.75	0.46	0.26	0.65	132.1	N	0.291	

Table B6-1 - Ratio of incidental to landed fishing mortality

Dredge Eff.	0.2	0.4	0.6	0.8
Caddy (1973)	0.6-0.8	0.23-0.3	0.1-0.13	0.04-0.05
Murawski and Serchuk (1989)	< 0.2	< 0.075	< 0.033	< 0.012

Table B6-2. Catch-biomass fishing mortality calculations and approximate variance calculations for sea scallop in the Georges Bank stock area. "Mean Meat Weight" is average meat weight per tow for fully recruited scallop (40+ mm, adjusted for survey and commercial dredge selectivity) in NEFSC sea scallop surveys. Survey data for 1989 are almost entirely interpolated. Estimates affected by interpolation are shaded. The CV for mean meat weight is based standard formulas for stratified means with adjustments for borrowed tows and for strata with non-zero catches but only one tow. "Minimum Swept Area Biomass" assumes that the NEFSC scallop dredge is 100% efficient. The CV for mimimum swept area biomass includes an assumed CV for the ratio of stock area and the average area swept by one tow. "F at 100% Efficiency" is the ratio of landings and minimum swept area biomass. The CV for F at 100% efficiency includes an assumed CV for landings data.

Assumed CV for Stock Area/Area Swept	5%
Assumed CV for Landings Data	20%

Calendar Year	Landings (MT)	Fully recruited survey bms (g/tow)	CV	Minimum Swept Area Biomss (MT)	CV	F at 20% Efficiency (y^{-1})	F at 40% Efficiency (y^{-1})	F at 60% Efficiency (y^{-1})	F at 80% Efficiency (y^{-1})	F at 100% Efficiency (y^{-1})	CV
1982	6,322	592	12%	3,275	13%	0.39	0.77	1.16	1.54	1.93	24%
1983	4,284	615	14%	3,400	15%	0.25	0.50	0.76	1.01	1.26	25%
1984	3,043	479	10%	2,646	11%	0.23	0.46	0.69	0.92	1.15	23%
1985	2,894	603	15%	3,332	16%	0.17	0.35	0.52	0.69	0.87	26%
1986	4,438	646	10%	3,573	11%	0.25	0.50	0.75	0.99	1.24	23%
1987	4,851	842	13%	4,659	14%	0.21	0.42	0.62	0.83	1.04	24%
1988	6,054	684	10%	3,781	11%	0.32	0.64	0.96	1.28	1.60	23%
1989	5,661	688	32%	3,806	33%	0.30	0.59	0.89	1.19	1.49	38%
1990	9,982	859	22%	4,753	22%	0.42	0.84	1.26	1.68	2.10	30%
1991	9,311	712	10%	3,937	11%	0.47	0.95	1.42	1.89	2.37	23%
1992	8,238	851	17%	4,709	17%	0.35	0.70	1.05	1.40	1.75	26%
1993	3,655	329	10%	1,817	11%	0.40	0.80	1.21	1.61	2.01	23%
1994	1,137	389	12%	2,149	13%	0.11	0.21	0.32	0.42	0.53	24%
1995	982	482	14%	2,667	15%	0.07	0.15	0.22	0.29	0.37	25%
1996	2,045	1,213	22%	6,708	23%	0.06	0.12	0.18	0.24	0.30	30%
1997	2,326	1,709	19%	9,451	19%	0.05	0.10	0.15	0.20	0.25	28%
1998	2,064	4,479	38%	24,768	38%	0.02	0.03	0.05	0.07	0.08	43%
1999	5,151	4,197	26%	23,208	27%	0.04	0.09	0.13	0.18	0.22	33%
1982-1994 avg	**5,375**	**638**	**5%**	**3,526**	**5%**	**0.30**	**0.59**	**0.89**	**1.19**	**1.49**	**8%**
1995-1999 avg	**2,479**	**2,232**	**16%**	**12,344**	**16%**	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**14%**
1982-1999 avg	**4,570**	**1,081**	**9%**	**5,975**	**10%**	**0.23**	**0.46**	**0.69**	**0.91**	**1.14**	**7%**

Table B6-3. Catch-biomass fishing mortality calculations and approximate variance calculations for sea scallop in the Mid-Atlantic Bight stock area. "Mean Meat Weight" is average meat weight per tow for fully recruited scallop (40+ mm, adjusted for survey and commercial dredge selectivity) in NEFSC sea scallop surveys. The CV for mean meat weight is based standard formulas for stratified means with adjustments for borrowed tows and for strata with non-zero catches but only one tow. "Minimum Swept Area Biomass" assumes that the NEFSC scallop dredge is 100% efficient. The CV for mimimum swept area biomass includes an assumed CV for the ratio of stock area and the average area swept by one tow. "F at 100% Efficiency" is the ratio of landings and minimum swept area biomass. The CV for F at 100% efficiency includes an assumed CV for landings data.

Assumed CV for Stock Area/Area Swept	5%
Assumed CV for Landings Data	20%

Calendar Year	Landings (MT)	Fully recruited survey bms (g/tow)	CV	Minimum Swept Area Biomss (MT)	CV	F at 20% Efficiency (y^{-1})	F at 40% Efficiency (y^{-1})	F at 60% Efficiency (y^{-1})	F at 80% Efficiency (y^{-1})	F at 100% Efficiency (y^{-1})	CV
1982	1,610	446	7%	2,834	9%	0.11	0.23	0.34	0.45	0.57	22%
1983	3,109	418	8%	2,655	9%	0.23	0.47	0.70	0.94	1.17	22%
1984	3,675	409	9%	2,598	10%	0.28	0.57	0.85	1.13	1.41	22%
1985	3,276	530	7%	3,365	9%	0.19	0.39	0.58	0.78	0.97	22%
1986	3,359	869	7%	5,516	9%	0.12	0.24	0.37	0.49	0.61	22%
1987	7,803	761	6%	4,834	8%	0.32	0.65	0.97	1.29	1.61	22%
1988	6,178	1,428	7%	9,068	9%	0.14	0.27	0.41	0.55	0.68	22%
1989	7,973	1,073	7%	6,814	8%	0.23	0.47	0.70	0.94	1.17	22%
1990	6,435	967	10%	6,141	11%	0.21	0.42	0.63	0.84	1.05	23%
1991	7,011	791	11%	5,022	12%	0.28	0.56	0.84	1.12	1.40	23%
1992	4,955	476	7%	3,022	9%	0.33	0.66	0.98	1.31	1.64	22%
1993	2,778	367	6%	2,333	8%	0.24	0.48	0.71	0.95	1.19	22%
1994	5,872	724	8%	4,598	9%	0.26	0.51	0.77	1.02	1.28	22%
1995	6,318	984	8%	6,249	10%	0.20	0.40	0.61	0.81	1.01	22%
1996	4,999	662	7%	4,201	8%	0.24	0.48	0.71	0.95	1.19	22%
1997	2,910	469	5%	2,977	7%	0.20	0.39	0.59	0.78	0.98	21%
1998	2,778	599	13%	3,803	14%	0.15	0.29	0.44	0.58	0.73	25%
1999	4,489	1,549	15%	9,831	16%	0.09	0.18	0.27	0.37	0.46	25%
82-94 avg	**4,926**	**712**	**2%**	**4,523**	**3%**	**0.23**	**0.45**	**0.68**	**0.91**	**1.13**	**6%**
95-99 avg	**4,299**	**863**	**6%**	**5,480**	**7%**	**0.17**	**0.35**	**0.52**	**0.69**	**0.87**	**10%**
82-99 avg	**4,752**	**754**	**3%**	**4,789**	**3%**	**0.21**	**0.42**	**0.64**	**0.85**	**1.06**	**5%**

Table B6-4. Survey-based fishing mortality estimates for sea scallop 80+ mm in the Georges Bank stock area during survey years 1982-1999 with approximate averages for calendar years 1982-1994, 1995-1999 and 1994-2000. R_t is abundance (number per tow) of scallops 80-99.9 mm shell height and P_t is abundance of scallops 100+ mm shell height. Abundance estimates from survey data include adjustments for survey dredge selectivity. Survey data for the Georges Bank stock area during 1989 are almost entirely interpolated. Sections of the table affected by interpolated data in 1989 are shaded. Survey years start in the middle of calendar years. Average F during calendar years 1982-1994 was approximated as a weighted average of F estimates for 1982-1987 and 1990-1994 with weight=0.5 for survey years 1994 and weight=1 for other survey years. Average F during calendar years 1995-1999 was approximated as a weighted aveage of F estimates with weight=0.5 for survey years 1994 and 1999 and weight=1 for other survey years. Average F for calendar years 1982-1999 used weight=0.5 for 1999, weight=0 for survey years and weight=1 for other survey years.

Survey Year	R_t (80-99.9 mm shell height)	CV	P_t 100+ mm shell height)	CV	F (y^{-1})	CV	3-Year Ave. F (y^{-1})	CV	5-Year Average F (y^{-1})	CV
1982	15.06	26%	12.05	11%	0.73	26%				
1983	21.62	28%	11.98	11%	1.04	20%				
1984	10.40	20%	10.87	10%	0.42	65%	0.73	18%		
1985	17.95	19%	12.76	26%	0.64	29%	0.70	19%		
1986	15.21	15%	14.80	10%	0.62	26%	0.56	22%	0.69	13%
1987	36.52	18%	14.69	13%	1.30	13%	0.85	12%	0.80	11%
1988	27.69	13%	12.63	11%	1.29	14%	1.07	9%	0.85	10%
1989	35.29	56%	10.10	15%	1.55	28%	1.38	12%	1.08	10%
1990	53.29	31%	8.86	10%	1.53	18%	1.46	12%	1.26	9%
1991	27.40	14%	12.22	11%	1.15	12%	1.41	13%	1.36	9%
1992	31.97	15%	11.41	9%	1.70	10%	1.46	8%	1.44	8%
1993	8.89	12%	7.17	12%	0.69	19%	1.18	7%	1.32	9%
1994	16.16	25%	7.34	10%	0.54	40%	0.98	10%	1.12	8%
1995	11.62	19%	12.53	13%	-0.18	157%	0.35	36%	0.78	11%
1996	43.27	27%	26.39	27%	0.22	122%	0.19	77%	0.60	17%
1997	28.22	20%	50.60	19%	-0.32	128%	-0.09	205%	0.19	65%
1998	66.19	41%	98.33	40%	0.34	112%	0.08	255%	0.12	119%
1999	61.38	18%	106.57	26%	-0.05	777%	-0.01	2114%	0.00	7383%
2000	132.22	25%	159.94	36%						
Ave. Cal. Years 82-94	**23.51**	**8%**	**11.40**	**4%**	**1.03**	**4%**				
Ave. Cal. Years 95-99	**57.15**	**14%**	**75.73**	**17%**	**0.06**	**234%**				
Ave. Cal. Years 82-99	**34.72**	**8%**	**32.84**	**13%**	**0.76**	**8%**				

Table B6-5. Survey-based fishing mortality estimates for sea scallop 80+ mm in the Mid-Atlantic Bight stock area during survey years 1982-1999 with approximate averages for calendar years 1982-1994, 1995-1999 and 1994-2000. Rt is abundance (number per tow) of scallops 80-98.49 mm shell height and Pt is abundance of scallops 98.5 mm shell height. Abundance estimates from survey data include adjustments for survey dredge selectivity. Survey years start in the middle of calendar years. Average F during calendar years 1982-1994 was approximated as a weighted average of F estimates for 1982-1994 with weight=0.5 for survey years 1982 and 1994 and weight=1 for other survey years. Similarly, average F during calendar years 1995-1999 was approximated as a weighted aveage of F estimates with weight=0.5 for survey years 1994 and 1999 and weight=1 for other survey years. Average F for calendar years 1982-1999 used weight=0.5 for 1982 and 1999, and weight=1 for other survey years.

Survey Year	R_t (80-98.49 mm shell height)	CV	P_t 98.5+ mm shell height)	CV	F (y^{-1})	CV	3-Year Average F (y^{-1})	CV	5-Year Average F (y^{-1})	CV
1982	10.86	15%	10.50	8%	0.55	24%				
1983	6.48	12%	11.28	10%	0.66	15%				
1984	15.92	16%	8.36	7%	0.60	23%	0.60	12%		
1985	17.09	10%	12.16	9%	0.50	23%	0.58	12%		
1986	39.95	12%	16.19	9%	1.31	8%	0.80	9%	0.72	7%
1987	40.36	8%	13.70	7%	0.64	14%	0.82	8%	0.74	7%
1988	70.11	11%	25.73	6%	1.65	7%	1.20	5%	0.94	5%
1989	54.99	9%	16.60	7%	1.72	6%	1.34	4%	1.16	4%
1990	49.21	10%	11.65	6%	1.27	15%	1.55	5%	1.32	4%
1991	34.11	11%	15.52	18%	1.39	9%	1.46	6%	1.34	4%
1992	15.99	11%	11.19	8%	1.15	9%	1.27	7%	1.44	4%
1993	13.08	9%	7.81	7%	0.89	14%	1.14	6%	1.28	5%
1994	45.04	10%	7.81	10%	1.27	9%	1.10	6%	1.19	5%
1995	51.06	9%	13.41	7%	1.75	6%	1.30	5%	1.29	4%
1996	38.56	9%	10.15	8%	1.19	8%	1.41	4%	1.25	4%
1997	12.39	9%	13.38	6%	0.76	13%	1.24	5%	1.17	4%
1998	27.19	25%	10.92	8%	0.35	59%	0.77	11%	1.07	5%
1999	83.77	19%	24.37	11%	0.34	56%	0.49	21%	0.88	8%
2000	153.66	16%	69.69	12%						
Ave. Cal. Years 82-94	**31.78**	**3%**	**12.96**	**3%**	**1.04**	**3%**				
Ave. Cal. Years 95-99	**42.59**	**9%**	**14.44**	**5%**	**0.97**	**6%**				
Ave. Cal. Years 82-99	**34.79**	**4%**	**13.37**	**2%**	**1.02**	**3%**				

Table B6-6a. Survey-based fishing mortality estimates for sea scallop 75+ mm in the Georges Bank stock area assuming faster growth than in Table B6-4 (K = 0.38).

Year	75-100	100+	F	3yr avg	5 yr avg
1982	22.15	12.06	0.95		
1983	27.67	11.99	1.20		
1984	12.82	10.86	0.52	0.89	
1985	23.71	12.77	0.80	0.84	
1986	21.76	14.79	0.81	0.71	0.86
1987	48.09	14.70	1.50	1.04	0.97
1988	37.08	12.62	1.49	1.27	1.03
1989	50.22	10.10	1.82	1.61	1.29
1990	78.40	8.84	1.87	1.73	1.50
1991	42.25	12.22	1.46	1.72	1.63
1992	62.31	11.41	2.23	1.85	1.77
1993	13.67	7.17	0.94	1.55	1.66
1994	19.76	7.34	0.67	1.28	1.43
1995	15.53	12.54	-0.04	0.53	1.05
1996	53.98	26.39	0.36	0.33	0.83
1997	32.74	50.58	-0.26	0.02	0.34
1998	78.10	98.12	0.40	0.17	0.23
1999	74.78	106.52	0.03	0.06	0.10
2000	212.53	159.91			
avg 82-94	**35.38**	**11.30**	**1.27**		
avg 95-00	**77.95**	**75.68**	**0.15**		
avg 82-00	**48.82**	**31.63**	**0.93**		

Table B6-6b. Survey-based fishing mortality estimates for sea scallop 80+ mm in the Mid-Atlantic stock area assuming slower growth than in Table B6-5 (K = 0.23).

Year	80-95 sh	95+ sh	F	3yr avg	5 yr avg
1982	9.75	12.11	0.47		
1983	5.22	12.36	0.49		
1984	13.51	9.76	0.39	0.45	
1985	14.71	14.19	0.26	0.38	
1986	36.22	20.09	1.02	0.56	0.53
1987	35.29	18.39	0.44	0.57	0.52
1988	63.08	31.40	1.38	0.95	0.70
1989	48.90	21.49	1.42	1.08	0.90
1990	45.65	15.41	1.10	1.30	1.07
1991	31.56	18.46	1.21	1.24	1.11
1992	13.49	13.54	0.96	1.09	1.21
1993	11.40	9.35	0.71	0.96	1.08
1994	43.30	9.27	0.97	0.88	0.99
1995	45.95	17.99	1.44	1.04	1.06
1996	36.36	13.77	1.07	1.16	1.03
1997	10.18	15.54	0.56	1.02	0.95
1998	26.37	13.29	0.03	0.55	0.81
1999	75.99	34.96	0.13	0.24	0.64
2000	134.67	88.16			
avg 82-94	**28.62**	**15.83**	**0.83**		
avg 95-00	**54.92**	**30.62**	**0.73**		
avg 82-00	**36.93**	**20.50**	**0.78**		

Table B6-7. Scaled catch-biomass fishing mortality estimates. Scaling factors are based on implied efficiencies, or on survey dredge efficiency estimates from field studies. Implied efficiencies were estimated from ratios of average catch-biomass F (i.e. average catch/minimum swept area biomass) and average survey based F. "Split Series" rescaled catch-biomass F's used different implied efficiencies for 1982-1994 and 1995-1999. "No Split" rescaled catch-biomass F's used a single implied efficiency for 1982-1999. "Field Estimates" are based on the field study efficiency estimate.

	Value	CV
Efficiency Estimate from Field Studies	0.5	30%
Implied Efficiency 1982-1994	0.69	8%
Implied Efficiency 1995-1999	0.25	235%
Implied Efficiency 1982-1999	0.66	11%

Calendar or Survey Year	Catch-Based F (Catch / Minimum Swept Area Biomass)	CV	Survey-Based F	CV	Rescaled Catch-Biomass F (Split Series)	CV	Rescaled Catch-Biomass F (No Split)	CV	Catch-Biomass F w/ Field Estimate of Eff	CV
1982	1.93	24%	0.72	26%	1.45	25%	1.23	7%	0.97	38%
1983	1.26	25%	1.03	20%	0.95	26%	0.80	7%	0.63	39%
1984	1.15	23%	0.41	65%	0.86	24%	0.73	6%	0.57	38%
1985	0.87	26%	0.63	29%	0.65	27%	0.55	8%	0.43	39%
1986	1.24	23%	0.61	26%	0.93	24%	0.79	6%	0.62	38%
1987	1.04	24%	1.30	13%	0.78	26%	0.66	7%	0.52	39%
1988	1.60	23%	1.28	14%	1.20	24%	1.02	6%	0.80	38%
1989	1.49	38%	1.54	28%	1.12	39%	0.95	16%	0.74	49%
1990	2.10	30%	1.53	18%	1.58	31%	1.34	10%	1.05	42%
1991	2.37	23%	1.15	12%	1.78	24%	1.51	6%	1.18	38%
1992	1.75	26%	1.70	10%	1.31	28%	1.11	8%	0.87	40%
1993	2.01	23%	0.68	19%	1.51	24%	1.28	6%	1.01	38%
1994	0.53	24%	0.53	40%	0.40	25%	0.34	7%	0.26	38%
1995	0.37	25%	-0.19	157%	0.09	236%	0.23	7%	0.18	39%
1996	0.30	30%	0.22	122%	0.07	236%	0.19	10%	0.15	43%
1997	0.25	28%	-0.32	128%	0.06	236%	0.16	9%	0.12	41%
1998	0.08	43%	0.33	112%	0.02	238%	0.05	20%	0.04	52%
1999	0.22	33%	-0.05	777%	0.05	237%	0.14	12%	0.11	45%

	Weighted Averages from Tables B6-2 and B6-4:				Simple Averages Computed in This Table:					
Avg 1982-1994	1.49	8%	1.03	4%	1.12	8%	0.95	2%	0.74	12%
Avg 1995-1999	0.25	14%	0.06	234%	0.06	113%	0.16	5%	0.12	20%
Avg 1982-1999	1.14	7%	0.76	8%	0.82	6%	0.73	2%	0.57	8%

Table B6-8. Scaled catch-biomass fishing mortality estimates. Scaling factors are based on implied efficiencies, or on survey dredge efficiency estimates from field studies. Implied efficiencies were estimated from ratios of average catch-biomass F (i.e. average catch/minimum swept area biomass) and average survey based F. "Split Series" rescaled catch-biomass F's used different implied efficiencies for 1982-1994 and 1995-1999. "No Split" rescaled catch-biomass F's used a single implied efficiency for 1982-1999. "Field Estimates" are based on the field study efficiency estimates.

	Value	
Efficiency Estimate from Field Studies		30%
Implied Efficiency 1982-1994	0.91	7%
Implied Efficiency 1995-1999	1.12	12%
Implied Efficiency 1982-1999	0.96	6%

Calendar or Survey Year	Catch-Based F (Catch / Minimum Swept Area Biomass)	CV	Survey-Based F	CV	Rescaled Catch-Biomass F (Split Series)	CV	Rescaled Catch-Biomass F (No Split)	CV	Catch-Biomass F w/ Field Estimate of Eff	CV
1982	0.57	22%	0.54	24%	0.52	23%	0.54	5%	0.40	37%
1983	1.17	22%	0.65	15%	1.07	23%	1.10	5%	0.82	37%
1984	1.41	22%	0.59	23%	1.29	23%	1.33	5%	0.99	37%
1985	0.97	22%	0.49	23%	0.89	23%	0.92	5%	0.68	37%
1986	0.61	22%	1.31	8%	0.55	23%	0.57	5%	0.43	37%
1987	1.61	22%	0.64	14%	1.47	23%	1.52	5%	1.13	37%
1988	0.68	22%	1.65	7%	0.62	23%	0.64	5%	0.48	37%
1989	1.17	22%	1.72	6%	1.07	23%	1.10	5%	0.82	37%
1990	1.05	23%	1.27	15%	0.95	24%	0.99	6%	0.73	38%
1991	1.40	23%	1.39	9%	1.27	25%	1.31	6%	0.98	38%
1992	1.64	22%	1.15	9%	1.49	23%	1.54	5%	1.15	37%
1993	1.19	22%	0.88	14%	1.08	23%	1.12	5%	0.83	37%
1994	1.28	22%	1.27	9%	1.16	23%	1.20	5%	0.89	37%
1995	1.01	22%	1.75	6%	1.12	23%	0.95	5%	0.71	37%
1996	1.19	22%	1.19	8%	1.32	22%	1.12	5%	0.83	37%
1997	0.98	21%	0.76	13%	1.09	22%	0.92	5%	0.68	37%
1998	0.73	25%	0.35	59%	0.81	25%	0.69	6%	0.51	39%
1999	0.46	25%	0.34	56%	0.51	26%	0.43	7%	0.32	39%
	Weighted Averages from Tables B6-2 and B6-4:				Simple Averages Computed in This Table:					
Avg 1982-1994	1.13	6%	1.04	3%	1.03	7%	1.07	2%	0.79	11%
Avg 1995-1999	0.87	10%	0.97	6%	0.97	11%	0.82	3%	0.61	17%
Avg 1982-1999	1.06	5%	1.02	3%	1.02	6%	1.00	1%	0.74	9%

Table B6-9a - Georges Bank Open Area Catch-Biomass Fishing Mortality Estimates

Year	Landings (MT)	Expl Bms (g/tow)	Min swept bms (MT)	F 20% eff	F 40% eff	F 60% eff	F 80% eff	F 100% eff
1995	982	455	1357	0.14	0.29	0.43	0.58	0.72
1996	2045	712	2123	0.19	0.39	0.58	0.77	0.96
1997	2326	1056	3147	0.15	0.30	0.44	0.59	0.74
1998	2064	522	1556	0.27	0.53	0.80	1.06	1.33
1999	2261	1301	3878	0.12	0.23	0.35	0.47	0.58
Average	**1936**	**809**	**2412**	**0.17**	**0.35**	**0.52**	**0.69**	**0.87**

Table B6-9b. Mid-Atlantic Open Area Catch-Biomass Fishing Mortality Estimates

Year	Landings (MT)	Landings Adj (MT)	Expl Bms (g/tow)	Min swept bms (MT)	F 20% eff	F 40% eff	F 60% eff	F 80% eff	F 100% eff
1995	6318	5054	762	3915	0.26	0.52	0.77	1.03	1.29
1996	4999	4000	480	2466	0.32	0.65	0.97	1.30	1.62
1997	2910	2328	440	2263	0.21	0.41	0.62	0.82	1.03
1998	2778	2500	394	2026	0.25	0.49	0.74	0.99	1.23
1999	4489	4489	918	4720	0.19	0.38	0.57	0.76	0.95
95-99 Avg	**4299**	**3674**	**599**	**3078**	**0.25**	**0.49**	**0.74**	**0.98**	**1.23**

Table B6-10. Regional Catch-Biomass Fishing Mortalities
Based on: 40% dredge efficiency in GB, 60% in MA
No incidental fishing mortality or unreported catch

REGION	*1995*	*1996*	*1997*	*1998*	*1999*	*95-99 Avg*
GB-Open	**0.38**	**0.40**	**0.31**	**0.54**	**0.25**	***0.38***
GB-All	**0.19**	**0.13**	**0.10**	**0.03**	**0.09**	***0.11***
NEP	1.01	0.15	0.07	0.41	0.08	*0.34*
SCh	0.27	0.44	0.57	0.47	0.52	*0.45*
SEP	0.19	0.62	0.60	0.51	0.19	*0.42*
CLII(S)	0.00	0.00	0.00	0.00	0.48	*0.10*
MA-Open	**0.63**	**0.73**	**0.61**	**0.74**	**0.59**	***0.66***
MA-All	**0.63**	**0.73**	**0.61**	**0.48**	**0.29**	***0.55***
NYB	0.70	1.03	0.74	0.53	0.35	*0.67*
Delmarva	0.54	0.50	0.38	1.02	1.21	*0.73*
VA/NC	0.10	0.05	0.18	0.09		*0.11*

Table B6-11 - Open Area Survey Fishing Mortality Estimates

(a) Georges Bank

Year	80-100sh	100+ sh	Survey F	DAS	DAS adjusted	DAS-trend F	Survey year
1995	12.82	10.35					
1996	40.12	8.47	0.91	33490	26792	0.85	95-96
1997	28.34	27.39	0.47	34404	27523	0.88	96-97
1998	26.69	7.92	1.85	30832	26207	0.84	97-98
1999	39.18	26.52	0.17	27208	24348	0.78	98-99
2000	132.49	33.63	0.57	24772	19552	0.62	99-00
Avg 95-00	**46.61**	**19.04**	**0.79**	**30141**	**24884**		

(b) Mid-Atlantic

Year	80-98.5 sh	98.5+ sh	Survey F	DAS	DAS adjusted	DAS-trend F	Survey year
1995	36.21	12.98					
1996	22.72	9.95	1.50	33490	26792	0.75	95-96
1997	9.30	13.29	0.80	34404	27523	0.77	96-97
1998	10.40	9.40	0.78	30832	26207	0.74	97-98
1999	44.54	17.42	0.03	27208	24348	0.68	98-99
2000	97.97	38.08	0.39	24772	19552	0.55	99-00
Avg 95-00	**36.86**	**16.85**	**0.70**	**30141**	**24884**		

Table B6-12. Open Area Rescaled Fishing Effort Mortality Estimate

Year	Mid-Atlantic Catch-Bms F	Mid-Atlantic Rescaled F	Georges Bank Catch-Bms F	Georges Bank Rescaled F
1995	1.06	0.67	0.94	0.79
1996	1.21	0.77	1.00	0.84
1997	1.02	0.65	0.78	0.66
1998	1.23	0.78	1.36	1.14
1999	0.99	0.63	0.62	0.52
Catch-bms 95-99 avg	1.10	0.70	0.94	0.79
Survey-based 95-99 avg	**0.70**		**0.79**	
Efficiency estimate 95-99	0.63		0.84	

Table B7-1 - Length-based YPR Output Runs

Stock	L_{inf}	K	a	b	M	h_d	d	i	a_f	rings	F_{max}	Y_{max}	B_{max}
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0	32	3.5	0.207	17.35	88.33
GB	152.46	0.3374	-11.6038	3.1221	0.1	*65*	*N/A*	0	32	3.5	0.203	17.21	88.85
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	*1*	0	32	3.5	0.201	17.13	89.90
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0	*22*	3.5	0.217	17.25	84.01
GB	152.46	0.3374	-11.6038	3.1221	*0.08/0.16*	75	0.2	0	32	3.5	0.276	16.34	63.77
GB	152.46	0.3374	-11.6038	3.1221	*0.1/0.15*	75	0.2	0	32	3.5	0.269	15.58	62.39
GB	152.46	*0.4*	-11.6038	3.1221	0.1	75	0.2	0	32	3.5	0.218	19.17	92.00
GB	152.46	*0.4*	-11.6038	3.1221	0.1	75	0.2	0	*22*	3.5	0.226	19.22	89.07
GB	*162*	0.3374	-11.6038	3.1221	0.1	75	0.2	0	32	3.5	0.196	20.37	108.02
GB	152.46	0.3374	*-11.4403*	*3.0734*	0.1	75	0.2	0	32	3.5	0.209	16.25	82.04
GB	152.46	0.3374	*-11.7656*	*3.1693*	0.1	75	0.2	0	32	3.5	0.204	18.68	96.22
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0	32	*4*	0.239	18.33	84.94
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.25	32	3.5	0.185	13.32	94.34
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.25	*22*	3.5	0.190	12.95	88.68
GB	152.46	0.3374	-11.6038	3.1221	*0.08/0.16*	75	0.2	0.25	32	3.5	0.241	12.34	68.46
GB	152.46	0.3374	-11.6038	3.1221	*0.1/0.15*	75	0.2	0.25	32	3.5	0.234	11.79	67.15
GB	152.46	*0.4*	-11.6038	3.1221	0.1	75	0.2	0.25	32	3.5	0.197	14.79	97.66
GB	152.46	*0.4*	-11.6038	3.1221	0.1	75	0.2	0.25	*22*	3.5	0.200	14.12	93.17
GB	*162*	0.3374	-11.6038	3.1221	0.1	75	0.2	0.25	32	3.5	0.179	15.63	113.28
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	0.25	32	*4*	0.199	13.63	93.20
GB	152.46	0.3374	-11.6038	3.1221	0.1	75	0.2	*0.15*	32	3.5	0.192	14.71	92.49
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0	32	3.5	0.195	16.62	90.02
MA	151.84	0.2997	-12.2484	3.2641	0.1	*65*	*N/A*	0	32	3.5	0.191	16.47	90.57
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	*1*	0	32	3.5	0.189	16.39	91.71
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0	*22*	3.5	0.207	16.49	84.65
MA	151.84	0.2997	-12.2484	3.2641	*0.08/0.16*	75	0.2	0	32	3.5	0.262	15.76	65.12
MA	151.84	0.2997	-12.2484	3.2641	*0.1/0.15*	75	0.2	0	32	3.5	0.257	14.89	62.83
MA	151.84	*0.23*	-12.2484	3.2641	0.1	75	0.2	0	*22*	3.5	0.199	13.65	74.62
MA	151.84	*0.23*	-12.2484	3.2641	0.1	75	0.2	0	*32*	3.5	0.184	13.81	81.30
MA	151.84	0.2997	*-12.3405*	*3.2754*	0.1	75	0.2	0	32	3.5	0.195	16.01	86.89
MA	151.84	0.2997	*-12.1628*	*3.2539*	0.1	75	0.2	0	32	3.5	0.195	17.23	93.38
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0	32	*4*	0.226	17.61	86.68
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0.05	32	3.5	0.189	15.63	91.57
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	*0.25*	32	3.5	0.174	12.63	95.49
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0.05	*22*	3.5	0.201	15.49	85.86
MA	151.84	0.2997	-12.2484	3.2641	*0.08/0.16*	75	0.2	0.05	32	3.5	0.244	13.97	64.93
MA	151.84	0.2997	-12.2484	3.2641	*0.1/0.15*	75	0.2	0.05	32	3.5	0.249	14.77	67.00
MA	151.84	*0.23*	-12.2484	3.2641	0.1	75	0.2	0.05	32	3.5	0.192	12.80	75.87
MA	151.84	*0.23*	-12.2484	3.2641	0.1	75	0.2	0.05	*22*	3.5	0.193	13.28	78.55
MA	151.84	0.2997	-12.2484	3.2641	0.1	75	0.2	0.05	32	*4*	0.214	16.44	89.24

Figure B3-1. Map of Georges Bank shellfish survey strata. The Georges Bank stock area (the strata in the region that are regularly surveyed) consists of the gray region.

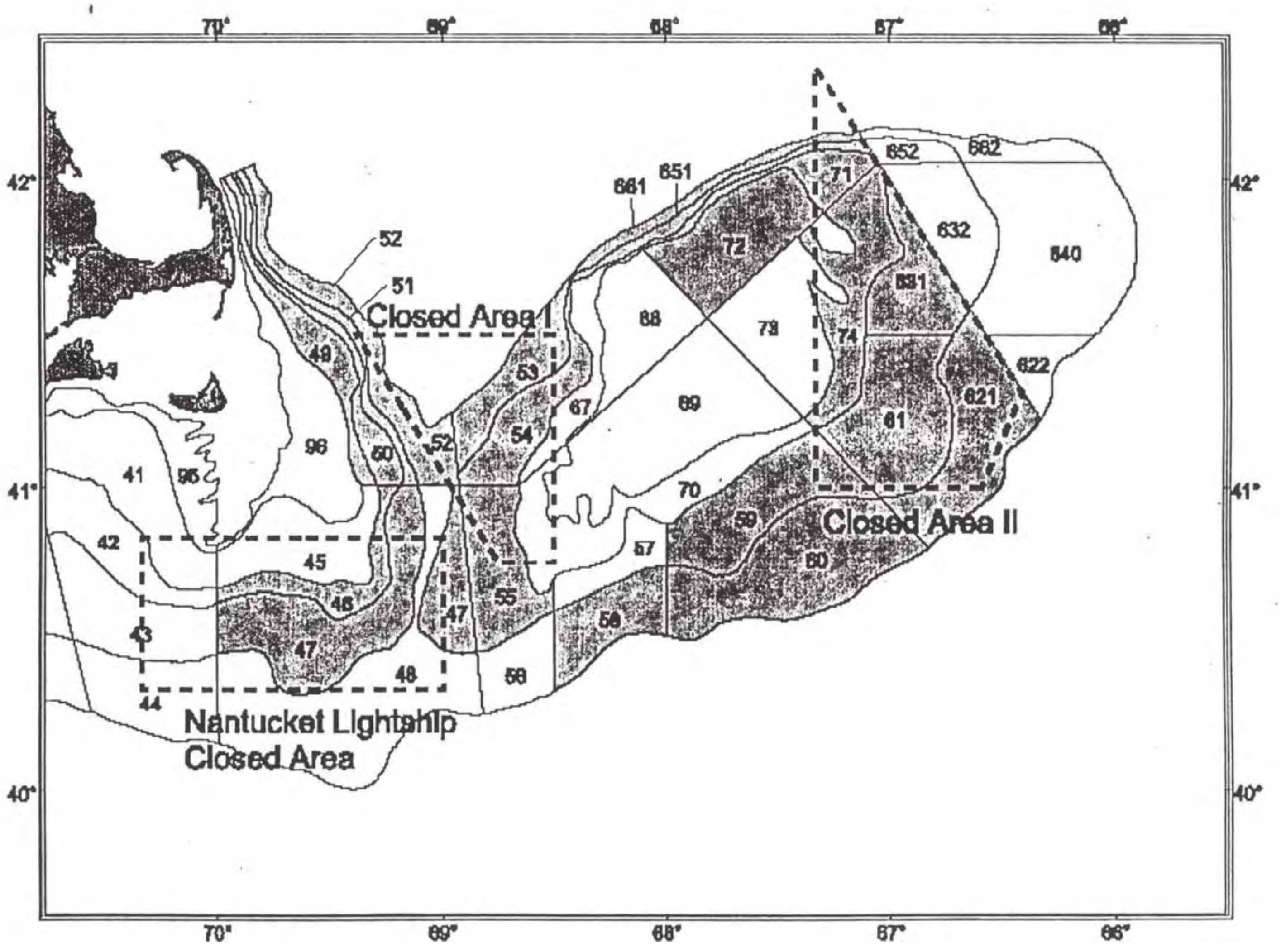


Figure B3-2. Map of Mid-Atlantic shellfish survey strata. The Mid-Atlantic stock area (the strata in the region that are regularly surveyed) consists of the gray region.

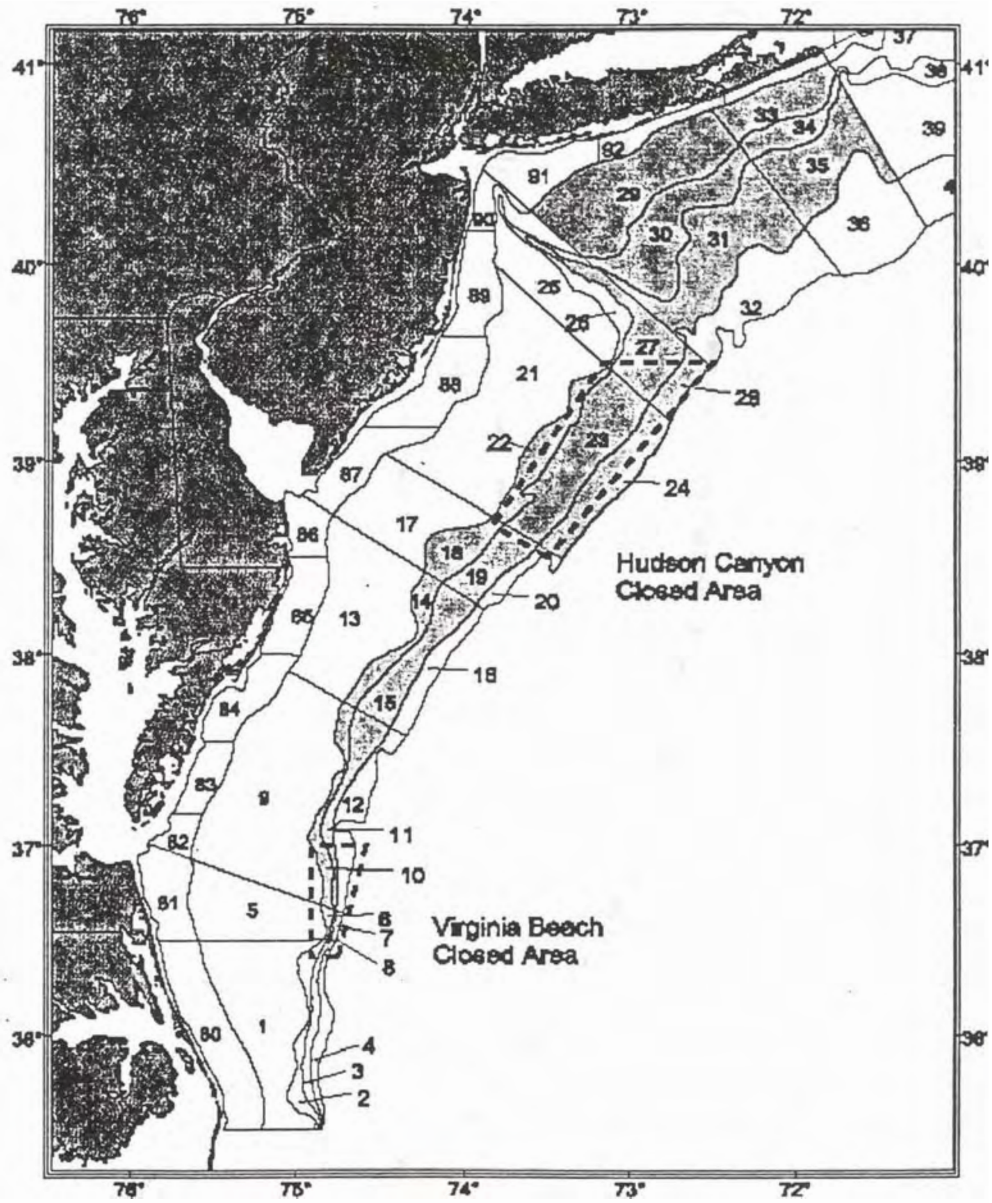


Fig. B3-3. Sea scallop age and growth models.

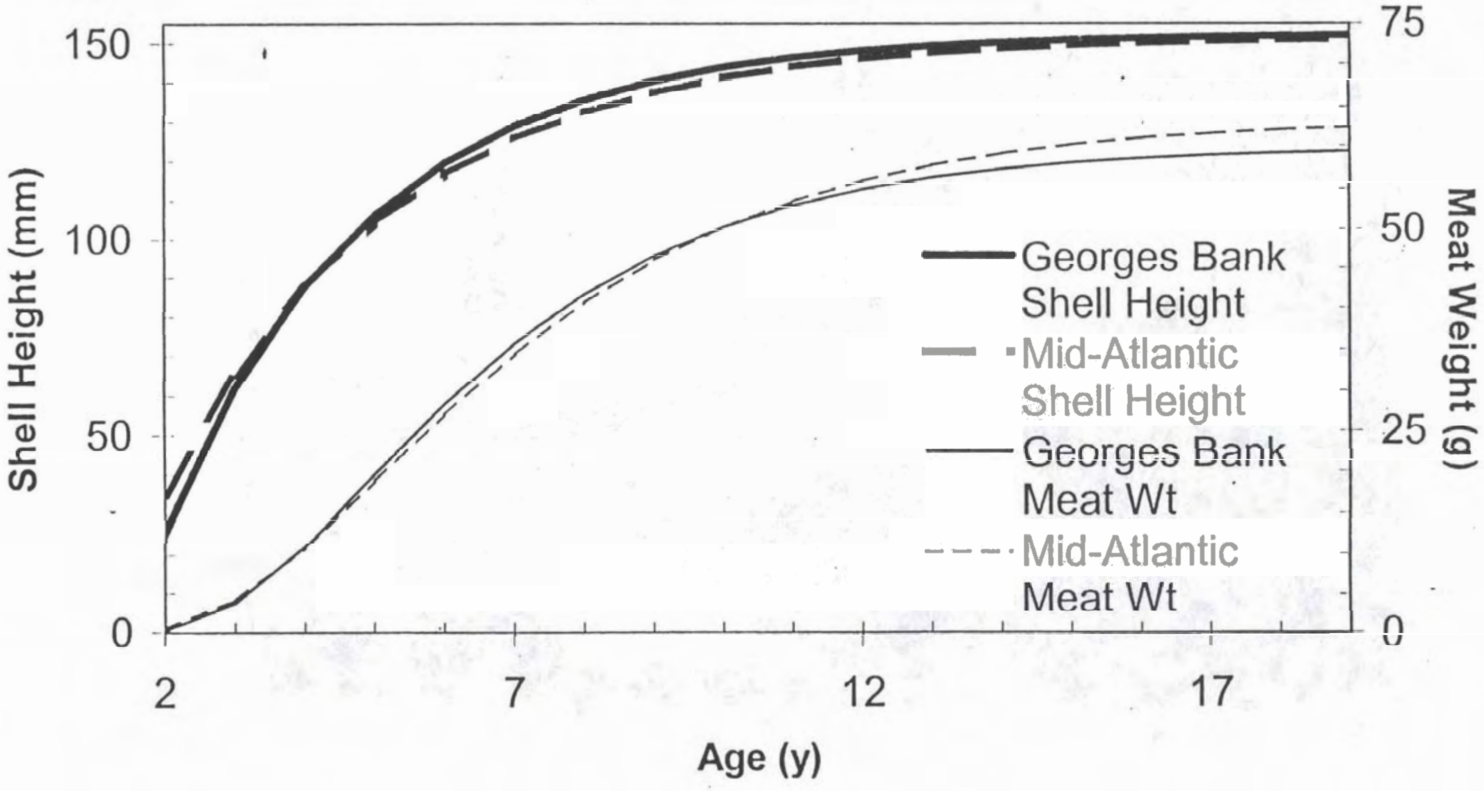


Figure B4-1. History of scallop management and major regulations during 1982-2000. "MPP" means meats per pound.

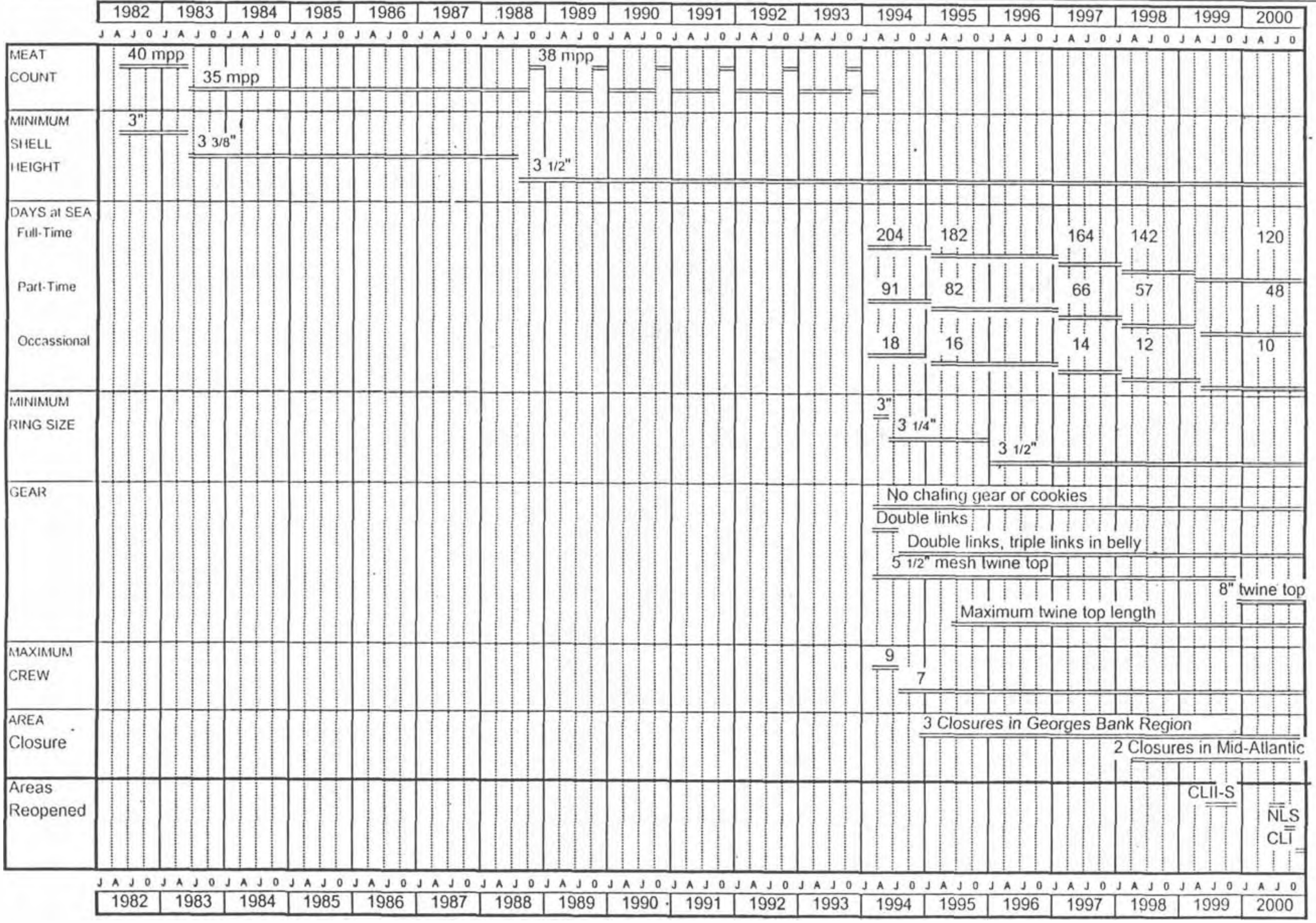


Fig B4-2. US and Canada (Georges Bank only) landings 1887-1999

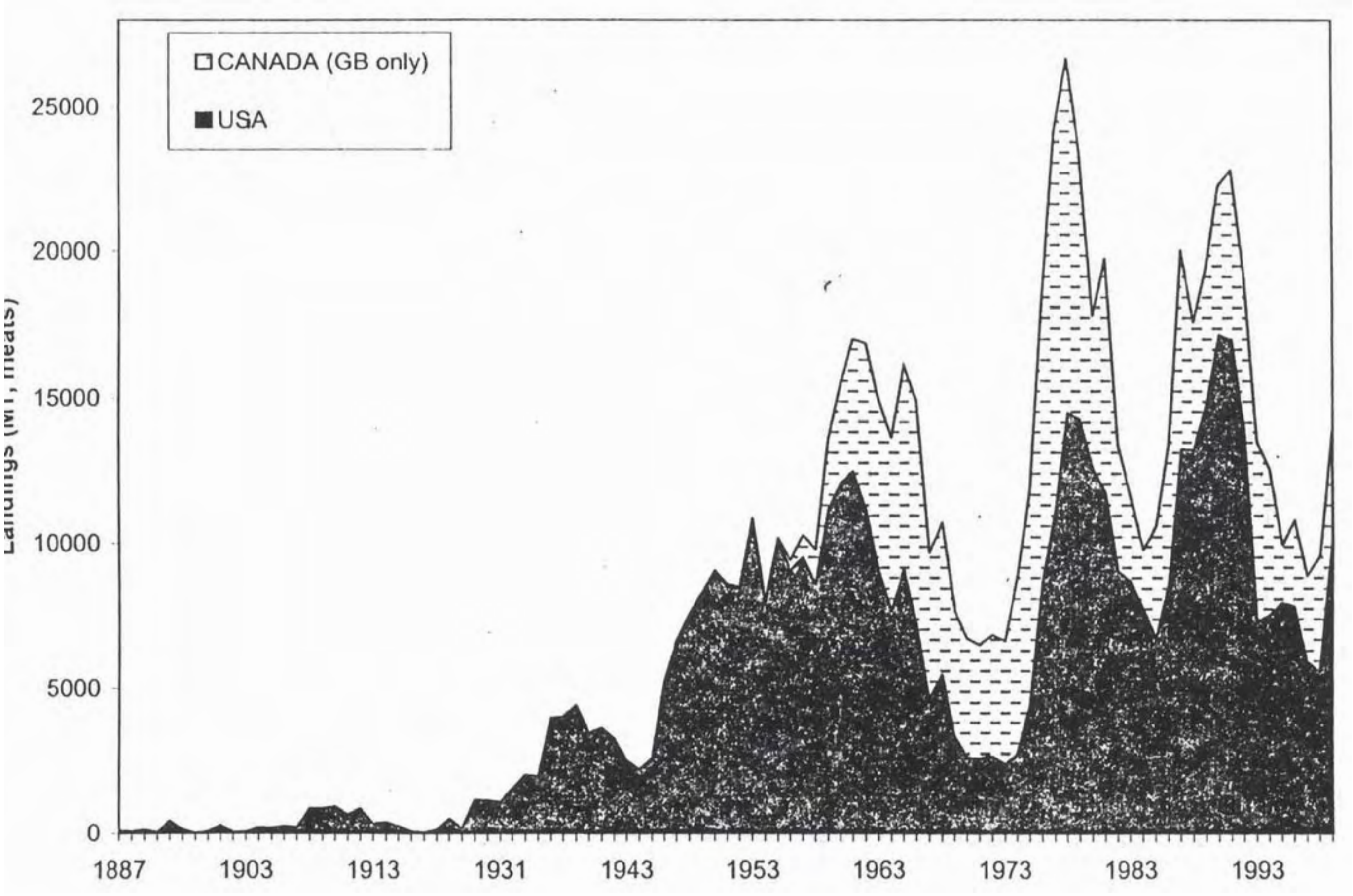


Fig. B4-3. U.S. sea scallop landings by stock area, 1964-1999.

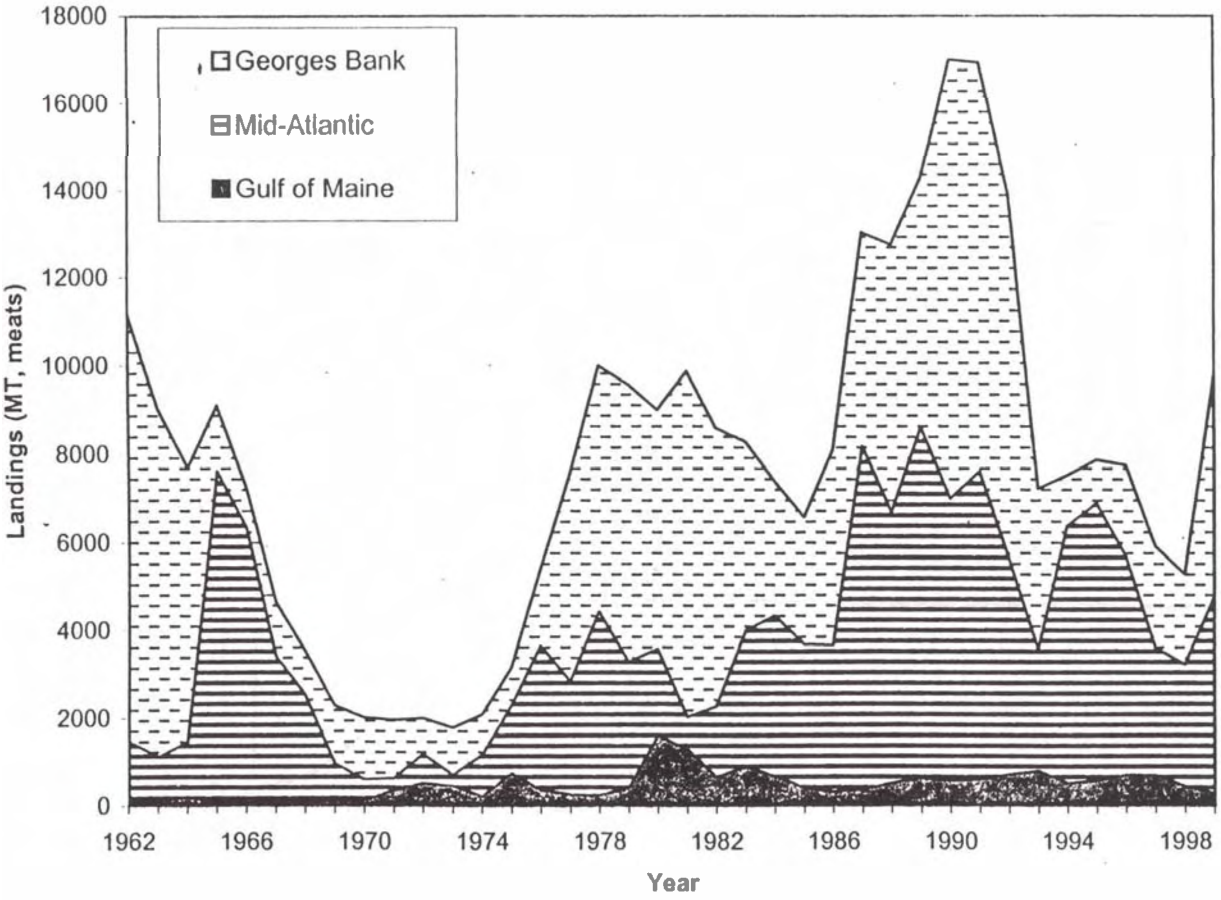


Fig. B5-1. Selectivities of survey and commercial dredges.

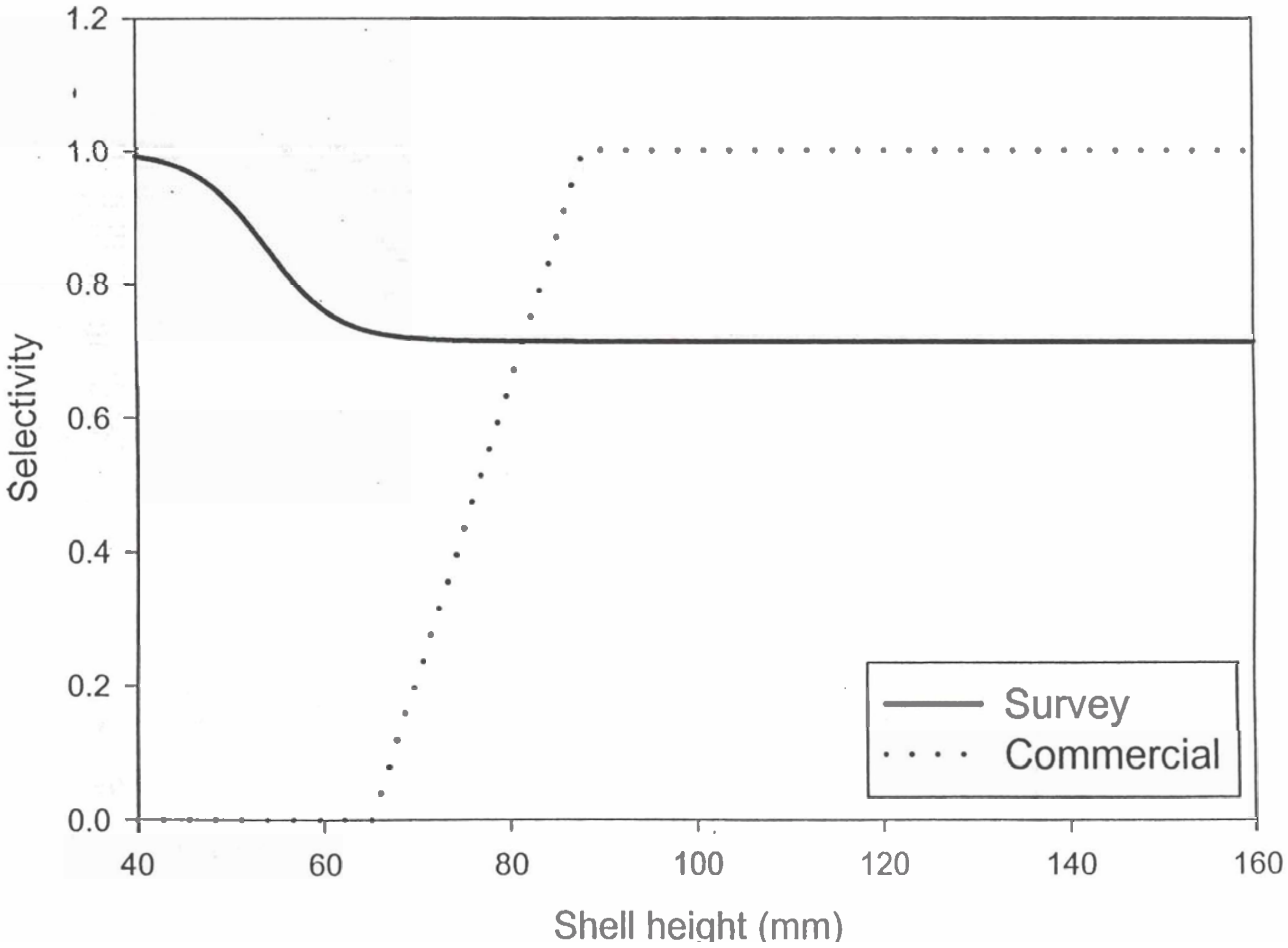


Fig. B5-2. Selectivity of the *F/V Tradition* commercial dredge

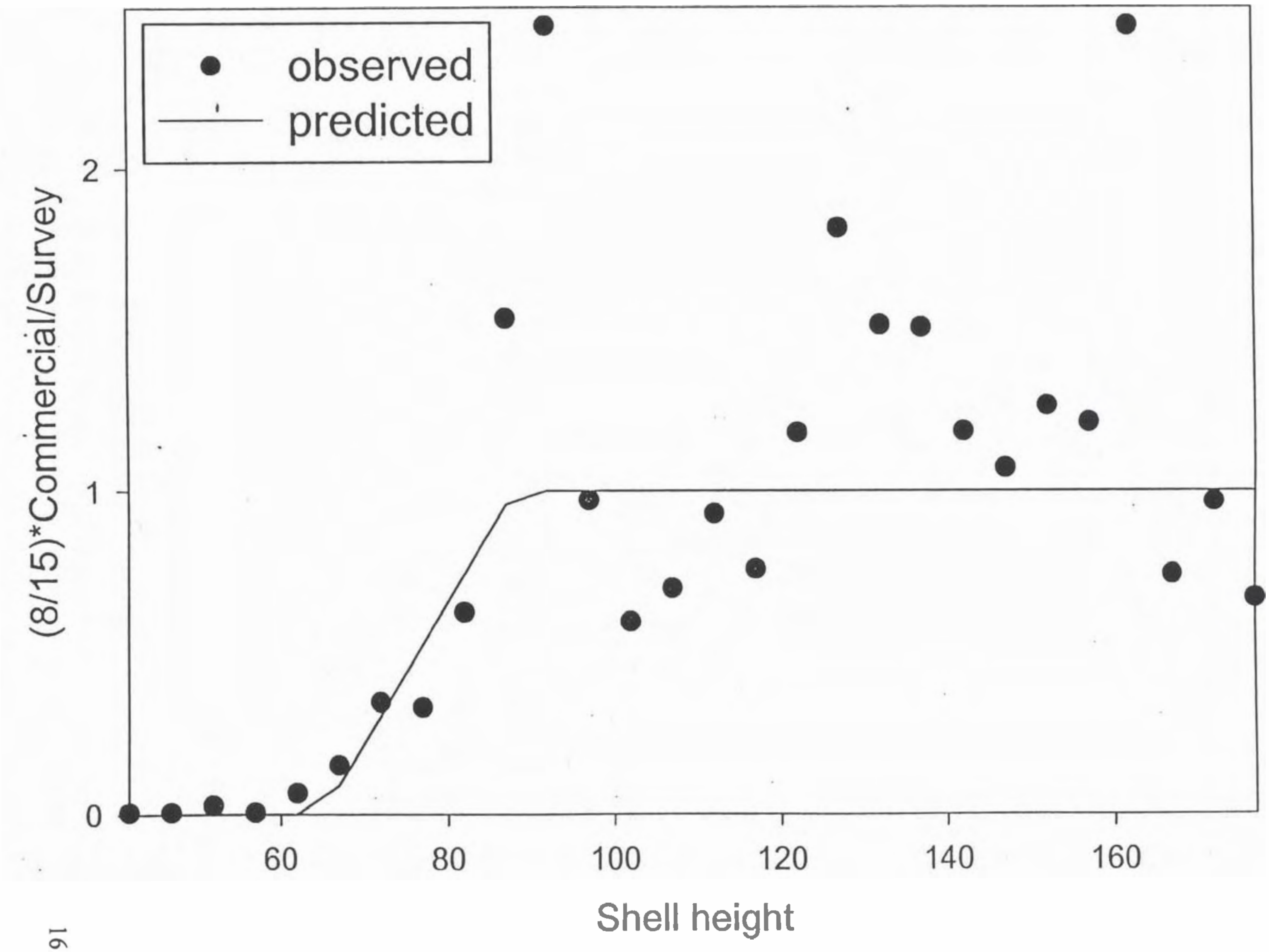


Fig B5-3a. Georges Bank Shell Height/Meat Weight Relationships

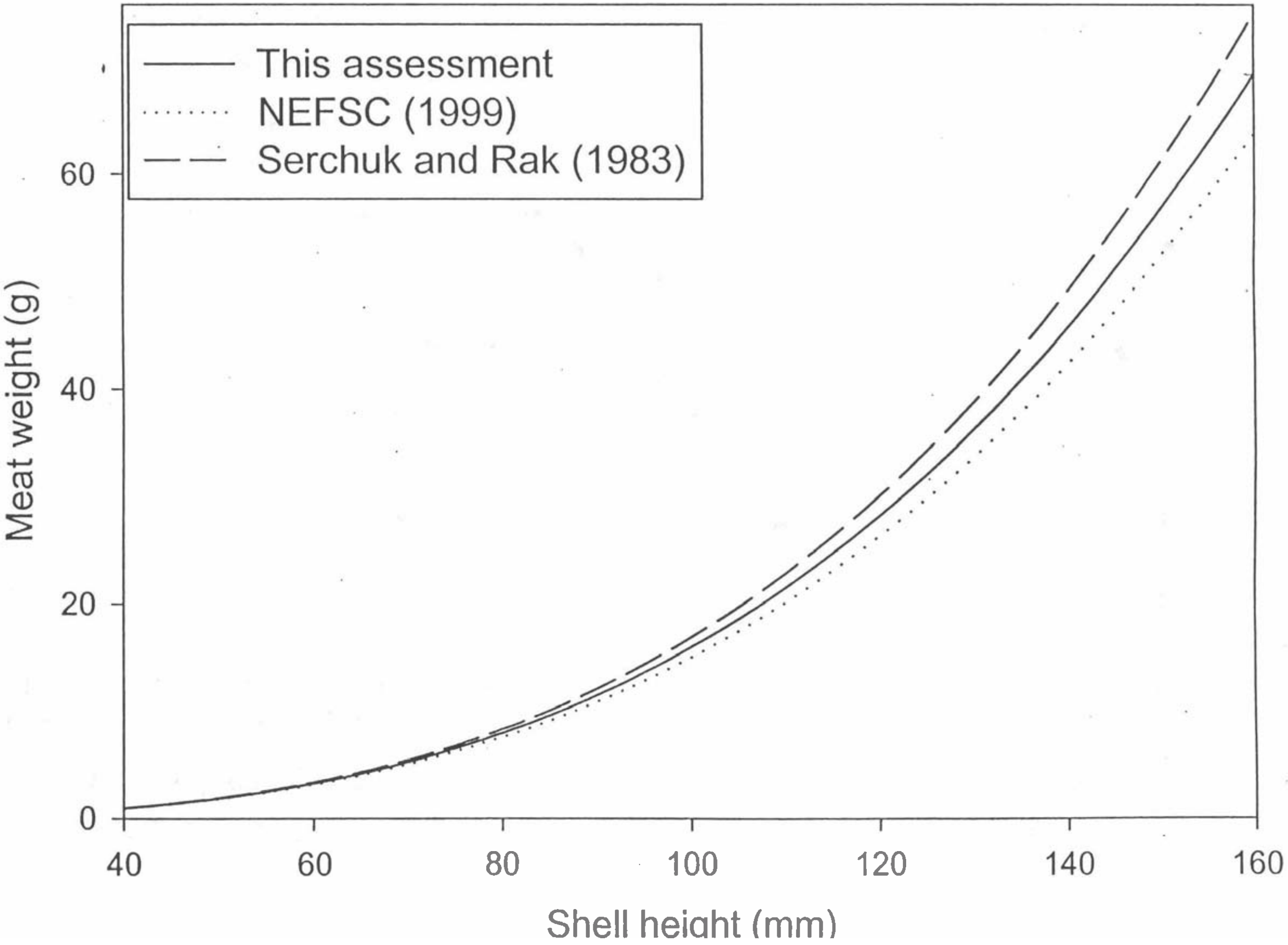
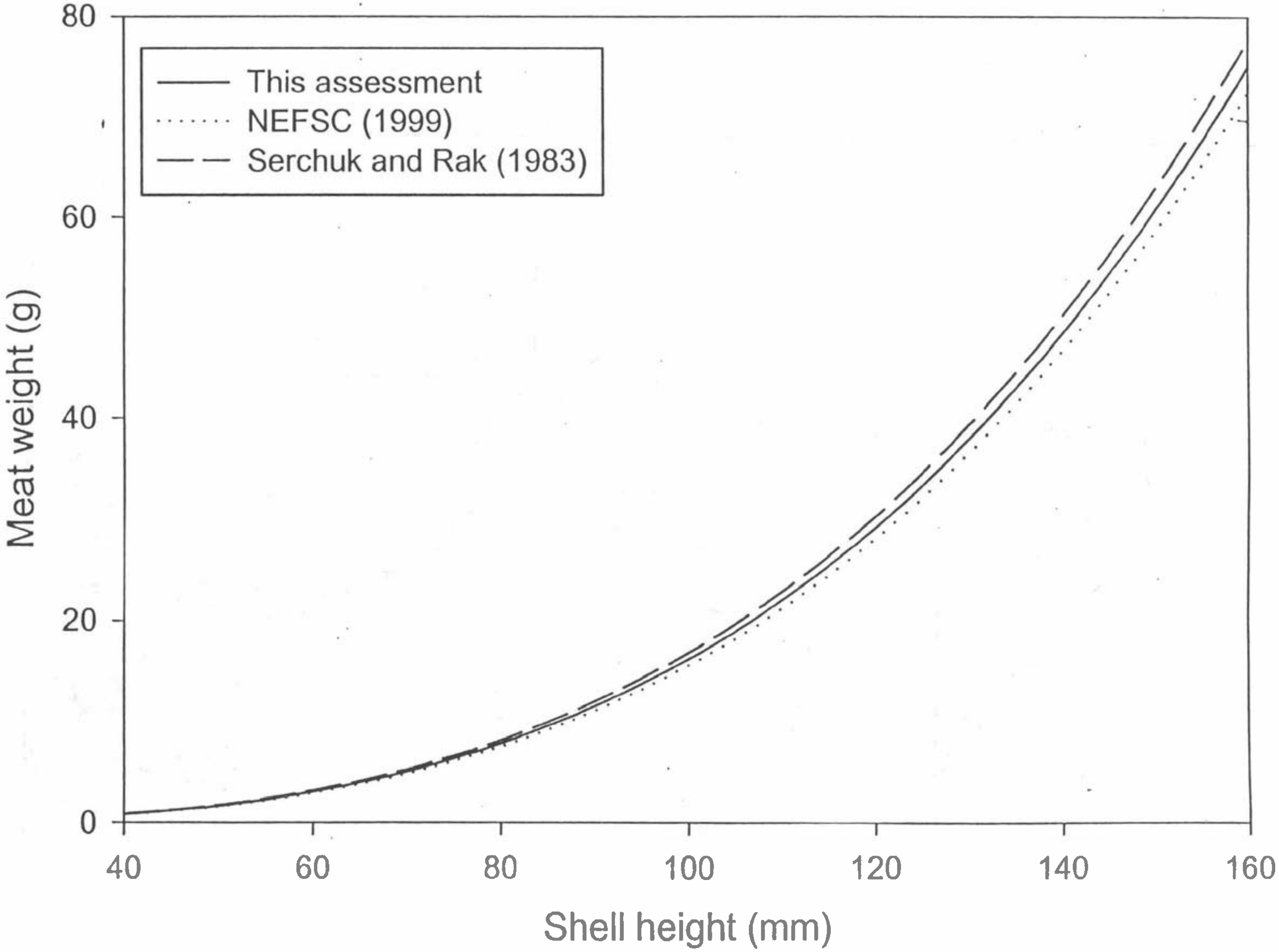
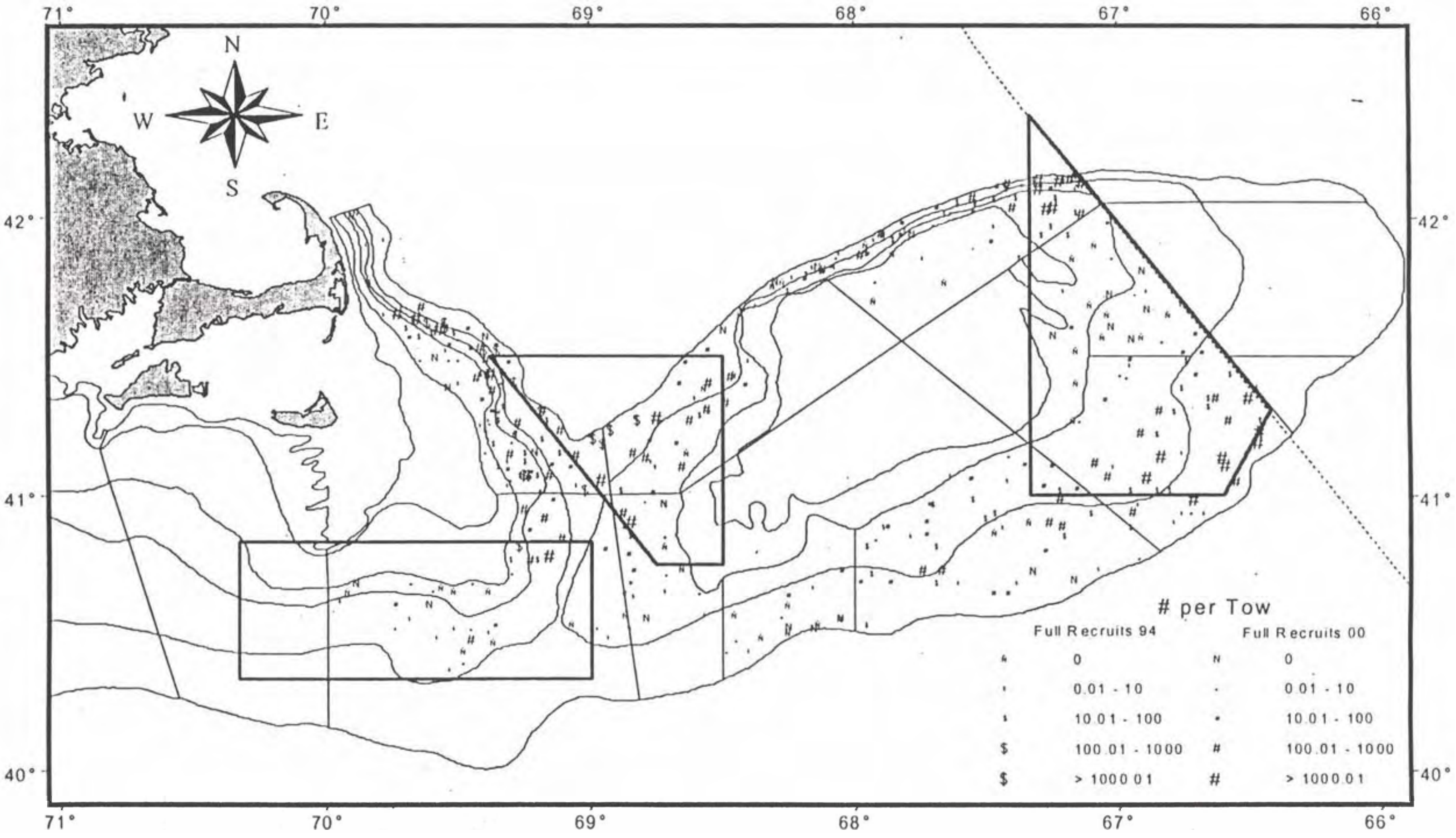


Fig B5-3b. Mid-Atlantic Shell-Height/Meat Weight Relationships



4
ig B5-4. Fully recruited scallop density (per survey tow) on Georges Bank in 1994 and 2000.



ig B5-5. Pre-recruit scallop density (per survey tow) on Georges Bank in 1994 and 2000.

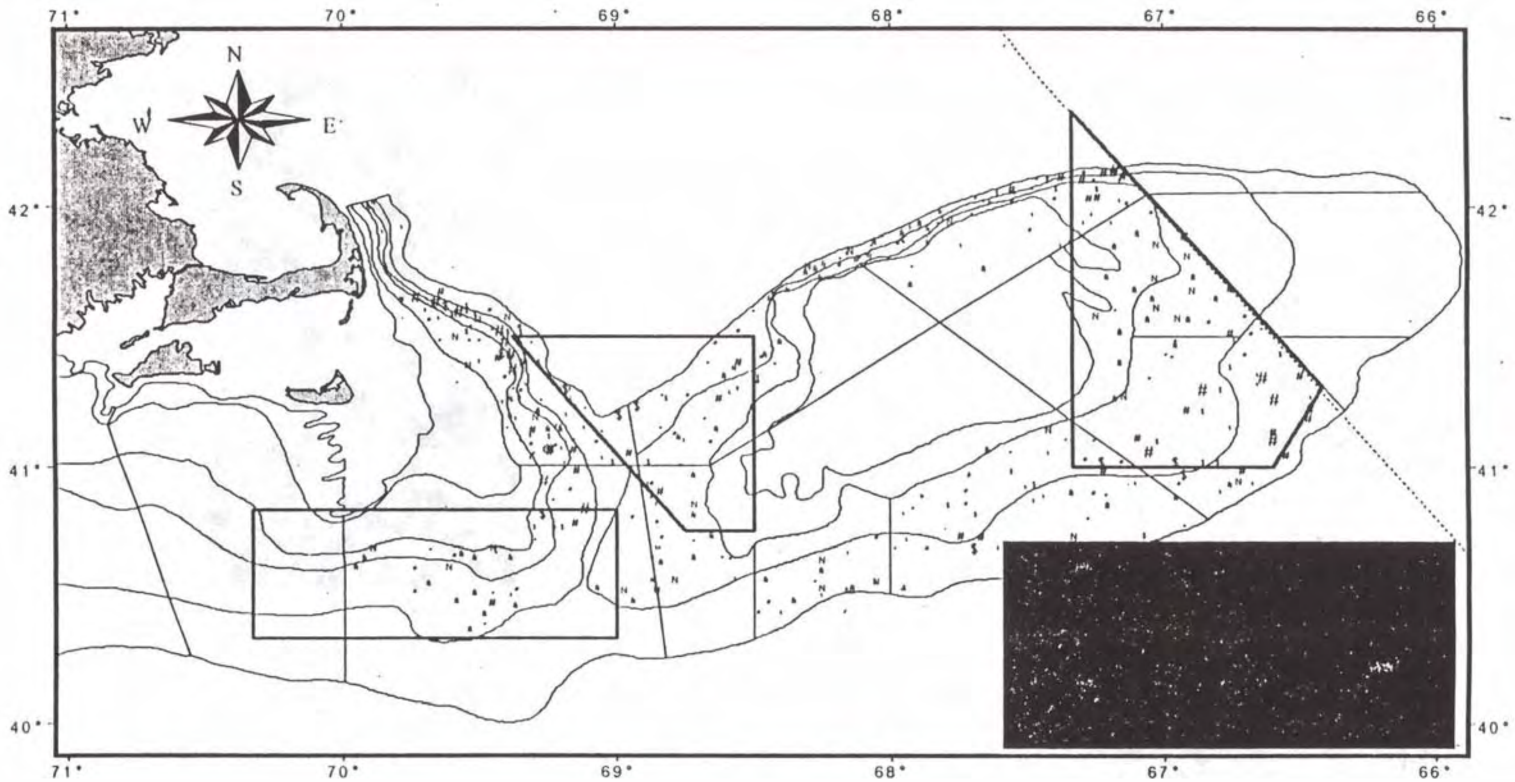


Fig B5-6. Fully recruited scallop density (per survey tow) on the Mid-Atlantic Bi
1994 and 2000.

Fig B5-7. Pre-recruit scallop density (per survey tow) on the Mid-Atlantic Bight in 1994 and 2000.

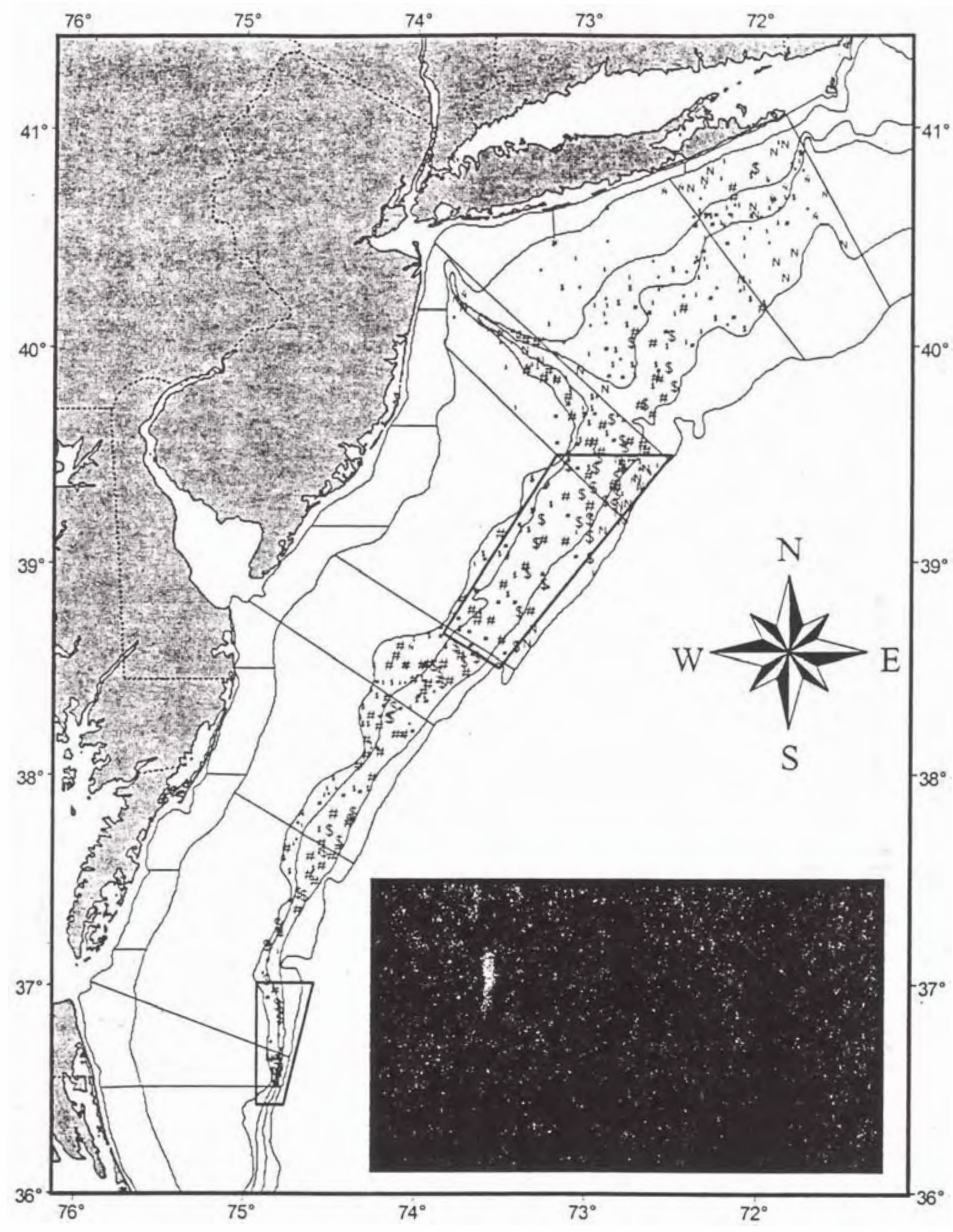


Fig. B5-8. Survey biomass in Georges Bank

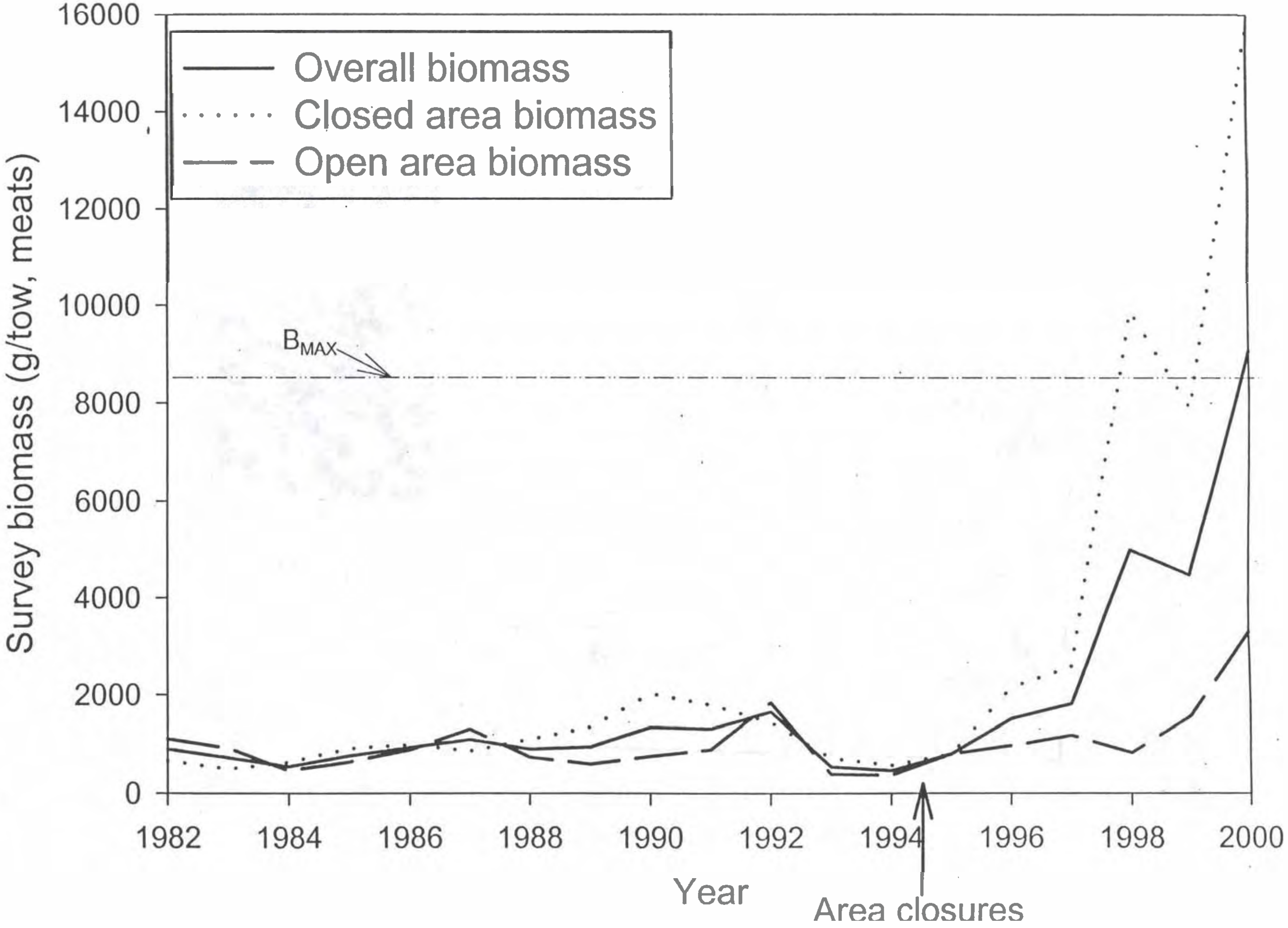


Fig. B5-9. Survey biomass in the Mid-Atlantic Bight.

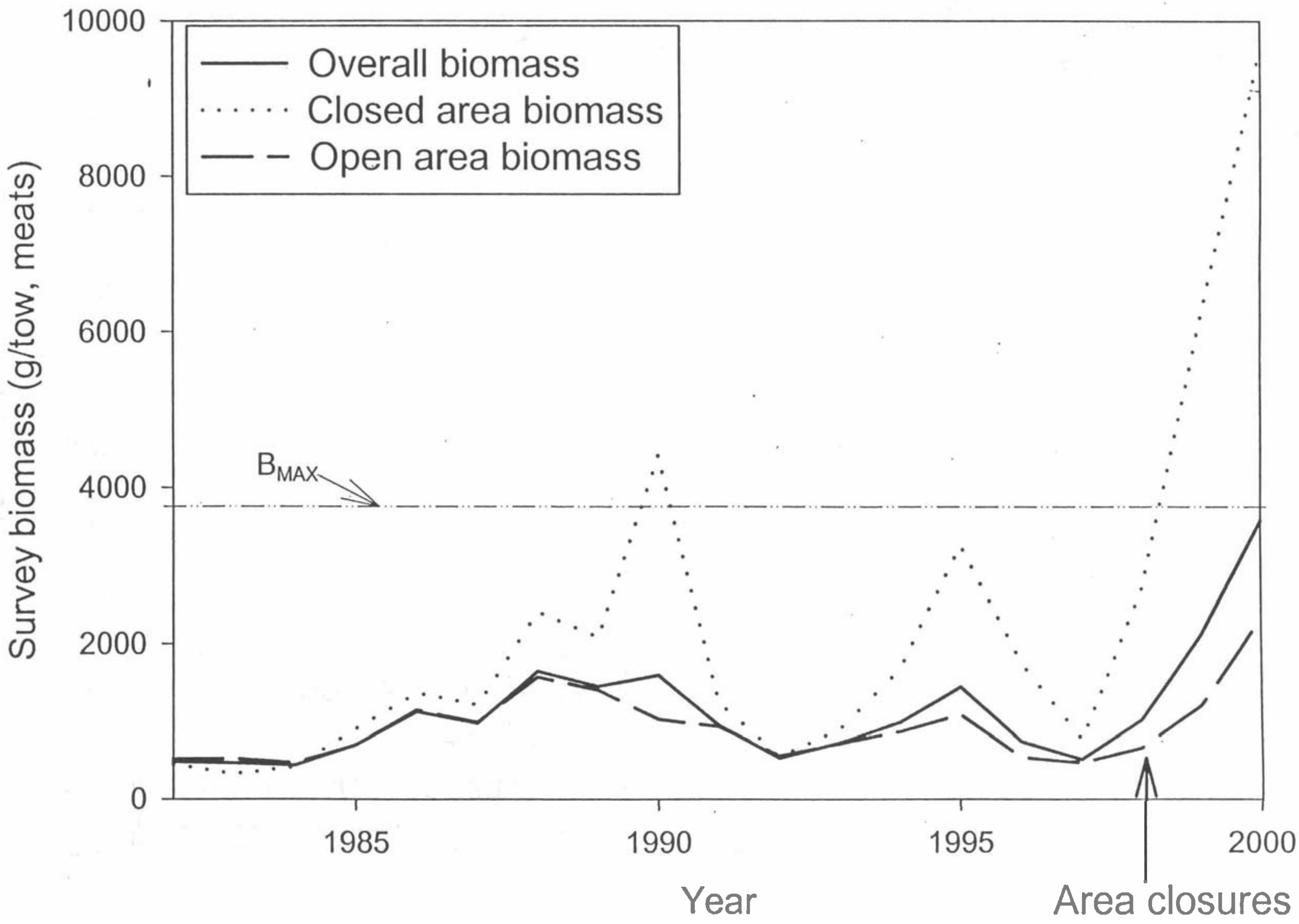


Fig. B5-10. Survey numbers in Georges Bank

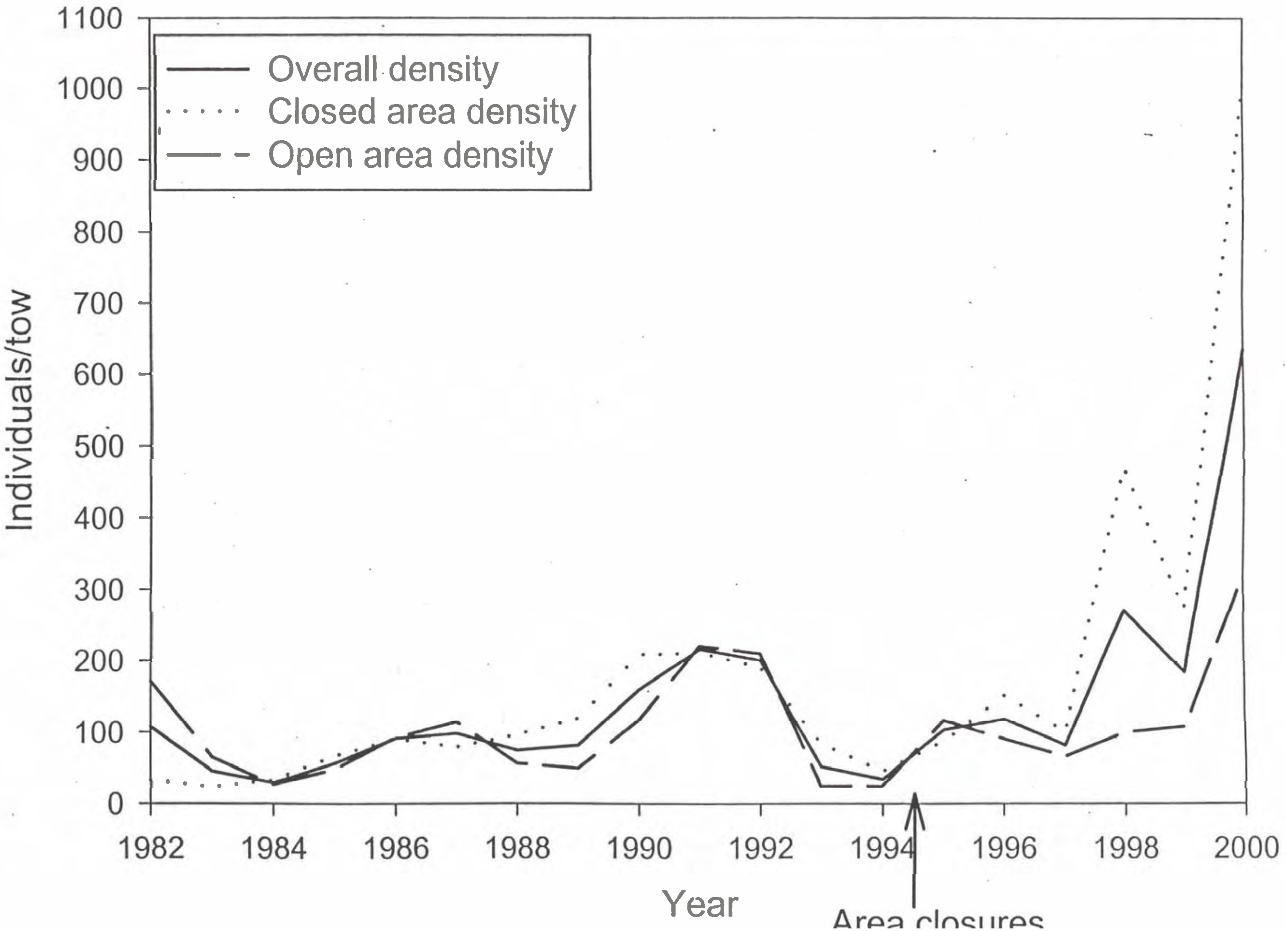


Fig. B5-11. Survey numbers in the Mid-Atlantic Bight.

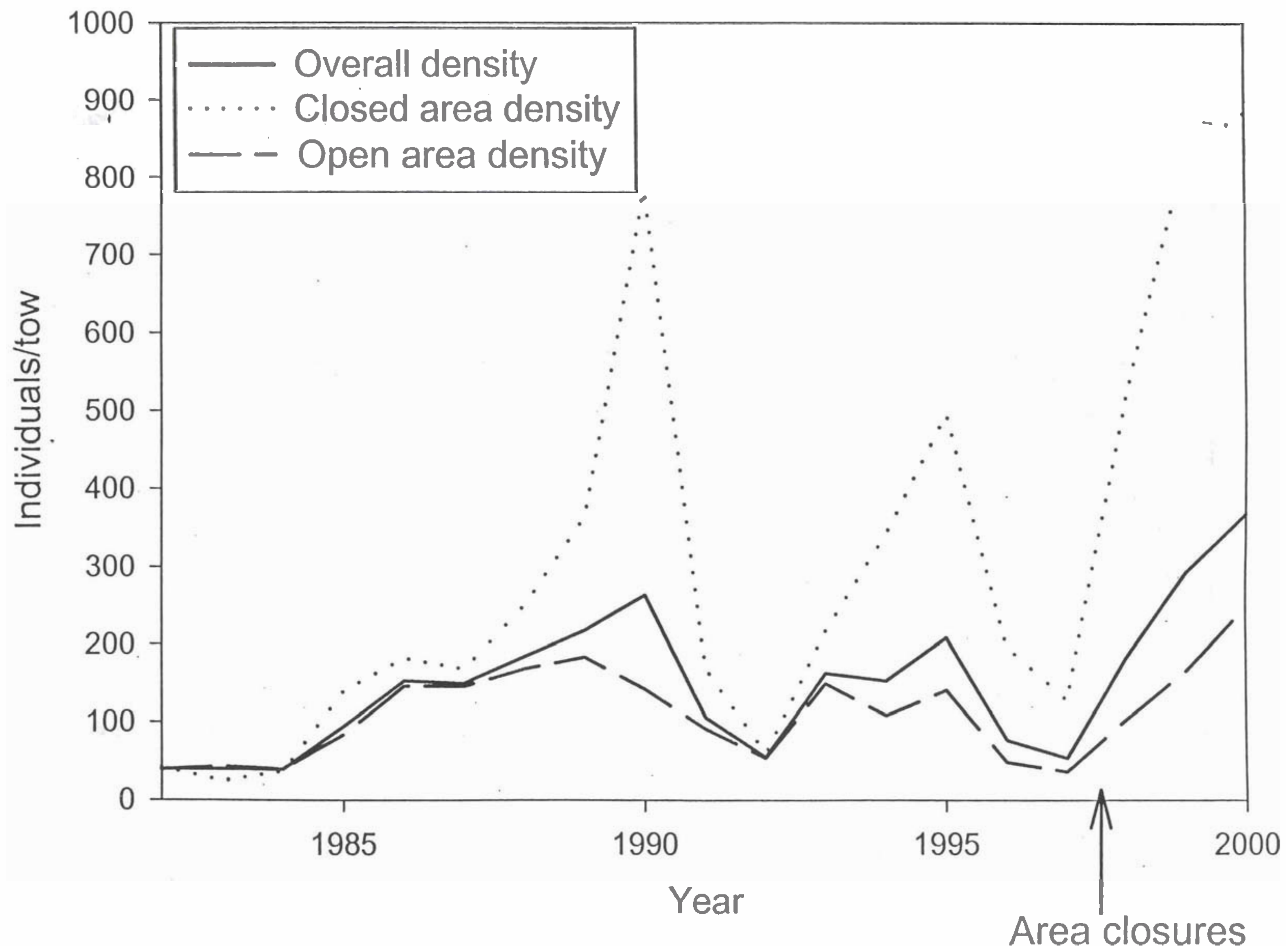


Fig. B5-12. Minimum swept area biomass in Georges Bank

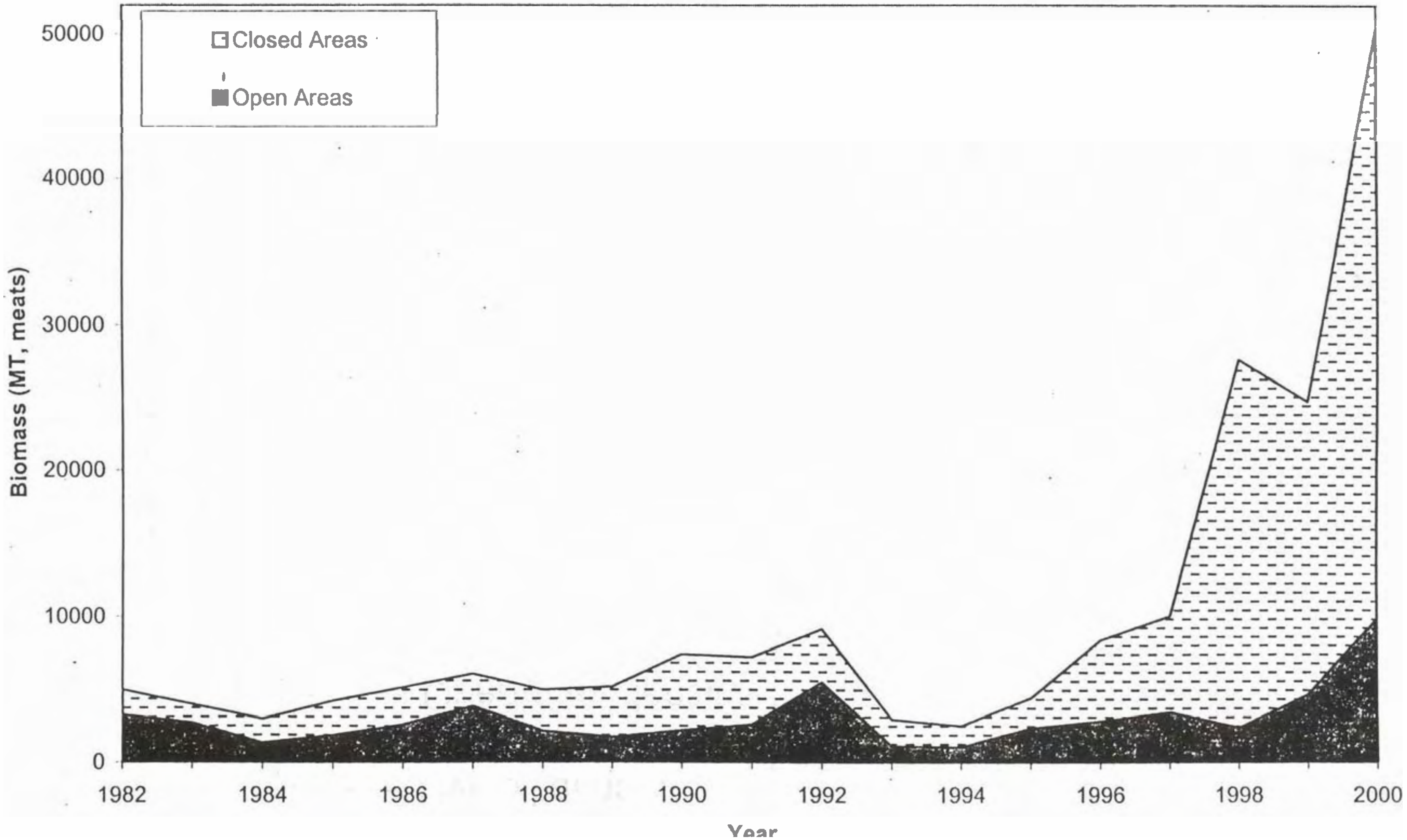


Fig. B5-13. Minimum swept area biomass in the Mid-Atlantic.

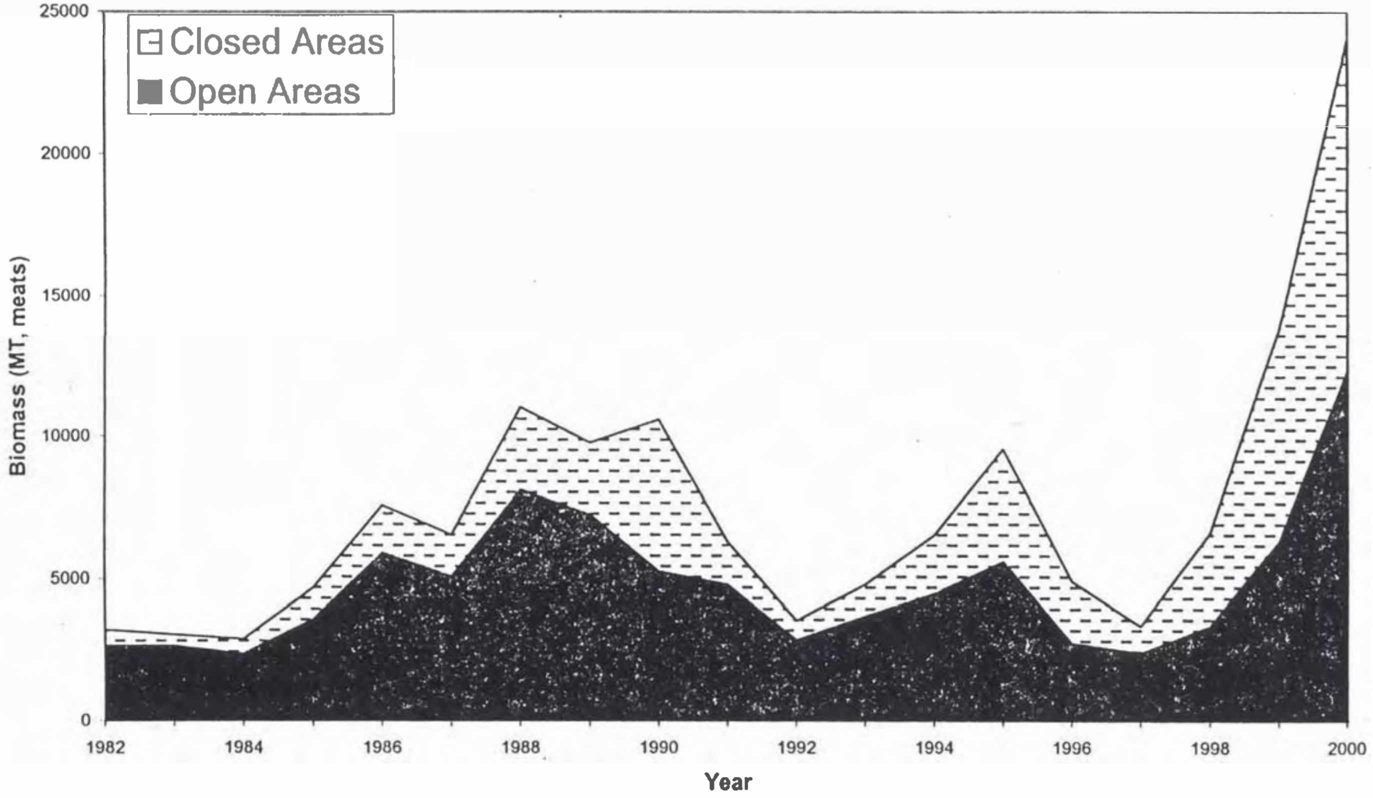
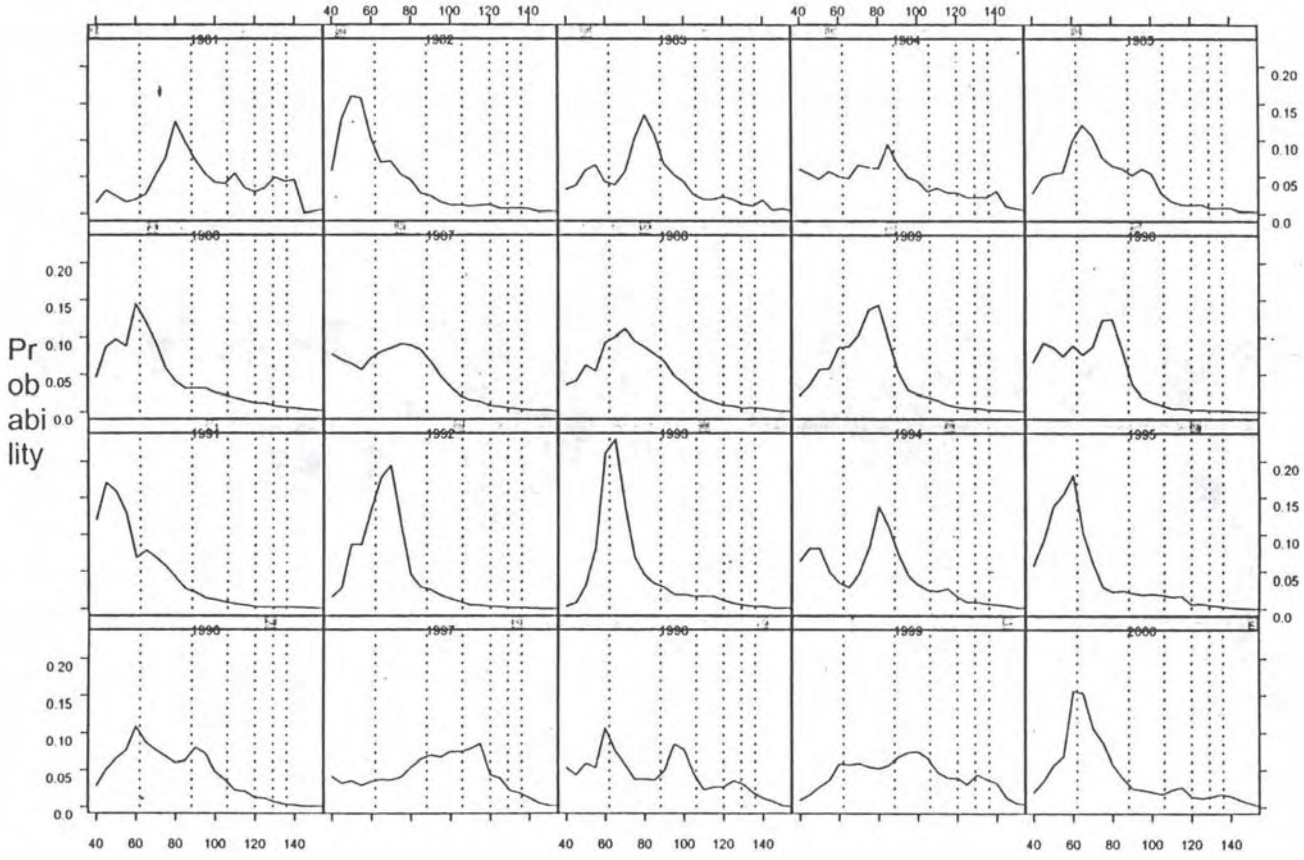


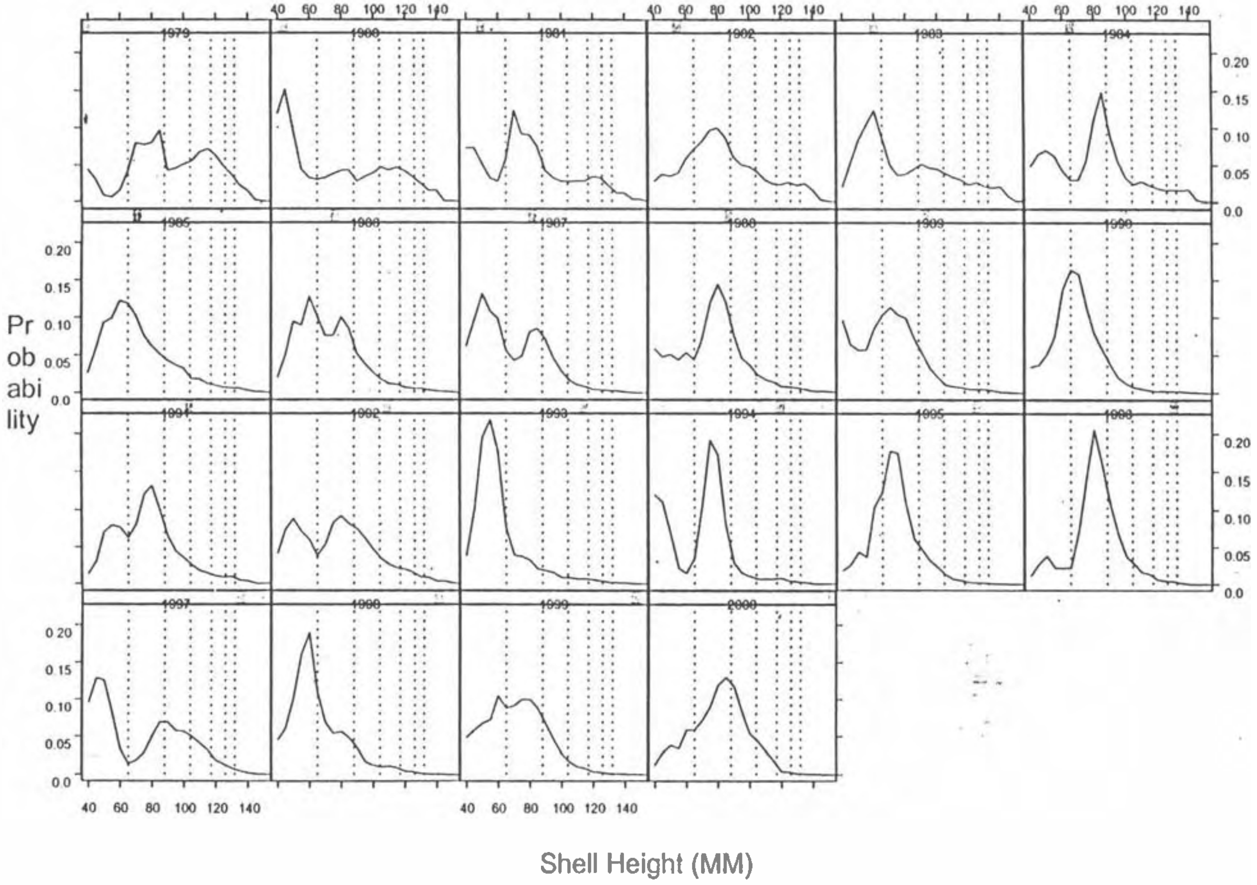
Fig. B5-14. Scallop Survey-All Regions in the Georges Bank



Shell Height

(Vertical Lines at Von Bertalanffy Size At

Fig. B5-15. Scallop Survey-All Regions in the Mid-Atlantic Bight Stock



(Vertical Lines at Von Bertalanffy Size At Ages 3-8)

Fig. B5-16. 2000 survey scallop size frequency in Georges Bank closed areas, with projected size frequencies assumming standard or fast growth.

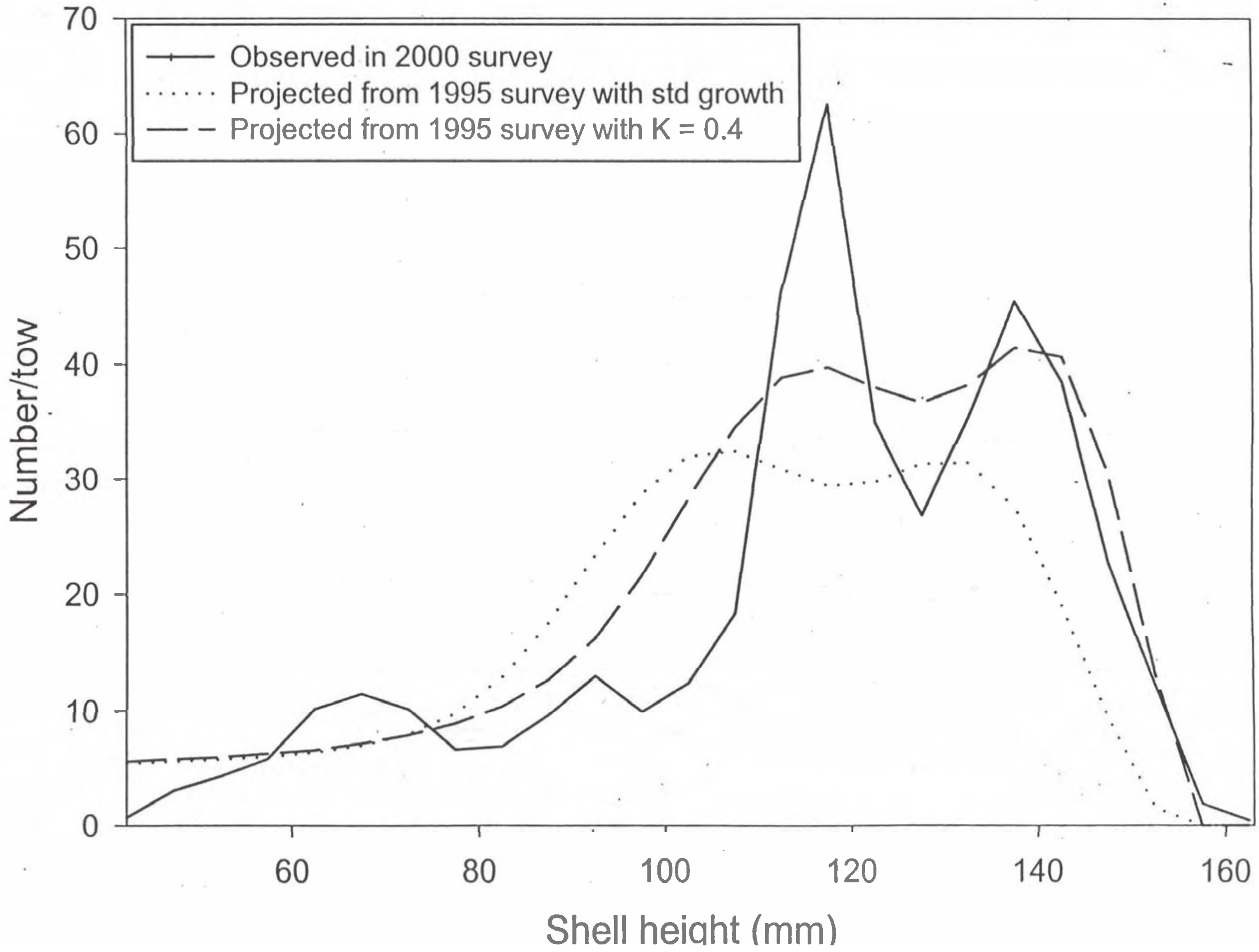
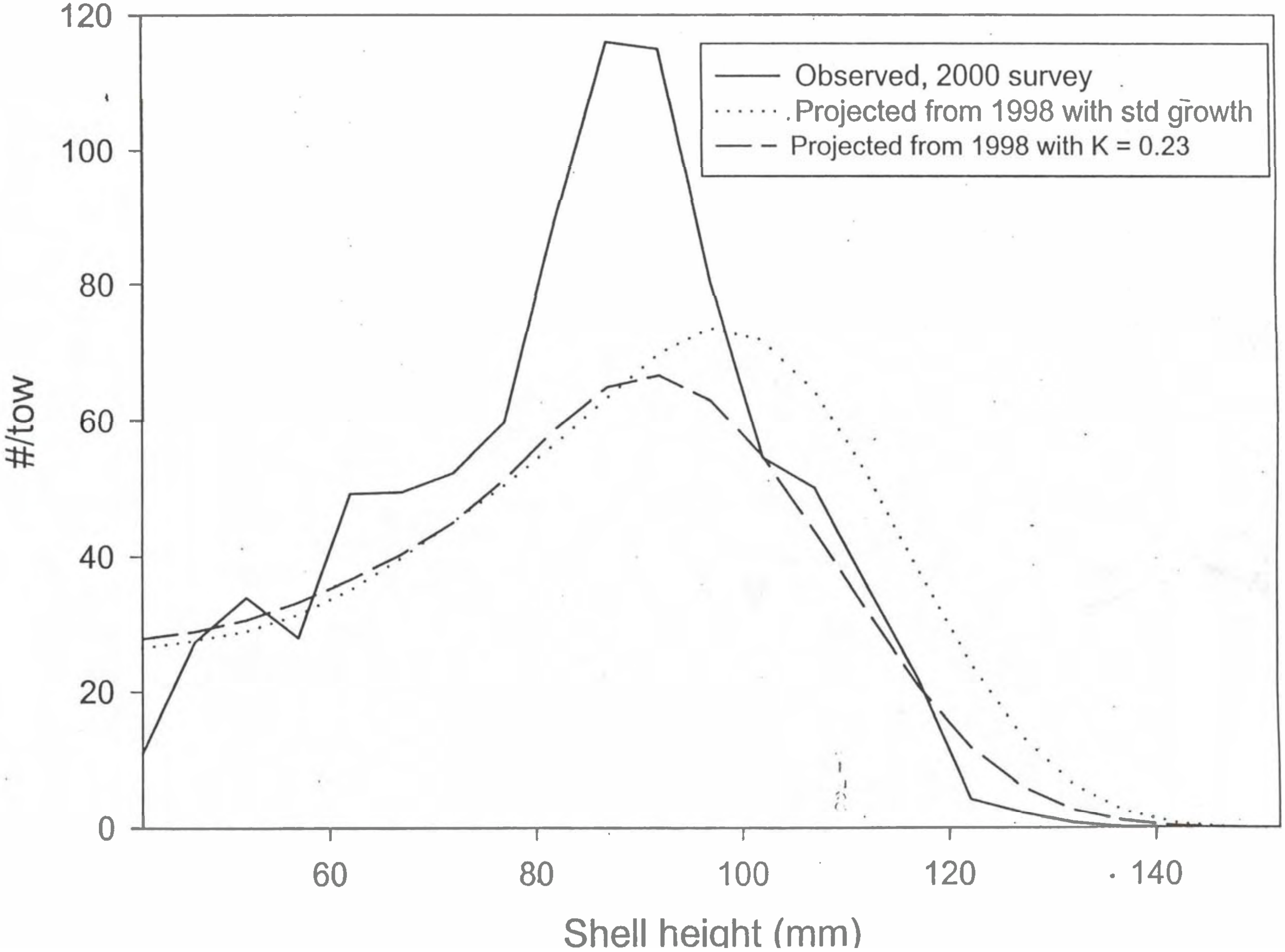


Fig. B5-17. 2000 survey scallop size frequency in Mid-Atlantic closed areas, with projected size frequencies assumming standard and slow growth.



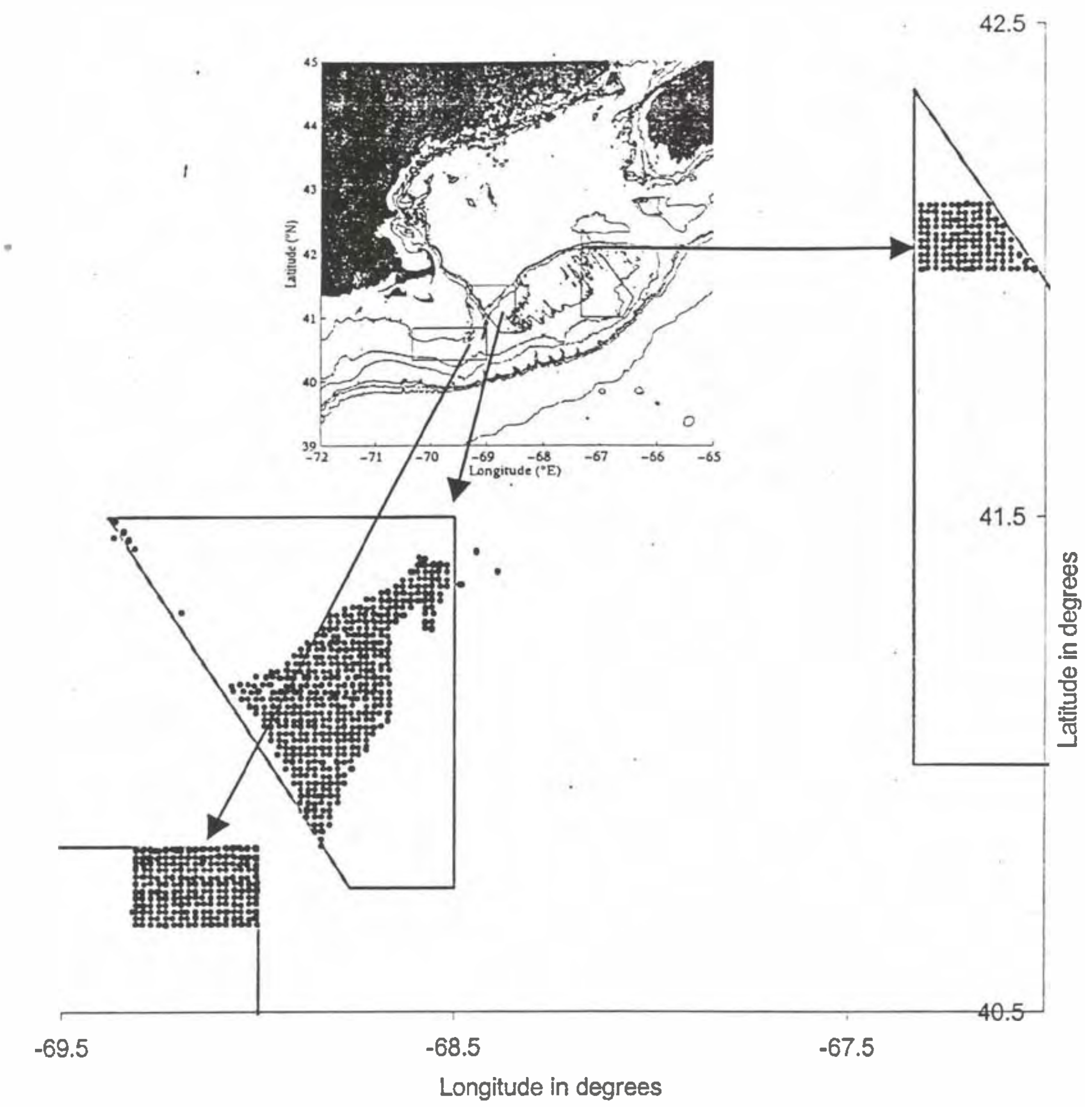


Figure B5-18. CMAST video survey conducted in Nantucket Lightship Area (NLSA Closed Area I (CAI) and Closed Area II (CAII) during the summer of 1999.

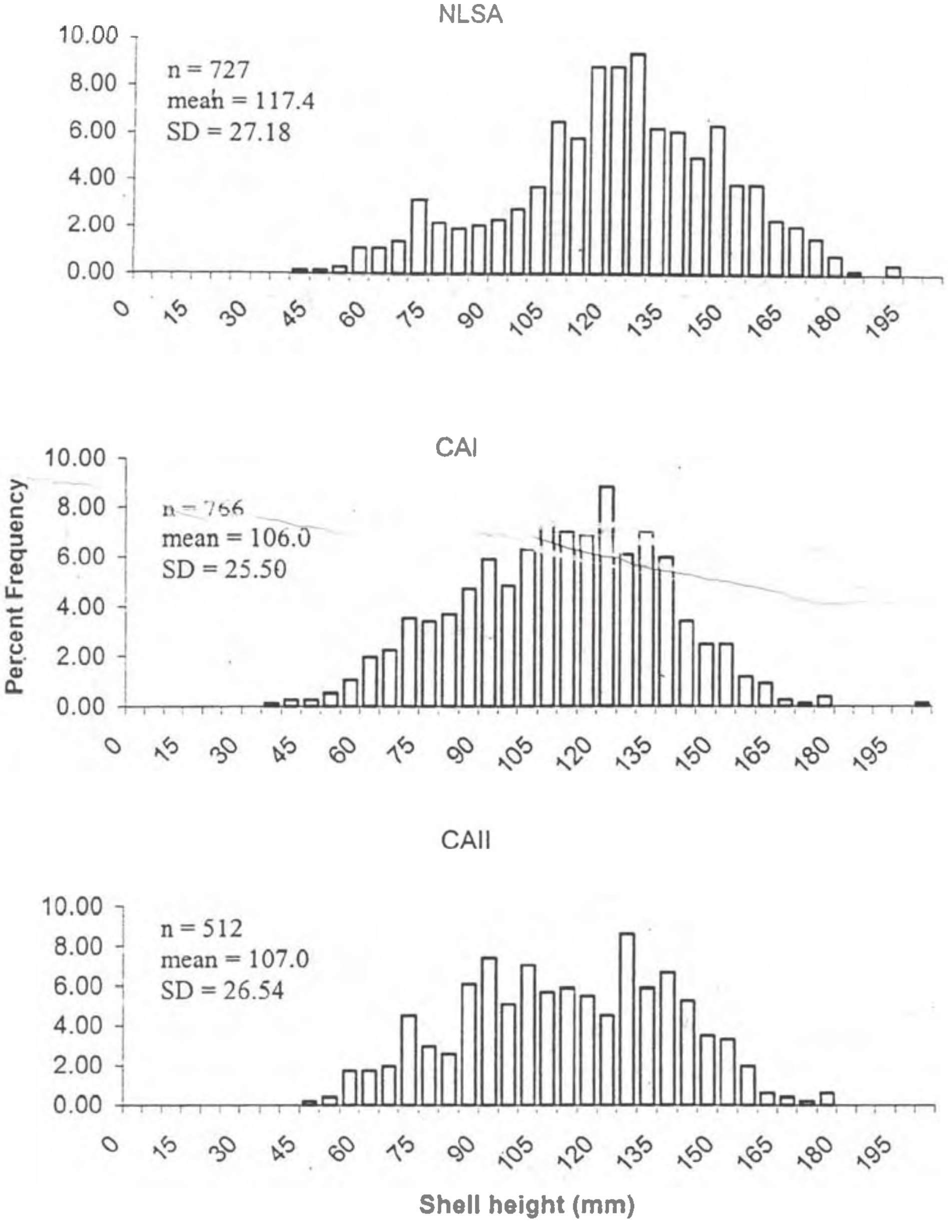


Figure B5-19. Shell height frequencies for each of the closed areas area of Georges Bank observed from July to September 1999.

Figure B5-20. Survey stations occupied in the Hudson Canyon closed area during the 2000 VIMS scallop survey.

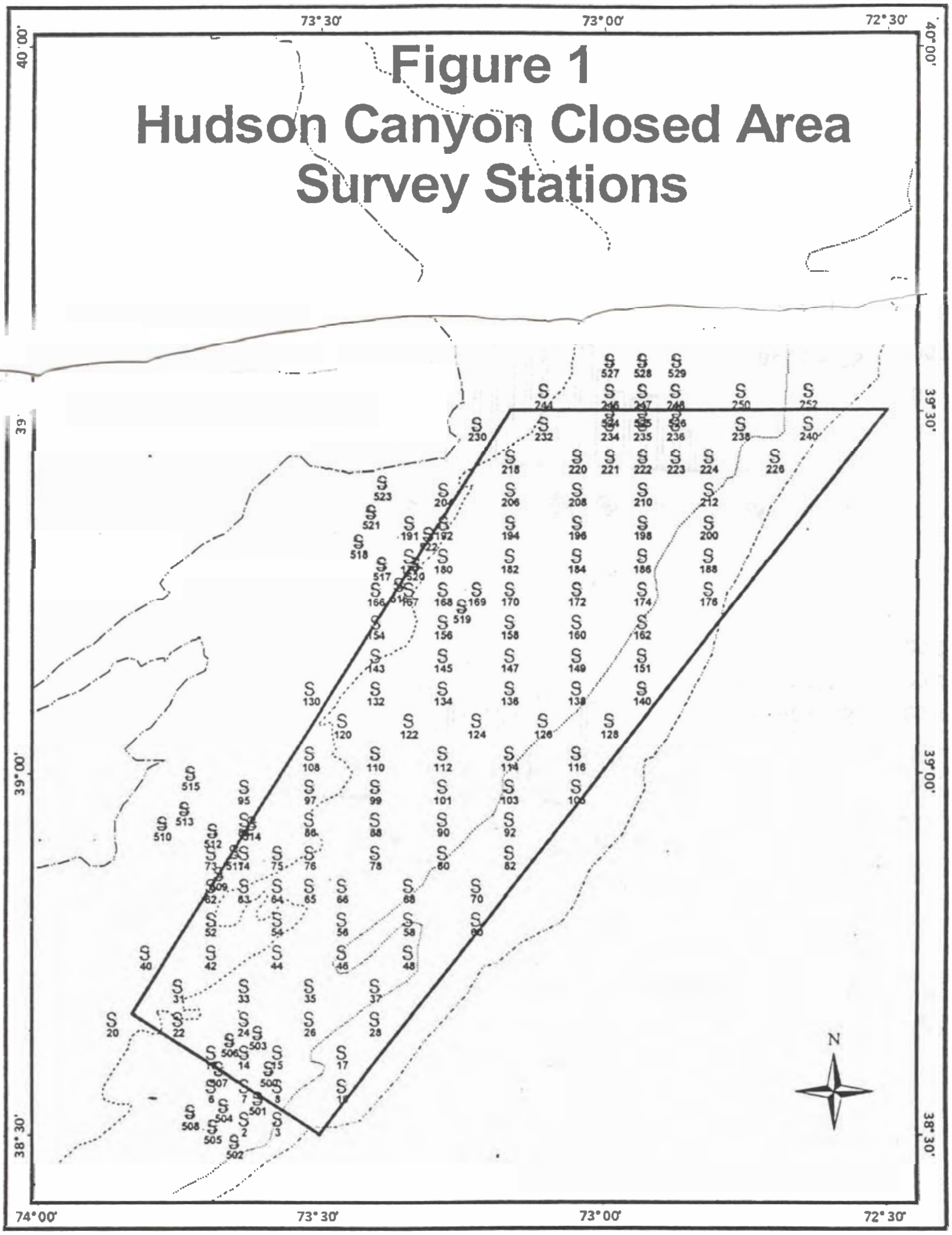
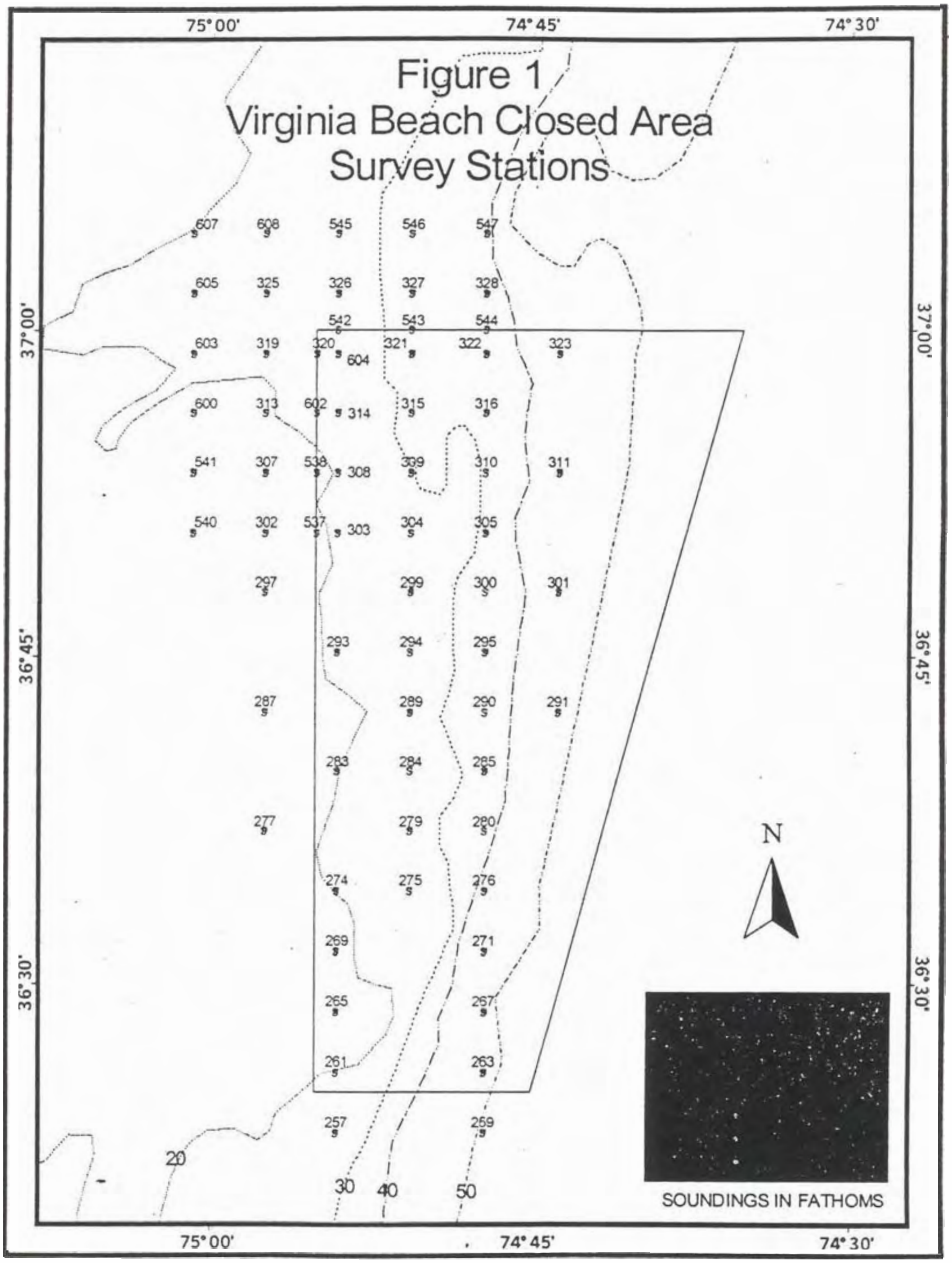


Figure B5-21. Survey stations occupied in the Virginia Beach closed area during the VIMS 2000 scallop survey.



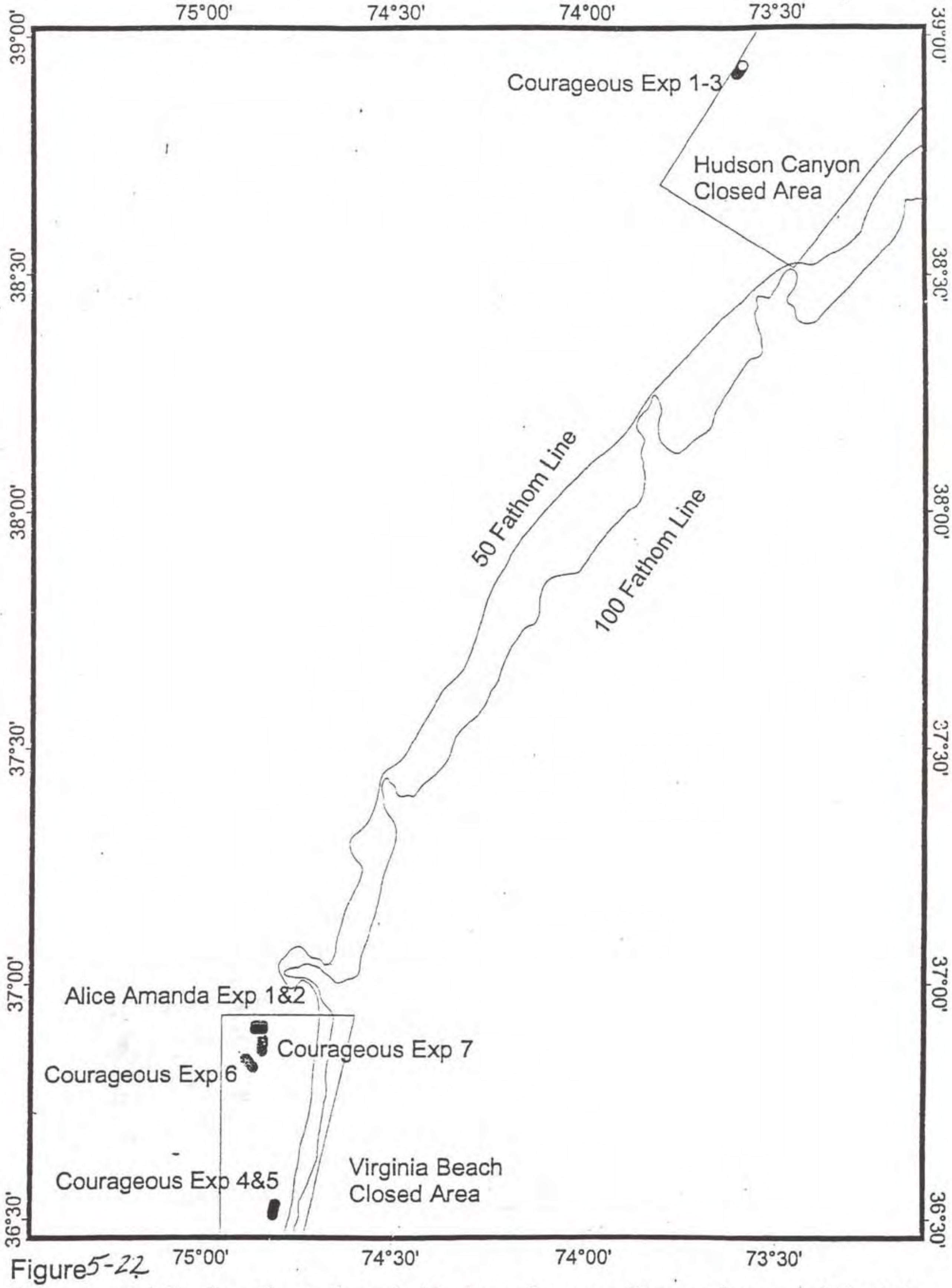


Figure 5-22
Commercial Scallop Depletions in Hudson Canyon Closed Area and Virginia Beach Closed Area, 1999 - 2000.

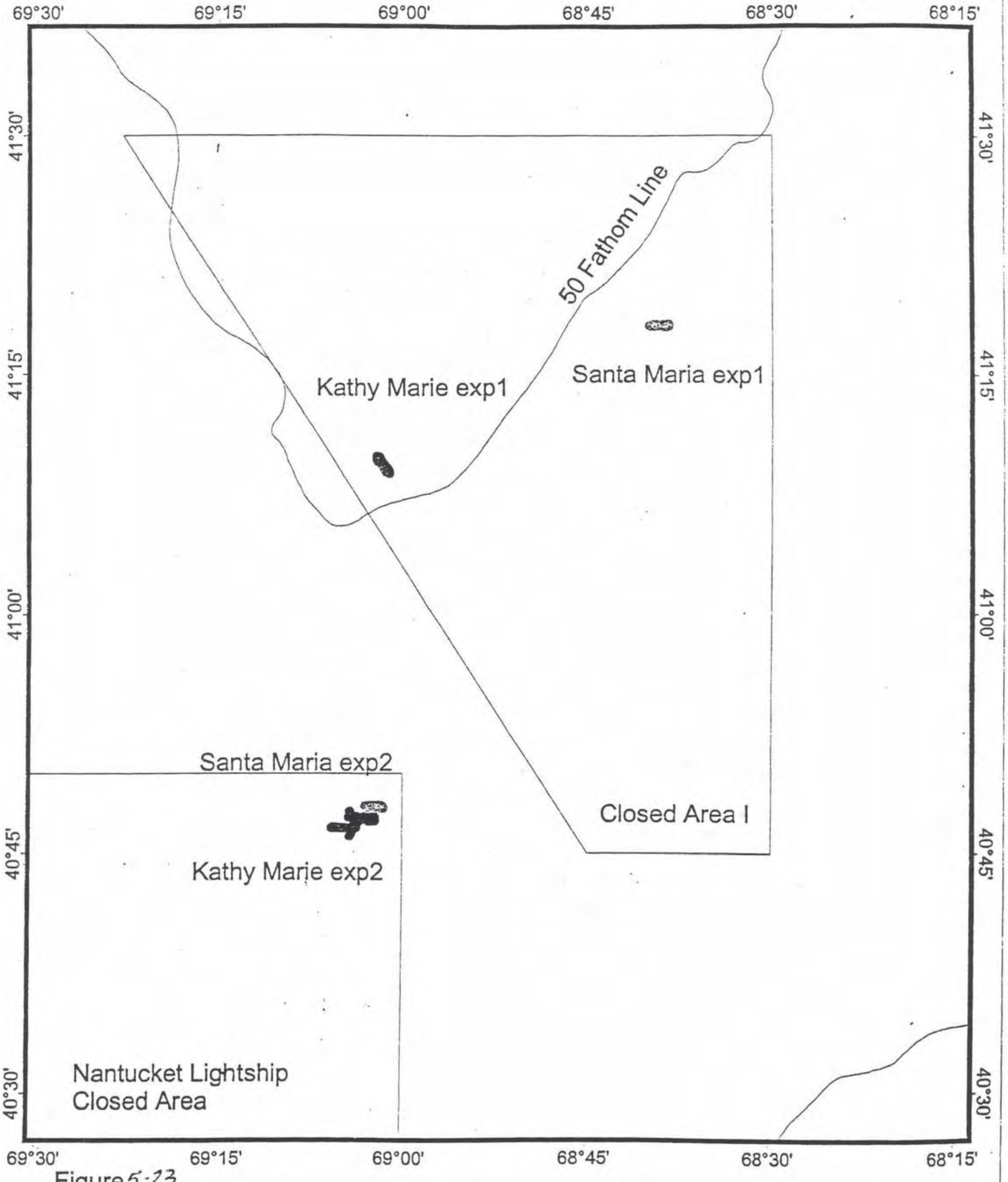


Figure 5-23
Commercial Scallop Depletions in Closed Area I and Nantucket Lightship Closed Area, 1999.

Fig. 5-21. Impact of Gamma on Pred. Catch
Santa Maria Exp. 1 (Gamma was raised from 0.5 to 0.75, holding other params at their "gamma 0.5" solutions)

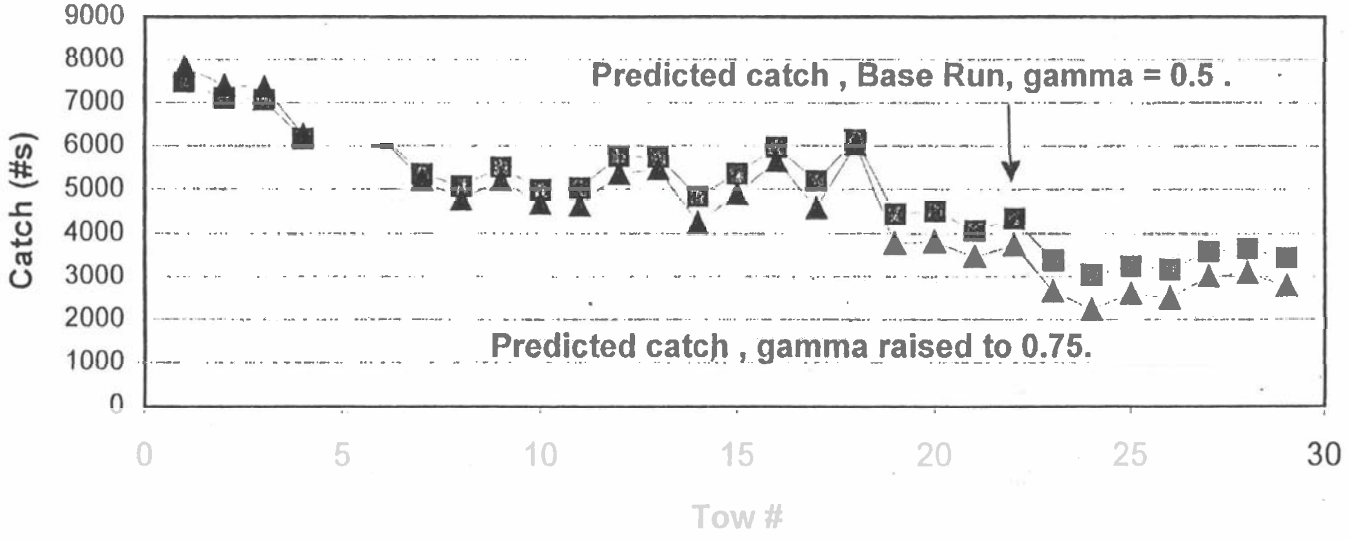
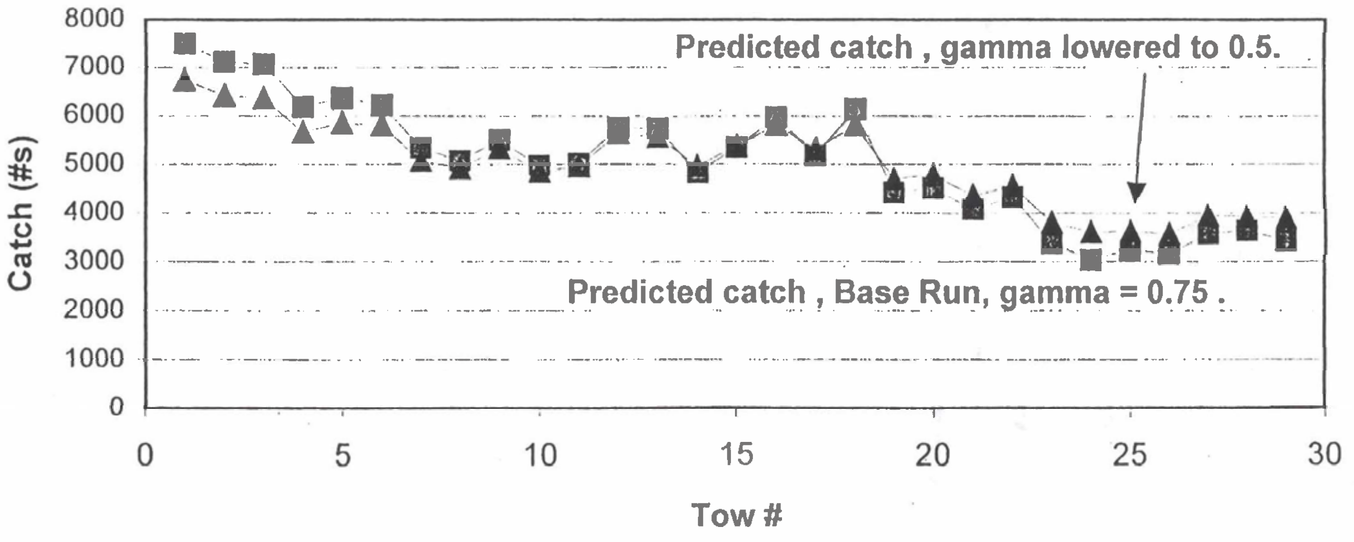


Fig. 5-25. Impact of Gamma on Pred. Catch

Santa Maria Exp. 1 (Gamma was lowered from 0.75 to 0.5, holding other params at their "gamma 0.75" solutions)



Predicted catch , gamma lowered to 0.5.

Predicted catch , Base Run, gamma = 0.75 .

00/gammatest/summary.xls SM11g.75to.5

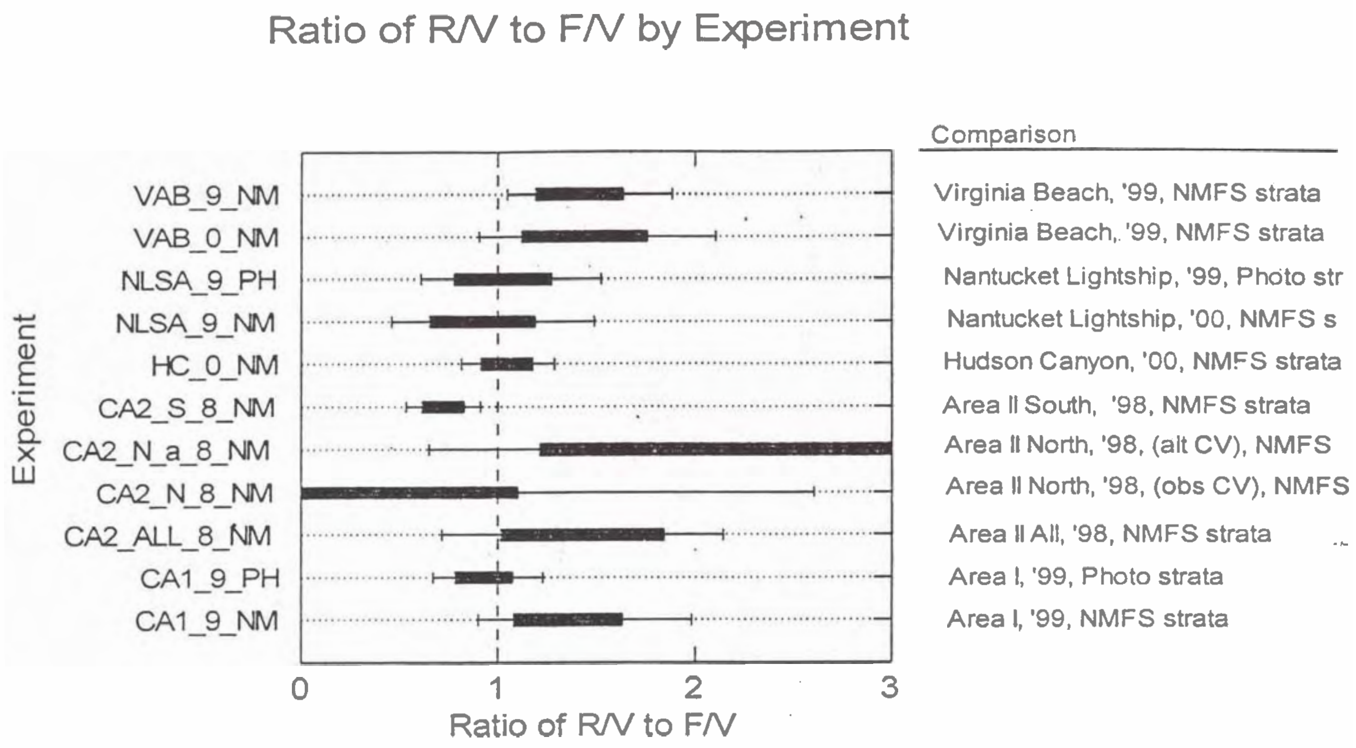


Figure B5-26. Ratio of biomass estimates between R/V Albatross and various commercial fishing vessels for areas surveyed by both types of vessels in 1998-2000.

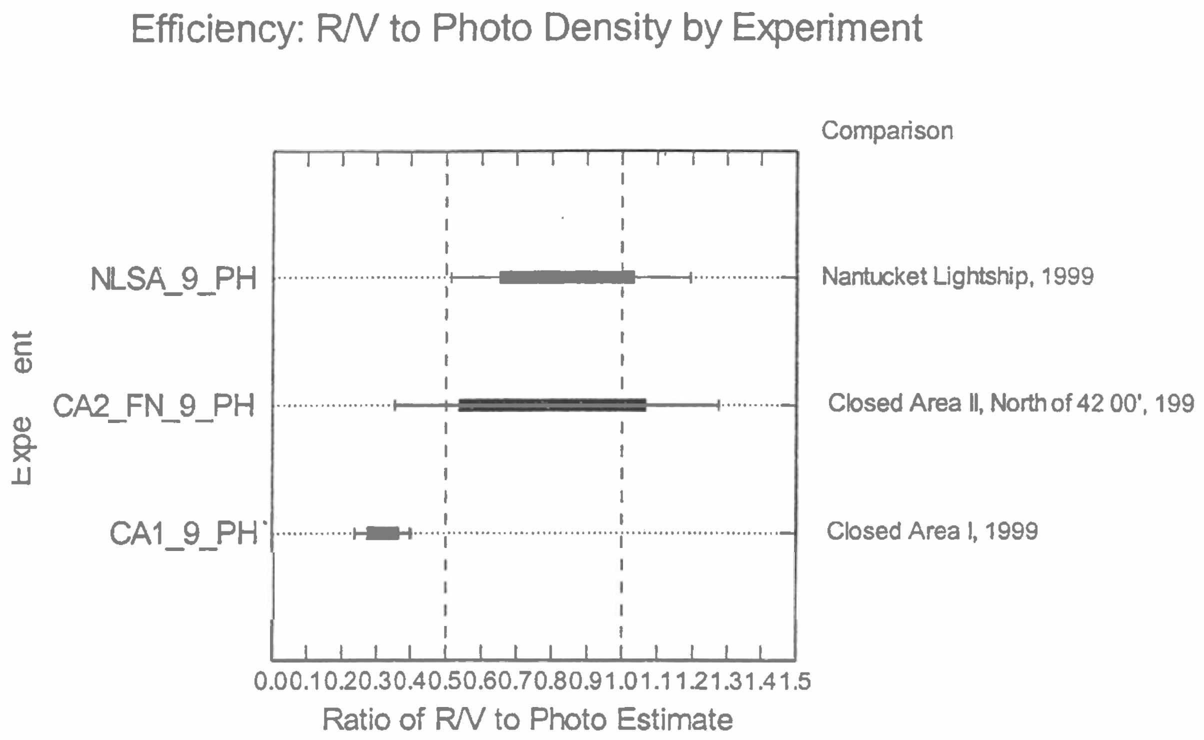


Figure B5-27. Ratio of biomass estimates from R/V Albatross IV in the Nantucket Lightship and Closed Area II and Closed Area I to biomass estimates from photographic survey in 1999.

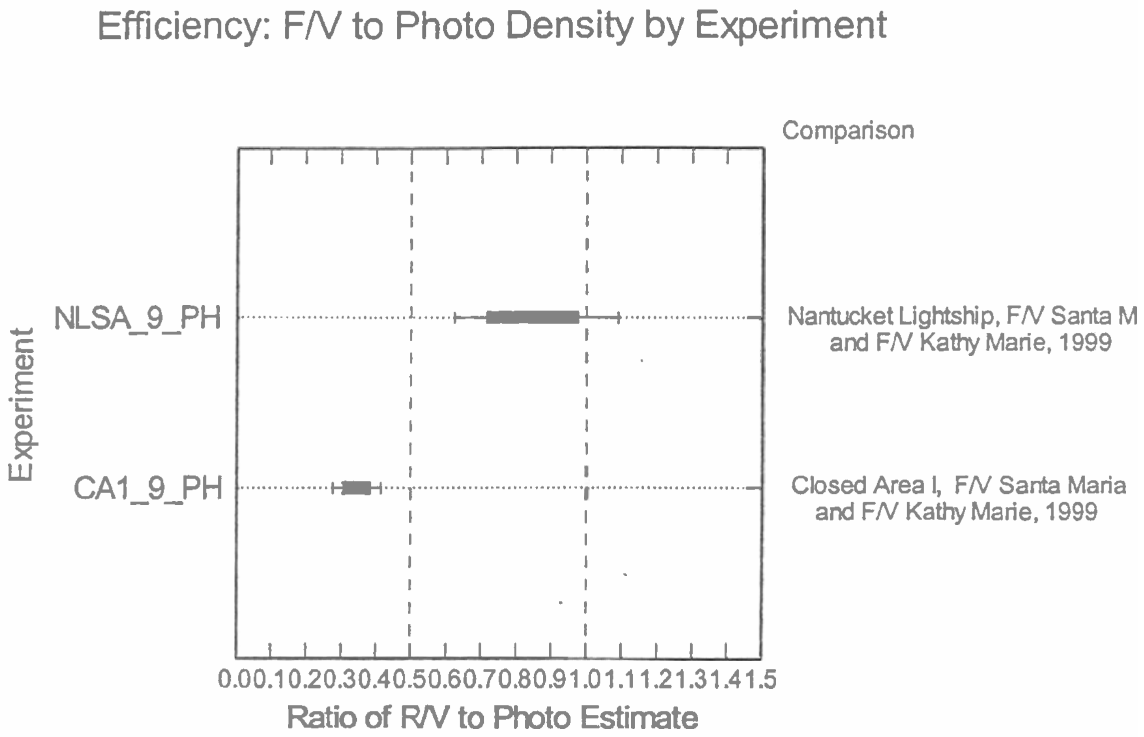


Figure B5-28. Ratio of biomass estimates from F/V Santa Maria and F/V Kathy Marie in the Nantucket Lightship and Closed Area I to biomass estimates from photographic survey in 1999.

Fig B6-1. Fishing mortality estimates for Georges Bank

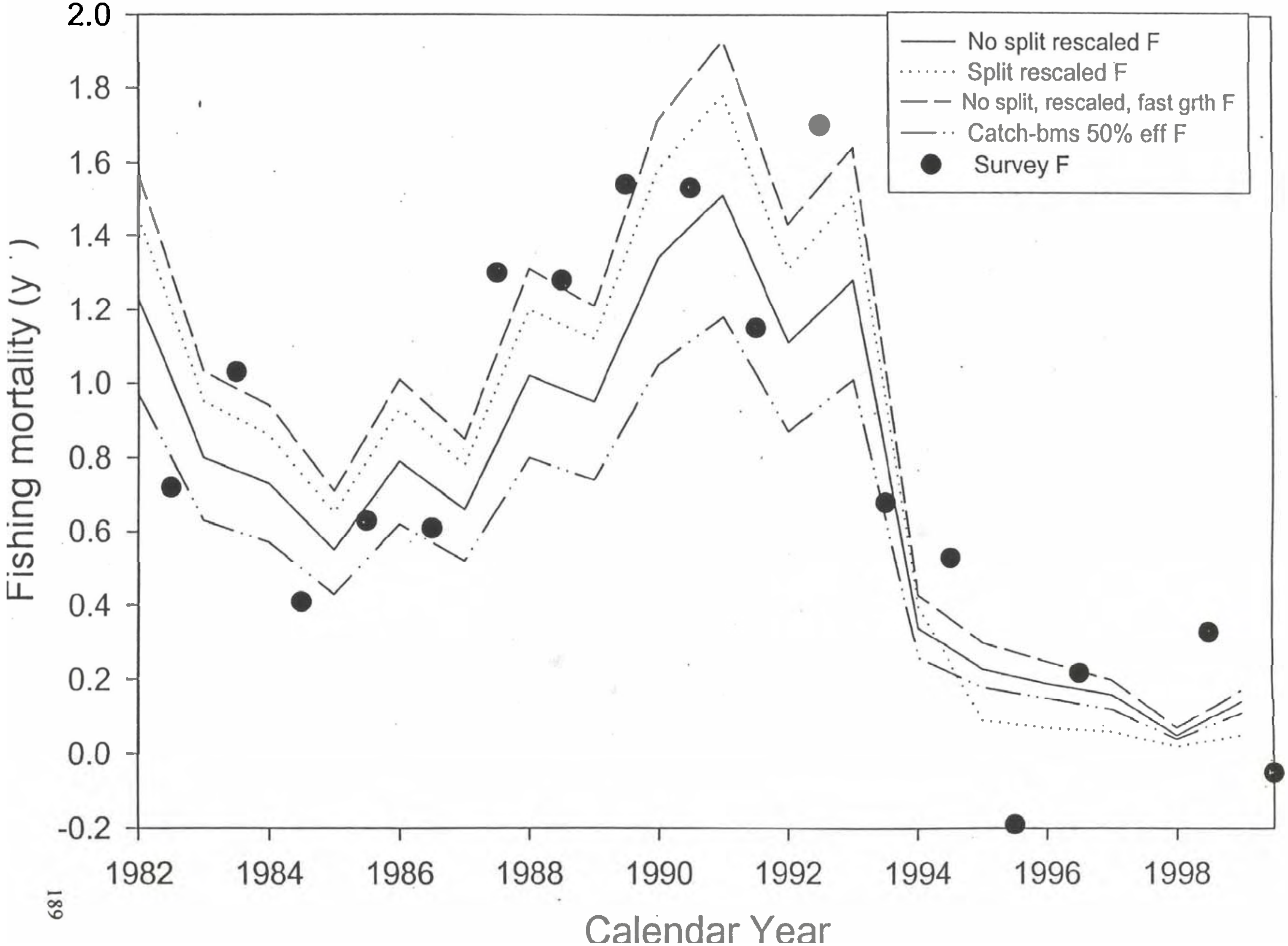
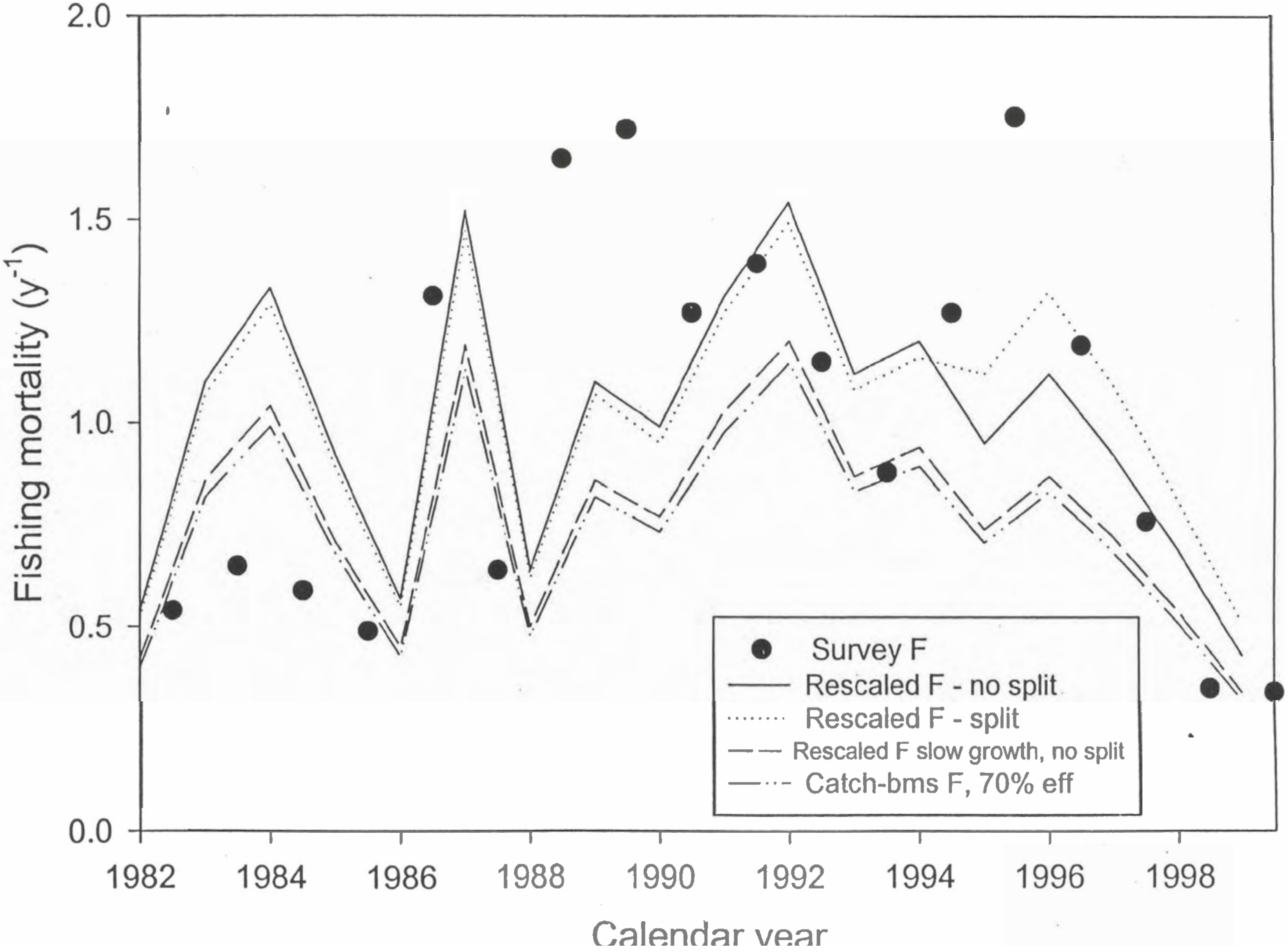


Fig B6-2. Whole-stock F estimates for Mid-Atlantic



C. SILVER HAKE

TERMS OF REFERENCE

(A) Update the status of silver hake stocks, 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 indices.

(D) Update the results of sea sampling and, to the extent feasible, characterize discarding.

INTRODUCTION

Silver hake (*Merluccius bilinearis*) is a short-lived gadid that ranges from Newfoundland to South Carolina. This species is an important component of the food web in the northeast continental shelf ecosystem (Sissenwine and Cohen 1991), and according to Bigelow and Schroeder (1953), "*Silver hake are strong swift swimmers, well armed and extremely voracious*". In the U.S. EEZ, the silver hake population was intensively harvested by distant water fleets during the 1960s and 1970s with peak annual landings of over 300 kt. Since 1980, annual landings have remained stable at roughly 20 kt in what is now an entirely domestic fishery. Silver hake was last assessed in 1993 at SAW 17. In that assessment, an age-structured analysis of the population in two stock areas was attempted, but results were not considered to be reliable. As a result, the previous assessment was index-based and current overfishing thresholds for silver hake are based on research survey information.

STOCK STRUCTURE AND DISTRIBUTION

Two subpopulations of silver hake are assumed to exist within the US EEZ (Almeida 1987). Analyses of morphometric characters (Conover et al. 1961, Almeida 1987) are the primary basis for this delineation. Recent analyses of otolith microconstituent data are also consistent with the existence of two or more stocks (Bolles and Begg 2000). However, genetic analyses of population structure have been inconclusive (Schenk 1981). For the purpose of assessment, the northern stock is assigned to areas of northern Georges Bank and the Gulf of Maine and the southern stock is assigned to areas of southern Georges Bank, southern New England, and the Mid-Atlantic Bight (Figure 1 and Figure 2). These boundaries were established in the late-1980s at SAW 11.

While it is recognized that the northern and southern stocks mix on Georges Bank, the amount of mixing and movement among northern and southern areas are unknown (Almeida 1987, Helser et al. 1995, Helser 1996). Silver hake spawn in the Gulf of Maine, southern New England, and on the southern flank of Georges Bank. Silver hake larvae entrained in the clockwise gyre of Georges Bank may settle in either the southern or northern stock areas (see Distribution of Eggs and Larvae below). As a result, reproductive isolation of the two stocks is unlikely. However, it is unknown to what extent the northern and southern stocks have independent demographic and genetic trajectories. If gene flow is high between northern and southern stocks, on the order of a few migrants per generation, genetic analyses may be of limited utility to separate the subpopulations in areas of mixing (Waples 1998).

Analyses of silver hake size-at-age data show that growth has varied in time and among areas. In particular, recent growth analyses (Helser 1996) indicate that there are consistent differences between silver hake growth in the Gulf of Maine and southern New England/Mid-Atlantic Bight areas. Helser also shows that growth patterns on Georges Bank and the Gulf of Maine were indistinguishable during 1988-1992 and that growth rate changes dynamically on Georges Bank. Growth analyses conducted for this assessment show that there are very minor differences in growth between northern and southern stock areas during the 1990s (see Growth below). In general, differences in silver hake growth between northerly and southerly areas can be expected if there is limited movement between areas based on differences in primary productivity and water temperature between the Gulf of Maine and the continental shelf areas of southern New England and Georges Bank.

The spatial distribution of silver hake has changed through time. Population density, as measured by the NEFSC fall bottom trawl survey has been increasing in northern stock areas (Gulf of Maine: offshore strata 24, 26-30, and 36-40, northern Georges Bank: offshore strata 20-23 and 25) since the late 1960s (Figure 3A). Density in southern stock areas has decreased (Figure 3B) since the 1960s in southern New England (offshore strata 1-12) and Mid-Atlantic Bight waters (offshore strata 61-76, note that 1963-1966 indices are based on average proportion during 1967-1999, see STOCK ABUNDANCE AND BIOMASS INDICES below) while density in southern Georges Bank waters (offshore strata 13-19) increased in the 1980s and subsequently decreased in the 1990s. In contrast, spring survey information on density is highly variable (Figure 4) and likely provides less information on trend in comparison to the fall survey.

In terms of the spatial distribution of total population biomass, there has been an increasing trend in the population biomass index in northern stock areas and a decrease in southern stock areas (Figure 5A). The total population biomass index has increased since the historic lows of the late 1960s, while the proportion of total biomass in the Gulf of Maine has increased from about 50% in the late 1960s to over 80% in the late 1990s (Figure 5B). In contrast, the proportion of total biomass in southern New England has decreased from about 40% in the late 1960s to about 10% in the late 1990s. As with the density data, the spring survey total biomass information is highly variable by stock area (Figure 6) and likely provides less information on trend in comparison to the fall survey. Overall, the Gulf of Maine has consistently had the highest density and proportion of biomass through time and this suggests that the Gulf of Maine is the best habitat for silver hake among northern and southern stock areas.

Changes in oceanographic conditions of shelf waters have likely affected silver hake distribution. Near-bottom water temperatures, as indexed during the NEFSC fall and spring bottom trawl surveys, in the northern and southern stock areas (Figure 7) show that the

1960s was a relatively cool time period and also show that temperatures have increased in recent years. In particular, water temperatures on northern and southern Georges Bank have slowly increased through time, relative to the Gulf of Maine. The ratio of population density of silver hake to temperature has also changed in both northern and southern stock areas (Figure 8). Density per degree has increased in northern areas (Figure 8A,C) and decreased in southern areas (Figure 8B,D). Overall, changes in temperature may have altered the spatial distribution of the two stock components.

Changes in broad-scale oceanographic conditions may also have affected silver hake distribution. NEFSC bottom trawl survey data collected during fall, winter, and spring (Figure 9) show that a portion of the population is consistently present in deeper waters of the upper continental slope at depths of 100-300 m. This depth range represents the boundary of the NEFSC bottom trawl surveys ,which are primarily designed to sample continental shelf waters. Near the shelf/slope break, warm slope waters impinge upon the upper continental slope and provide year-round habitat for silver hake. In fact, the USSR fishery for silver hake documented this feature of silver hake distribution in the 1960s (Figure 10). The association of a fraction of the silver hake population with slope waters suggests that changes in the slope water mass between the Gulf Stream and the continental shelf water probably affect the offshore distribution of silver hake. In particular, changes in the position of the shelf/slope front (Drinkwater et al. 2000) and Gulf Stream position alter slope water characteristics and may influence silver hake distribution in deeper water at the shelf/slope break. One broad-scale feature that has been correlated with changes in Gulf Stream position is the North Atlantic Oscillation (NAO) index (Jones et al. 1997, Taylor and Stephens 1998). The NAO index has trended up sharply since the 1960s (Figure 11) and this trend may have affected the amount of habitat available to silver hake in offshore waters of the upper continental slope.

In summary, four additional pieces of information on silver hake stock structure have been examined for this assessment. First, the density and proportion of population biomass has decreased in the southern area and increased in the northern area. Second, growth patterns have changed through time and have been similar in northern and southern areas during the 1990s. Third, ichthyoplankton data show that silver hake eggs are continuously distributed over Georges Bank. Fourth, changes in oceanographic conditions over the past 40 years may have influenced the spatial distribution of stock components.

THE FISHERY

The silver hake fishery has changed through time from an inshore fishery prosecuted with pound and trap nets to an otter trawl fishery (Fritz 1960). During the 1960s, landings of silver hake increased substantially (Table 1 and Figure 12). Most of the increase in harvest was due to directed fishing for silver hake by the distant water fleet of the former USSR. During the 1980s and 1990s, total silver hake landings have remained relatively low in comparison to historic yields.

Recreational Fishery

Silver hake once supported a recreational fishery in the Mid-Atlantic Bight (Fritz 1960) with annual landings of around 1,000 mt (2.2 million pounds) in the southern stock area.

Recreational fishery landings decreased substantially in the 1970s and 1980s and are currently very low. Recreational landings of silver hake have averaged only 18,000 fish per year during 1995-1999.

Commercial Fishery

Directed commercial fishing for silver hake began in the 1920s. The domestic commercial fishery has been relatively stable since the late 1970s. Market demand for silver hake does not appear to have changed much over the past two decades, and landings have remained at roughly 15,000 to 20,000 mt per year.

Commercial Landings

Commercial landings of silver hake during 1993-1999 were collected from the NEFSC weigh-out database. During 1994-1999, the area where silver hake were captured was not recorded for many trips in the weigh-out database (unknown area) due to changes in the reporting system for fishery statistics. As a result, the unknown-area landings were prorated to the northern and southern stock areas based on fishing location information stored in the vessel-trip reporting database (e.g., fishery logbook data). These prorated landings by stock area for 1994-1999 are considered to be provisional until a final evaluation of the fishery logbook data has been completed.

Silver hake are landed in three commercial market categories: small, large, and unclassified. The vast majority of landings are reported as unclassified (Tables 2).

Sampling Intensity

The adequacy of length frequency sampling of commercial silver hake landings has varied during 1993-1999 (Table 3). Sampling has generally been adequate for the unclassified market category but has been poor for the large and small market categories in several years. Sampling in the northern stock area has generally been lower than in the southern area (Figure 13). Most commercial fishery length samples collected in port during 1994-1996 had an unknown stock area in the commercial fishery length database (Figure 13). These unknown-area samples were assigned to northern and southern stock areas by identifying each sample with the corresponding vessel trip in the fishery logbook database, wherever possible.

The length samples by market category were evaluated for use in constructing commercial fishery catch at age during 1993-1999. Mean lengths of commercial fishery length samples from the 1st and 2nd half of the year were generally similar for the southern stock (Table 3). Few comparisons between 1st and 2nd half samples were possible in the north but the available data suggested that mean lengths were similar within a market category during the year. As a result, length frequency data from the 1st and 2nd half of each year were combined by market category. Similarly, comparisons of mean lengths of unclassified samples from northern and southern stock areas suggested that there was no practical difference between unclassified silver hake from the two areas. For the small and large market categories, there were few data for comparison and it was inconclusive whether differences existed for these minor categories. Because northern and southern samples were similar for the predominant unclassified category, commercial length frequency samples from the two stock areas were combined by market category to derive the length frequency of the landings.

Sampling intensities (1 sample consists of 100 fish lengths) for annual landings combined by half-year and stock area for small, unclassified, and large categories were: 623, 487, and 275 mt per sample in 1993; 377, 234, and 352 mt per sample in 1994; 371, 376, and 146 mt per sample in 1995; 306, 709, and 453 mt per sample in 1996; 215, 277, and 57 mt per sample in 1997; 238, 177, and 90 mt per sample in 1998; 163, 224, and 79 mt per sample in 1999. Overall, sampling intensities for the silver hake fishery have improved in the last couple of years.

Length distributions of commercial fishery landings were computed as a catch-weighted average of the length distributions by market category (Figure14). Mean length of commercial landings ranged from a high of 31 cm in 1995 to a low of 28 cm in 1999 and averaged 29 cm during 1993-1999.

Commercial Landings at Age

Commercial landings at age data for 1955-1992 were based on the previous silver hake assessment (NEFSC 1994). Commercial landings at age during 1993-1999 were derived from commercial length frequency data, research survey age-length keys, and length-weight relationships derived from research survey data. Commercial length frequency distributions were derived from market category samples as described above. The silver hake age-length key for each year was calculated as the average of the age-length keys from the spring and fall NEFSC bottom trawl surveys during each year because no commercial fishery age data are available for silver hake. The length-weight relationship for each year was calculated as the average of the length-weight relationships from the spring and fall NEFSC bottom trawl surveys. The spring survey age-length keys were not available for 1998-1999 and the age-length keys in 1998 and 1999 were derived from the spring 1997 age-length key and the fall age-length key for that year.

Commercial landings at age have varied substantially through time (Table 4). During 1955-1959, roughly 300 million silver hake were landed each year. Landings peaked at an average over 1 billion silver hake per year in the late 1960s. Landings of silver hake have decreased since then and now average roughly 85 million fish per year, less than one-tenth of the peak value. The age composition of silver hake landings has also changed substantially through time. In the late 1950s to 1960s, age-4 and older silver hake comprised almost half of the landed catch. In contrast, during the 1990s, age-4 and older silver hake account for less than 20% of the landed catch. Similarly, age-6 and older silver hake accounted for 5% or more of the landed catch during 1955-1974, but these age classes were very rare in the sampled catch during the 1990s.

Bycatch and Discards

Bycatch and discard of silver hake occurs in directed and non-directed fisheries. Several sources of information were used to examine patterns of discarding. These were weigh-out interview data for 1983-1993, sea sampling data for 1989-1999, and fishing vessel logbook data for 1994-1999. Data on discarding patterns prior to 1983 were very limited and no estimates of the magnitude of discarding were attempted for this assessment.

Weigh-out interview data were screened to include only trips that were also recorded in the commercial weigh-out database. This was done to ensure that ratios of discarded catch weight to kept catch were accurate. The weigh-out interview data for otter trawl fishing operations indicated that discard to kept ratios ranged from 10% to 80% during 1983-1993. Based on the interview data, the average discard to kept ratio was roughly 30%.

Sea sampling data collected during 1989-1999 showed that discarding of silver hake captured by otter trawls occurred throughout the northern and southern stock areas. Discarding of silver hake by scallop dredges also occurred in both northern and southern stock areas while discarding by sink gill nets occurred primarily in the northern stock area. Discard to kept ratios by weight, summarized by year, quarter, gear-type, and stock area, varied through time and ranged from 0% to over 100% for the directed silver hake fishery (small mesh otter trawl, codend mesh 3" or less) and for the non-directed fisheries (large mesh otter trawl, shrimp trawl, sink gill net, and scallop dredge). Overall, it is unknown whether the variability the discard ratios was due to non-random coverage of the fleet, small sample sizes, or inherent variation in discard rates and practices.

Fishery logbook data collected during 1994-1999 also showed that silver hake discarding practices vary through time and differ between directed and non-directed fisheries. Discard to kept ratios in the logbook data, summarized by year, quarter, and gear-type, represented a fraction of all fishing operations and ranged from 0% to over 100%. For scallop dredges, there were apparently no records to tabulate although some silver hake are discarded in the sea scallop fishery.

STOCK ABUNDANCE AND BIOMASS INDICES

Research Survey Indices

Research survey indices for relative biomass and population numbers at age were recomputed for the combined stock area using NEFSC spring and fall survey data. Abundance indices were computed using the delta-distribution to improve precision. In addition, inshore survey strata were excluded from the southern area because these strata represent a very small proportion of biomass and because these strata were not sampled in the 1960s and were inconsistently sampled in the 1970s. Survey data were not adjusted for possible day-night variation in silver hake distribution in the water column. Although day-night differences in catchability may be expected for this species (Bowman and Bowman 1980), the NEFSC surveys operate continuously through day and night and no systematic bias would be expected since allocation of a tow location to day or night is random. On the other hand, use of survey catch information from day and night time periods can be expected to increase the variability of calculated indices.

During 1963-1966, survey strata in the Mid-Atlantic Bight (offshore strata 61-76) were not sampled. To calculate the survey biomass time series of the southern stock for 1963-1966, it was assumed that the proportion of total silver hake biomass in the Mid-Atlantic Bight during these years was equal to the long-term average of 1.8%. Given this assumption, the fall biomass index for the southern area was extended to 1963-1966. This was crucial for population modeling because the largest silver hake catches occurred during the 1963-1966 period.

Biomass indices for northern and southern stock areas show differing trends (Table 5). Biomass indices for the northern stock area show an increasing trend while biomass indices for the southern stock area show a decreasing trend (Figure 15). Biomass indices for the combined stock area show an increasing trend in the fall (Figure 16) and vary without trend in the spring.

Numbers-at-age indices from the NEFSC

spring and fall bottom trawl surveys were computed for the combined stock area using all available age-length data (Tables 6 and 7). For the spring survey, there were no ageing data collected prior to 1973. It was assumed that the average of the spring age-length keys during 1973-1975 was an adequate representation of silver hake size-at-age during 1968-1972. In addition, there were no age-length data available for spring during 1998-1999 and here it was assumed that the 1997 spring age-length key was an adequate representation of silver hake size-at-age during 1998-1999. Similarly, for the fall survey, there were no age data collected prior to 1973 and no age data collected in 1974. The average of the 1973 and 1975 age-length keys was used to represent silver hake size at age during 1963-72 and 1974, when no age data were collected.

LIFE HISTORY PARAMETERS

Recent research on silver hake life history parameters includes studies of larval settlement and growth (Steves and Cowen 2000), variation in otolith morphometrics (Bolles and Begg 2000), growth variation of larvae in relation to water masses (Jeffrey and Taggart 2000), acoustic measurements of the distribution of silver hake and euphausiid prey (Cochrane et a. 2000), spatial and temporal patterns of growth (Helser 1996), and potential effects of density-dependent growth and maturation on population dynamics (Helser and Brodziak 1998). Together, these studies have expanded the information base on silver hake population dynamics.

Distribution of Eggs and Larvae

Silver hake have a protracted spawning period that lasts from late-spring through autumn. Spawning occurs during May-October on Southern Georges Bank, during June-October in the Gulf of Maine and northern Georges Bank, and during June-December in the Mid-Atlantic Bight (Colton et al. 1979). Silver hake larvae are widely distributed in continental shelf waters during summer and early autumn. Silver hake has been classified as a ubiquitous, extended spawner by Sherman et al. (1984) based on the broad distribution of its larvae and its protracted spawning period. Ichthyoplankton surveys conducted from 1977-1987 show the extensive distribution of silver hake eggs during May to October (Figures 17 and 18). This broad distribution may be in part due to multiple spawnings by individual fish; Fahay (1974) reported that silver hake can spawn up to three times per year. In addition, Fahay (1974) observer that larger females tend to mature and spawn earlier in the season compared to smaller mature females. More recently, Steves and Cowen (2000) investigated settlement patterns and habitat use of juvenile silver hake and reported that the outer continental shelf was an important nursery habitat for silver hake in the Southern New England/Mid-Atlantic Bight region. Because most of these observations are based on data that were collected over a decade ago, it is unclear whether these distributional patterns have persisted in recent years.

Growth

Helser (1996) investigated dynamic changes in growth rates of silver hake from Cape Hatteras to the Gulf of Maine during 1975-1992. He found that there were spatial and temporal patterns in growth among four areas: the Mid-Atlantic Bight/Southern New England area (MAB, offshore strata 1-12, 61-76), Southern Georges Bank (SGB, offshore strata 13-19), Northern Georges Bank (NGB, offshore strata 20-23, 25), and the Gulf of Maine (GM, offshore strata 24, 26-30, 36-40).

In particular, there were three distinct growth patterns during 1975-1980: MAB, SGB/NGB, and GM. During 1982-1987, there were four distinct growth patterns: MAB, SGB, NGB, and GM. More recently, there were only two distinct growth patterns: MAB and SGB/NGB/GM. This shows that silver hake growth changes in space and time and suggests that growth on Georges Bank is influenced by stock mixing. In addition, the study by Helser and Brodziak (1998) shows that density-dependent changes in growth rates can have a substantial impact on management advice for silver hake.

Growth analyses conducted for this assessment were based on NEFSC survey size-at-age data from the spring and fall surveys. Growth curves were computed for the early 1970s (1973-1974) and the 1990s (1993-1999) to investigate time periods not covered in Helser's study. Schnute's growth model (1981) was fit to mean size-at-age data for these analyses. As in Helser (1996), growth curves were computed for size at age on January 1st where spring survey data were assigned ages of observed year plus 3 months and fall survey data were assigned ages of observed year plus 8 months. Results showed a substantial change in growth between the early 1970s and the 1990s for the northern and southern stock areas and the combined stock area (Figure 19). During the early 1970s, the average silver hake growth pattern conformed to a von Bertalanffy model while during the 1990s, the average growth pattern has been nearly linear with age. The recent change in growth pattern was not expected to be a result of errors in age determinations because quality control measures are in place to ensure consistent age readings. For example, paired comparisons of otolith readings from the fall 1998 survey show 92% agreement between age readers. One implication of recent increases in growth rate is that the mean weights at capture of some age classes have increased during the 1990s (Table 8).

Natural Mortality

Silver hake are assumed to have a relatively high natural mortality rate consistent with their lifespan. The assumed natural mortality rate of 0.4 is generally consistent with estimates derived from life history parameters (e.g., Hoeing (1983) and Quinn and Deriso (1999)). Regardless, there is probably age-specific, geographic, and temporal variation in the natural mortality rate of silver hake in the northwest Atlantic.

The maximum age of silver hake in NEFSC surveys has changed dramatically through time (Figure 20). Maximum ages averaged 9.5 y during 1963-1988 and subsequently decreased to an average of 5.6 y during 1989-1999 based on spring and fall survey data. The important question raised by this truncation of age structure is, what has happened to the older fish? One possibility is that natural mortality on older ages changed substantially in the late 1980s due to environmental changes. Another possibility is that the availability of older silver hake to the NEFSC surveys has changed due to a shift in their spatial distribution. Another possibility is that fishing mortality from directed and non-directed fisheries has been too high to allow the age structure to rebuild. Unfortunately, this important question is unlikely to be answered through age-structured modeling because estimation of natural mortality and survey selectivity parameters determining capture probabilities at older ages are probably confounded (Thompson 1994). As a result, further field investigation will be needed to determine the most likely cause of the truncation of age structure.

Silver hake are an important component of the northeast continental shelf food web. Silver hake diet primarily consists of shrimp, small fish, and other hakes (Garrison and Link 2000a,b). Smaller silver hake feed intensively on euphausiids. Silver hake undergo an ontogenetic shift to increased piscivory (Garrison and Link 2000b,c). Fish has been a consistent component of silver hake diet through time, although fish consumption by silver hake was relatively lower in the 1980s. There has been a shift in diet in recent years from sand lance to herring (Pers. comm. Jason Link, NEFSC, unpublished data). Silver hake exhibit a higher frequency of cannibalism than other gadids in the northwest Atlantic, with medium-sized adults (age-2 and age-3) preying heavily upon age-0 and age-1 juveniles (Pers. comm., Jason Link, NEFSC and unpublished data). Predation by silver hake on groundfish is also substantial and may be on the order of 100 kt per year (Overholtz et al. 1999, Overholtz et al. 2000).

Length-Weight Relationship

Length-weight relationships of silver hake for northern, southern, and combined stock areas during 1992-1999 were estimated using methods described in Hayes et al. (1995). For each year, the estimated curves for the spring and fall were averaged to predict the mean weight at length at the midpoint of the year for determining the number of fish landed at age. In addition, possible changes in condition factor, as indexed by predicted mean weight at 25 cm of length, were investigated to see whether there had been declines in weight at length similar to those observed in the Scotian Shelf silver hake population (Hunt 1997, Showell and Fanning 1998). Results showed that there has been no apparent decline in silver hake condition factor in either northern or southern stock areas during the 1990s (Figure 21). Thus, the Scotian Shelf silver hake population appears to have a different trend in condition factor compared to the population in the US EEZ.

Maturity and Fecundity

Density-dependence in fraction of silver hake mature at age has been suggested for the northern and southern stock areas (see Helser and Brodziak 1998, and references therein). These density-dependent maturity models were not used in this assessment because of their dependence upon absolute estimates of stock sizes from a particular model. Instead, maturity ogives from the most recent assessment reported in Helser and Mayo (1994) were used to characterize population percent mature at age. In particular, percent mature at ages 1 through 6 and older were: 10%, 75%, 100%, 100%, 100%, and 100%, where the age-1 and age-2 values were the average of northern and southern stock values to the nearest 5%. These values of fraction mature at age were used in age-structured population modeling to provide an index of spawning biomass through time.

ESTIMATION OF FISHING MORTALITY RATES AND STOCK SIZE

Brief History of Assessments

The first preliminary assessment of silver hake in Subarea 5 (Georges Bank and the Gulf of Maine) is given in Gulland (1968) in the form of a series of interpretations of the likely sustainability of catches from the early 1960s. The foundation for the present VPA assessment framework was laid down in a series of papers by Anderson (1975a, 1975b, 1977), and a description of changes in ageing techniques is provided in (Anderson and Nichy 1975). Since the late 1970s, the assessment has been performed by several individuals in the form of multi-year updates (Anderson 1977, Anderson and Almeida 1979, Anderson and Almeida 1981, Almeida 1987, NEFC 1990a, NEFC 1990b).

There are 4 major events in the evolution of the catch at age data which has formed the basis of the assessment of the silver hake stocks:

1) Pooled age-length keys from USA and USSR ageing based on whole otoliths were used to derive the 1955-1972 catch at age.

2) Thin sectioned otoliths were used for ageing beginning in 1973 and this practices continues to present.

3) Discard estimates were included in the initial catch at age matrix for Division 5Y and Subdivision 5Ze silver hake assessments in the 1975 assessments. Discards primarily consisted of age 0 and 1 fish. Discards were excised from the catch at age data in all subsequent assessments.

4) A change in the assumed stock structure from 3 stocks to 2 stocks was implemented in the 1987 assessment.

VPAs were tuned using age-aggregated *ad hoc* techniques prior to 1990. In 1990 (SAW 11) both Laurec-Shepherd and ADAPT tuning methods were attempted. VPAs for both silver hake stocks were accepted with reservation at SAW 11, but the subsequent VPA assessments were rejected at SAW 17, due to a high degree of uncertainty and instability in parameter estimates.

Exploitation Rate Indices

Indices of relative exploitation rate were computed for northern and southern stock areas based on the ratio landings to fall survey biomass index (Figure 22). The exploitation rate index for the northern stock area shows high values for 1963-1975 followed by low values since 1976. The index for the southern stock is higher than for the northern stock throughout the time series. The southern exploitation rate index shows high values during 1963-1977 followed by a period of low values during 1978-1993. Since 1994, the southern exploitation rate index appears to be increasing. Together, the exploitation rate indices suggest that exploitation rates in recent years are much lower than during the 1960s and 1970s when foreign distant water fleets intensively harvested silver hake.

Age-specific exploitation rate indices were calculated for the combined stock area using NEFSC spring and fall survey data. The age-specific indices were examined to see whether the ratio of landings at age to survey numbers at age has changed through time. Substantial changes in age-specific exploitation rate indices were apparent (Figure 23). Some of the changes in the early 1970s coincide with prohibitions on fishing for silver hake in southern New England waters during January-March in 1970-1972 and during April 1973-1974 (Anderson et al. 1980). The age-specific exploitation rate indices were very high for ages 4, 5, and 6+ during the late 1960s and early 1970s. Between 1974 and 1975 there was a reduction in exploitation rate indices for the fall survey to low values that have persisted to the present. For the spring survey, there was a gradual reduction in the exploitation rates from 1975 to 1980 after which the indices were low and stable. Thus, the age-specific exploitation rate indices show that exploitation rates were higher in the

1960s through early 1970s, especially for older ages, and have remained low since around 1980.

Total Mortality Rates from Research Surveys

Estimates of instantaneous total mortality were computed for the combined stock area using NEFSC spring and fall numbers-at-age data and Heincke's method as used in the most recent assessment (NEFSC 1994). Results indicated that total mortality was high during the 1960s and that there has been an increasing trend in total mortality since the early 1980s (Table 9). If natural mortality has been constant and equal to 0.4, then the increasing trend in total mortality implies that fishing mortality has increased and is currently very high (F>1). This increase in F appears to contradict the trend in exploitation rate indices.

Sequential Age-Structured Population Analyses

An age-structured population analysis was conducted to estimate stock size and fishing mortality for silver hake in the combined stock area. This approach contrasts the approach taken in the most recent assessment where separate analyses were attempted for northern and southern stock areas. There were six reasons why separate age-structured analyses were not conducted for the northern and southern stock areas. First, catch-at-age data from the stock mixing area of Georges Bank likely contain errors in allocation to northern and southern components due to stock mixing and also due to errors in reporting catch amount and location, especially during the 1960s when distant water fleets intensively harvested silver hake on Georges Bank. Second, the commercial length frequency sampling of the northern stock area has been poor in the 1990s and was considered to be inadequate to characterize this component in isolation. Third, there has been a south to north shift in distribution of population biomass in recent years with the possible implication that silver hake stock components do not have the same spatial distribution through time. Fourth, there have been spatial changes in silver hake growth through time (see Helser 1996) and these changes in growth are not consistent with two distinct subpopulations separated by a boundary across Georges Bank. Fifth, analyses of silver hake growth data from the 1990s show that growth rates in northern and southern stock areas are very similar and therefore, silver hake from the two stock areas are currently exhibiting similar growth dynamics. Sixth, the most recent age-structured assessment based on two stocks was rejected because the models did not fit the data. Thus, it was expected that similar two-stock analyses would reproduce this lack of fit and provide no technical improvement over an index-based assessment of population status.

The ADAPT tuned-VPA model was applied to conduct age-structured analyses of the combined silver hake population using derived input data for catch at age (Table 4), survey numbers at age (Tables 6 and 7), catch weight at age (Table 8), and assumed natural mortality of 0.4. There were multiple model formulations that were examined. Of these, output for two model formulations that represent the baseline model with a very poor fit to the data and the best fit model were examined in detail at SAW32 whereas key features of other model formulations were summarized.

Residual patterns for model predictions of age-specific survey indices were very poor in the baseline model. There was a clear non-random trend in residuals across all age indices that went from low to high values. As a result, the baseline model was not considered to be reliable.

The best fit model was a model with 3 time periods of constant catchability for the spring and fall survey indices. These time periods were 1963-1974, 1975-1980, and 1981-1999. These periods were chosen based on observed residual patterns, changes in age-specific exploitation rate indices in 1974/75 for the fall survey and 1980/81 for the spring survey, possible changes in silver hake distribution associated with changes in the position of the shelf/slope front and the northern edge of the Gulf Stream (see Drinkwater et al. 2000), as well as reduced landings by the foreign fishery. The residuals for the 3-period catchability model appeared satisfactory, although some indications of low or high residuals were apparent. Estimated catchabilities for the 3-period catchability model showed an increasing trend through time for both spring and fall surveys (Figure 25), with the exception of the age-1 index during 1975-1980. This implied that the spatial distribution of the population had changed and was more available to both spring and fall surveys since 1980. Overall, recent outputs of the best fit ADAPT model (Figure 26) appeared to be inconsistent with the long-term trend in exploitation rate indices and for this reason, the model was discounted by the Northern Demersal Working Group.

Biomass Dynamics Population Analyses

A Bayesian state-space formulation of the Schaefer surplus production model was developed by Meyer and Millar (1999) and an extension of their model forms the basis for biomass dynamics analyses of silver hake in the northern, southern, and combined stock areas. We briefly describe the model, the Northern Demersal Groups' consensus on the most appropriate model structure and priors, and then show the surplus production results for the northern, southern, and combined silver hake stock areas.

The Bayesian surplus production (BSP) model uses a reparameterized form of the Schaefer surplus production model. The standard form of the Schaefer model relates stock biomass in year t (B_t) to biomass the previous year, intrinsic growth rate (r), carrying capacity (K) and catch the previous year (C_{t-1}) as

$$B_t = B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}$$

The reparameterized form relates the fraction of carrying capacity ($P_t = B_t/K$) to intrinsic growth rate, carrying capacity, and the catch time series as

$$P_t = P_{t-1} + rP_{t-1}\left(1 - P_{t-1}\right) - \frac{C_{t-1}}{K}$$

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. The state equations determine changes in relative stock biomass through time (t=1,...,N) via:

$$P_1 = \exp(u_1)$$

$$P_t = \left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}\right)\exp(u_t)\ for\ t \geq 2$$

$$C_t \sim Uniform[C_{L(t)}, C_{U(t)}]$$

where the independent lognormal process errors for relative biomass are $\exp(u_t)$ with $u_t \sim N(0,\sigma^2)$ and the annual catch error distribution is a uniformly distribution with time-varying upper ($C_{U(t)}$) and lower ($C_{L(t)}$) bounds.

Relative abundance in year t is measured by the mean weight per tow index (I_t) from the

NEFSC autumn and/or spring bottom trawl surveys. in the simplest form, the survey index is assumed to be proportional to stock biomass with constant survey catchability (q) throughout the assessment time horizon

$$I_t = qB_t$$

This relationship is the basis of the observation equations for the state-space model. Stock biomass is measured by the time series of survey indices. The observation equations relate the observed survey indices to model parameters via:

$$I_t = qKP_t \cdot \exp(v_t) \ for\ t = 1,\ldots,N$$

where the independent lognormal observation errors are $\exp(v_t)$ with $v_t \sim N(0,\tau^2)$.

In the simplest form for two surveys with constant catchability, the BSP model has eight parameters (r, K, q_{FALL}, fall_σ^2, fall_τ^2, q_{SPR},spr_σ^2,spr_τ^2), N unknown relative biomasses (P_t), and N unknown catches (C_t) for a total of 2N+8 unknowns. To describe the Bayesian estimation procedure, let the joint prior of the parameters and unobservables be p(r,K,q_{FALL},fall_σ^2,fall_τ^2, q_{SPR},spr_σ^2,spr_τ^2, P_t, C_t) ≡ p(Θ). Further, let the joint likelihood of the survey indices given the parameters and unobserved states be p(I_t | r,K,q_{FALL},fall_σ^2,fall_τ^2, q_{SPR},spr_σ^2,spr_τ^2, P_t, C_t) ≡ p(Data | Θ) and the joint posterior distribution of the unobservables be p(r,K,q_{FALL},fall_σ^2,fall_τ^2, q_{SPR},spr_σ^2,spr_τ^2 P_t, C_t | I_t) ≡ p(Θ | Data).

Bayes' theorem determines the posterior as a function of the prior and likelihood via

$$p(\Theta|Data) = \frac{p(Data|\Theta)p(\Theta)}{\int_{\Theta} p(Data|\Theta)p(\Theta)d\Theta}$$

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.

Several candidate versions of the three BSP models (northern, southern, and combined silver hake) were evaluated during the Northern Demersal Working Group meeting. These included models that used the fall survey biomass index alone with constant catchability, as well as models that included both surveys with 2 time periods of catchability and population dynamics. The single index models did not perform well and had moderate to strong residual patterns for the predicted survey indices. The Working Group concluded that the single index models had less information than the two index model, and as a result, the single index models were not used in further analyses. The 2-period catchability models using both survey indices were fit for 1963-1974 and 1975-1999 time periods with separate values of catchability, intrinsic growth rate, and carrying capacity for each time period. The 2-period, 2-index models had adequate residual patterns but did not have plausible biological parameters; these models implied marked changes in carrying capacity that were considered to be unrealistic. As a result, the Northern Demersal Working Group chose to use BSP models with a single catchability using both spring and fall survey indices as the basis for assessing stock status.

Initial choices of prior distributions for parameters and unobservables were refined for northern, southern, and combined silver hake BSP models following discussions of the Northern Demersal Working Group. The prior distribution for carrying capacity was a lognormal distribution with parameters chosen to set the 10th and 90th percentiles of the distribution. These percentiles were: combined area (700kt, 2000 kt), northern area (200 kt, 1000 kt), southern area (400 kt, 2000 kt). The prior distribution for intrinsic growth rate was a broad uniform distribution for each model with r~Uniform[0.01, 1.99].

The prior distribution for the inverse of survey catchability was chosen to be a high-variance gamma distribution as described in Meyer and Millar (1999). That is, the inverse of q was assumed to be distributed as Gamma(0.001,0.001). This choice gives a vague 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 [0.001, 10]. In effect, the bounding of q ensured 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 for both northern and southern monkfish. 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 parameter (τ^2) was chosen to be an inverse gamma distribution for both northern and southern monkfish. 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. Also note that the prior distribution for process error variance parameter was stochastically dominated by the prior for observation error variance parameter. That is, observation error was assumed to be somewhat larger than process error.

The prior distributions for the relative biomasses (P_t) were lognormal distributions for each BSP model. The prior distribution for relative biomass in the initial year of the assessment time horizon was $P_1 \sim \text{Lognormal}(0, \sigma^2)$. 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.

Uniform error distributions were assumed for total annual catch of northern, southern, and combined silver hake models during two time periods, 1963-1976 and 1977-1999. These time periods were based on the Northern Demersal Working Group discussion of the reliability of the time series of annual catches $\{C_t\}$ for each stock area. In particular, the accuracy of reported catches of silver hake by distant water fleets was raised. It was pointed out that there was a potential for under-reporting or over-reporting of silver hake catches during the 1960s and 1970s. Thus, catches were initially modeled during 1963-1976 as being Uniform[$C_{L(t)}$, $C_{U(t)}$] = [0.5C_t , 1.5C_t], where C_t was the reported landings (Table 1). This implied that the catch error was up to 50% during 1963-1976. After viewing the posterior distribution of total catches, the Working Group concluded that there was no information to estimate the total catch during this time period and chose to set the catch error distribution to be Uniform[$C_{L(t)}$, $C_{U(t)}$] = [0.9C_t , 1.1C_t]. This implied that the catches were likely measured with error but were unbiased. For the 1977-1999 period, it was assumed that total catch was under-reported due to discarding. The Working Group concluded that discard rates were not well-known and chose to go forward with a uniform catch error distribution of Uniform[$C_{L(t)}$, $C_{U(t)}$] = [C_t , 1.1C_t] for the period 1977-1999. This implied that the mean discard rate was 5% of reported catch since 1977.

Residual patterns of the three BSP models as well as convergence diagnostics were examined by the Working Group. The distribution of model predictions for the spring and fall survey indices were generally adequate and appeared randomly distributed for the combined, northern, and southern BSP models. For each parameter, convergence of the MCMC samples to the stationary posterior distribution was also evaluated using the corrected ratio (R_C) of mixture-of-sequences variance to the within-sequence variance as defined by German and Rubin (1992) and generalized by Brooks and German (1998). At convergence, the R_C is expected to be near 1. For each of the three models, the convergence diagnostics generally indicated that the model parameters had converged. In contrast, the extremely low intrinsic growth rate (r=3%) for the southern stock led the Northern Demersal Working Group to discount this model. Overall, given the uncertainties about misallocation of catches to northern and southern stocks and the north-south changes in the spatial distribution of the silver hake population, the Working Group recommended that the combined BSP model be used for management advice.

Summary statistics and marginal densities of model parameters of interest (r,K,q_{FALL},fall_σ^2,fall_τ^2, q_{SPR},spr_σ^2,spr_τ^2) were computed. In addition, several derived parameters were also summarized: B[YEAR], stock biomass (kt) at the beginning of the each year where YEAR=1 corresponds to 1963; H[YEAR], the exploitation rate in YEAR starting with YEAR=1 for 1963; HMSP, the exploitation rate that would produce maximum surplus production; HRATIO, the ratio of the exploitation rate in 1999 to HMSP.; MSP, the maximum surplus production (kt) from the stock. Time series of stock biomass (Figure 27) and exploitation rate (Figure 28) were also computed.

BIOLOGICAL REFERENCE POINTS AND HARVEST CONTROL RULE

Age-Based Biological Reference Points

Yield- and spawning biomass per recruit analyses were conducted for combined silver hake. Catch weights at age were the 7-year average of observed catch weights at age. The growth curve for 1993-1998 was used to compute stock weights at age, except for ages 5 and 6 where the catch weights were used. The fraction mature at age and natural mortality rate were the same as used in the ADAPT analyses. Analyses were conducted for two partial recruitment patterns: dome-shaped and flat topped selectivity at older ages. For the dome-shaped analysis, partial recruitment values were the 7-year average of most recent values taken from the best fit ADAPT model. For spawning biomass per recruit analyses, the value of 40% of unfished spawning potential was chosen as a target based on Clark's (1993) paper and based on previous values used for northern and southern silver hake stocks. Results show that F40%=0.49 and F0.1= 0.38 for dome-shaped selectivity while F40%=0.40=M and F0.1=0.34 for flat-topped selection.

Index-Based Biological Reference Points

Proxies for determining whether northern and southern silver hake were overfished was put forward by a panel that reviewed overfishing definitions for northeast groundfish stocks in 1998 (NEFMC 1999). In 1999, the northern stock would be classified as above its biomass target while the southern stock would be classified as being below its biomass threshold using the best available survey data (Table 10). As a result, the northern stock would be considered to be healthy while the southern stock would be considered to be depleted.

Biomass-Based Biological Reference Points

The biomass dynamics models provide estimates of the biomass that would produce maximum surplus production, BMSP, the harvest rate that would produce maximum surplus production, HMSP, and the amount of maximum surplus production, MSP, for the combined, northern, and southern stock areas (Table 11). As noted in the section on Biomass Dynamics Analyses, the Northern Demersal Working Group recommended that the combined silver hake analyses be used for management advice given the changes in spatial distribution of the resource and the potential misallocation of catches to northern and southern components.

Harvest Control Rule

Hypothetical harvest control rules were developed for northern, southern, or combined silver hake stock areas using information from the surplus production model. The target harvest rate was proposed to be 60% of the median of the distribution of exploitation rate that would produce maximum surplus production for the stock unit. The limit harvest rate was proposed to be the median of the distribution of exploitation rate that would produce maximum surplus production. A value of 60% was chosen for the uncertainty reduction in the target harvest rate to account for the importance of silver hake within the northeast continental shelf food web as well as to account for uncertainties due to misallocation of catch to stock unit and also due to discarding of silver hake.

CONCLUSIONS

The population dynamics of silver hake in the US EEZ have changed through time. In particular, patterns of growth and spatial distribution have changed substantially over the past 40 years. The age structure of the silver hake population in recent years appears to be truncated at about age-6 whereas historically, silver hake of age 6 and older were much more frequently observed. Older silver hake may be less vulnerable to the fishery and survey in recent years because their spatial distribution has changed. Alternatively, continued high fishing mortality rates may have precluded the rebuilding of age structure following the cessation of the foreign distant water fleet fishery. Survey data indicate that biomass in the northern stock area is high and that biomass in the southern stock area is low. For the combined stock area, biomass is likely near carrying capacity and harvest rates appear to be low. Regardless of uncertainties about the status of northern and southern components, the silver hake population constitutes an important link in the food web and increases in exploitation rate should be made with due caution.

NORTHERN DEMERSAL WORKING GROUP COMMENTS

Stock Structure

In the past, silver hake off the Northeastern USA has been considered to be two stocks (north & south components), based on morphometric analysis. These differences may not be biologically important, and evidence was presented that suggested the entire area might be treated as a single stock. Examination of temperature patterns and trends in silver hake distribution support the view that there has been a shift in range from south to north, forced by environmental conditions. Stock mixing occurs on Georges Bank, but the amount of mixing is unknown and likely changes over time.

The Working Group noted that the stock definition in the Gulf of Maine did not include portions of Division 4X covering the Bay of Fundy and surrounding area. It appears likely silver hake in these areas are more closely associated with the Gulf of Maine rather than the Scotian Shelf stock, and that survey data from these strata are excluded from tuning indices for the Scotian Shelf silver hake assessment. The Working Group notes that this is likely a transboundary stock in this region, and recommends that information from the western Scotian Shelf be examined in conjunction with data from the Gulf of Maine.

Life History

Natural mortality for this species has been assumed to be 0.4, which is consistent with a likelihood profile from several ADAPT VPA analyses. Concern was raised over whether this value was appropriate, and it was noted that existing methods to estimate M should be examined to determine whether 0.4 is consistent with the life history of this species. Variation in M over time and ages should also be investigated.

A truncation of older ages and an interpretation of changes in growth was observed from the survey data in recent years. The possibility of the reduction of older age groups being related to possible changes in interpretation of otolith readings was discounted, given that routine checks and age validation procedures are in place.

The Fishery

Catches for silver hake were highest in the mid-1960's when the bulk of the fishery was conducted in the southern area by USSR distant water fleets. Catches peaked at more than 300,000mt in 1963, but have dropped to relatively low levels since the late1970's. The very high landings reported by the USSR in 1963-66 was noted by the Working Group, and the accuracy of these statistics was debated. Further information on reporting practices by foreign fleets can be investigated to facilitate interpretation of catches during this period.

The Working Group noted that seasonal and spatial coverage of the commercial port sampling was generally poor in 1994 and 1995 with respect to characterizing length composition of the landings by northern and southern components.

Landings data do not include estimates of discards, although discarding occurs in this fishery. Landings therefore represent an underestimate of total catch. Although very little discarding is considered to occur on silver hake directed trips in recent years, discarding of silver hake by-catch in other fisheries may be substantial. The extent to which this occurs should be investigated.

Research Vessel Surveys

The Working Group noted that 200 fm was the maximum depth fished during the Research Vessel surveys and that catches are often high in deep strata on the shelf edge. This suggests that a component of the population may not be sampled by the surveys. The question of size segregation by depth was raised. If larger fish move to the deeper water and are not sampled, interpretation of the Research Vessel data becomes complicated. Further investigation of size distribution by depth is warranted.

There was some concern expressed over the results of the RV surveys, noting that catch rates appear low in some areas where commercial catch rates are known to be high. A strong day/night difference in commercial and survey catch rates was noted, and adjustment for this effect should reduce the variability of survey abundance estimates.

Relative F (catch-at-age numbers divided by survey numbers) was calculated to show exploitation trends. From this, highest exploitation was seen in the early part of the series (mid-1960's to early 1970's) for both the spring and fall survey. An apparent shift in age specific exploitation indices for the fall survey and coincident changes in environmental conditions were evident between 1975 and 1981, suggesting a possible change in catchability. However, the Working Group noted that catchability of the survey was likely confounded with that of the fishery, making interpretation difficult. The Working Group suggested that a separable VPA be performed to evaluate possible changes in q in the catch-at-age data alone. These results suggest that some abrupt changes in catchability occurred during the earlier time periods. The Working Group also noted that no ageing data exists prior to 1973, and that commercial and survey catch at age information were derived from imputed age length keys; this was considered a source of uncertainty for age structured analyses.

Total mortality (Z) was calculated from the research vessel survey abundance at age estimates for spring and fall surveys. From this analysis, Z appeared to be high during the early part of the series (1964-72), somewhat lower from 1973-82, and high again in recent years. The possibility that the high Z in the most recent period might be a cumulative effect related to the removal of older age groups was discussed. The appropriateness of including data based on imputed age/length keys prior to 1973 in the analysis was questioned.

POPULATION RECONSTRUCTION

ADAPT VPA.

A baseline VPA using 1963-99 catch-at-age, spring and fall RV survey indices and constant survey catchability was presented. Results of the analysis showed a clear lack of fit, with strong low to high patterns evident in the residuals for all age indices. A second VPA was presented, with the RV surveys treated as three separate indices with break points at 1975 and 1981 (i.e., where q appeared to change in the relative F analysis). While the residual patterns appeared somewhat better for this analysis, the Working Group noted that this reconstruction of the population showed F to be very high in recent years when catches are at very low levels, and to be only moderate in the early period when catches were very high. A number of different ADAPT formulations were suggested by the Working Group:

- shorten the data series - use catch-at-age from 1967 onward
- shorten the data series - use data from 1981 onward
- increase m over time, for older ages in the most recent years

In each of these VPA formulations, the residual pattern persisted, but was less severe than in the original analysis. Further, the Working Group noted that terminal year estimates of N and F derived from the VPA were quite variable and sensitive to inclusion or exclusion of pre-1981 catch and survey data. VPA results were also inconsistent with observed trends in the survey indices used to calibrate the VPA, as indicated by the persistent residual pattern.

Bayesian Surplus Production Model

A surplus production model using a Bayesian approach was presented. Analyses were conducted for the Northern and Southern components both combined and separately, with catchability constant and divided into two periods. The model was run with the two periods to take into account the previously noted possible changes in catchability. However, the two-period model was considered to be over-parameterized, and the abrupt changes in carrying capacity (K) estimated by this formulation of the model were not considered credible. The Working Group therefore recommended that the production model analyses be based on a single time period.

Following a detailed explanation of the method, discussion centered on possible adjustments to the ranges of input `priors` used in the analysis. The assumption of a maximum 5% discard level was questioned as too low. The Working Group came to consensus on priors for major model parameters, including catch error distribution. The Working Group examined separate production models for the northern and southern stocks and noted considerable differences, particularly in the estimation of r and K. Taking into account trends in survey biomass indices and exploitation ratios, changes in environmental conditions over time, and mixing of northern and southern components, the Working Group considered that a combined stock analysis was more appropriate than a split stock analysis.

In conclusion, the Working Group noted that the age-aggregated production model is not subject to uncertainty in estimates of catch at age that undermine confidence in the VPA approach for silver hake. The Working Group therefore considers an age-aggregated approach more appropriate for deriving trends in population status, and for deriving reference points for this stock.

Working Group Recommendation

It was noted that for analysis of growth, condition and truncation of age groups, males and females were grouped. This approach was questioned given known differences in growth rates between the sexes for this species. The Working Group ***recommends*** *that in future analyses males and females should be examined separately.*

SOURCES OF UNCERTAINTY

Population structure.

Total commercial removals.

The cause(s) for the truncation of the age structure of the silver hake population.

RESEARCH RECOMMENDATIONS

Develop survey information that covers the offshore range of population.

Conduct surveys of spawning aggregations on the southern flank of Georges Bank.

Investigate bathymetric demography of population.

Investigate spatial distribution, stock structure, and movements of silver hake within Georges Bank, the Gulf of Maine, and the Scotian Shelf in relation to physical oceanography.

Quantify age-specific fecundity of silver hake.

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Table C1. Silver hake landings (mt) by area, 1955-1999 (prorations to area during 1994-99 are provisional).

Year	Foreign Fishery Total Northern Stock Area	US Total Northern Stock Area	Total Landings Northern Stock Area	Foreign Fishery Total Southern Stock Area	US Total Southern Stock Area	Total Landings Southern Stock Area	Unreported Stock Area
1955		53,361	53,361		13,842	15,717	
1956		42,150	42,150		14,871	16,564	
1957		62,750	62,750		17,153	17,153	
1958		49,903	49,903		13,473	13,473	
1959		50,608	50,608		17,112	17,112	
1960		45,543	45,543		9,206	9,206	
1961		39,688	39,688		13,209	13,209	
1962	36,575	42,427	79,002	5,325	13,408	18,733	
1963	37,525	36,399	73,924	74,023	19,359	93,382	
1964	57,240	37,222	94,462	127,036	26,518	153,584	
1965	15,793	29,449	45,242	283,366	23,765	307,131	
1966	14,239	33,477	47,716	200,058	11,212	211,270	
1967	6,882	26,489	33,371	81,749	9,500	91,249	
1968	10,506	30,873	41,379	49,422	9,074	58,496	
1969	8,047	15,917	23,964	67,396	8,165	75,561	
1970	12,305	15,223	27,528	20,633	6,879	27,512	
1971	25,243	11,158	36,401	66,344	5,546	71,890	
1972	18,784	6,440	25,224	88,381	5,973	94,396	
1973	18,086	13,997	32,083	97,989	6,604	104,593	
1974	13,775	6,905	20,680	102,112	7,751	109,863	
1975	27,308	12,566	39,874	65,812	8,441	74,253	
1976	151	13,483	13,634	58,307	10,434	68,741	
1977	2	12,455	12,457	47,850	11,458	59,308	
1978		12,609	12,609	14,353	12,779	27,132	
1979		3,415	3,415	4,877	13,498	18,375	
1980		4,730	4,730	1,698	11,848	13,546	
1981		4,416	4,416	3,043	11,783	14,826	
1982		4,656	4,656	2,397	12,164	14,561	
1983		5,310	5,310	620	11,520	12,140	
1984		8,289	8,289	412	12,731	13,143	
1985		8,297	8,297	1,321	11,843	13,164	
1986		8,502	8,502	550	9,573	10,123	
1987		5,658	5,658	2	10,121	10,121	
1988		6,767	6,767		9,195	9,194	
1989		4,646	4,646		13,169	13,169	
1990		6,379	6,379		13,615	13,615	
1991		6,053	6,053		10,093	10,093	
1992		5,302	5,302		10,288	10,288	
1993		4,360	4,360		12,912	12,912	
1994		103	103		7,039	7,039	8,916
1995		245	245		2,728	2,728	11,755
1996		318	318		3,082	3,082	12,799
1997		133	133		2,416	2,416	13,036
1998	-	118	118		1,849	1,849	12,992
1999		540	540		2,422	2,422	11,139

Silver hake landings (mt) prorated to area, 1994-1999

Table C2. Silver hake landings (mt) by market category and period.

Annual Total Landings (mt)

		Market Category		
Year	Small	Unclassified	Large	Total
1993	1,320	15,598	387	17,306
1994	5,567	10,067	423	16,058
1995	2,269	11,700	759	14,727
1996	3,348	12,145	707	16,199
1997	4,660	9,903	1,022	15,585
1998	3,694	10,199	1,067	14,959
1999	3,664	9,626	811	14,100
Average	3,503	11,320	739	15.562

1st Half of Year Total Landings (mt): January-June

		Market Category		
Year	Small	Unclassified	Large	Total
1993	1	7,692	125	7,819
1994	2,949	4,311	233	7,493
1995	1,418	5,280	389	7,087
1996	1,514	6,091	337	7,941
1997	2,741	4,864	621	8,226
1998	1,622	5,471	560	7,653
1999	2,362	4,960	426	7,748
Average	1,801	5,524	384	7,710

2nd Half of Year Total Landings (mt): July-December

		Market Category		
Year	Small	Unclassified	Large	Total
1993	1,319	7,906	262	9,487
1994	2,618	5,756	190	8,564
1995	851	6,420	370	7,641
1996	1,834	6,054	370	8,258
1997	1,919	5,039	401	7,359
1998	2,072	4,728	506	7,306
1999	1,301	4,667	385	6,353
Average	1,702	5,796	355	7.852

Landings (mt) with Half of Year Not Reported

		Market Category		
Year	Small	Unclassified	Large	Total
1993		1,091		1,091
1994		857		857

Table C3. Silver hake commercial length frequency samples by time period, area, and market category , 1993-1999.

1993			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish					1414	41
	Avg Length (cm)					29.5	39
2nd Half	Number of Fish		886		212	900	100
	Avg Length (cm)		28.1		26.3	31.4	43.3

1994			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish		297		762	1593	120
	Avg Length (cm)		29.6		27.9	31	43.4
2nd Half	Number of Fish		612		617	1605	
	Avg Length (cm)		29.7		27.4	30.7	

1995			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish	202	348		409	2226	337
	Avg Length (cm)	28.1	35.4		28	31.7	43.2
2nd Half	Number of Fish		252	92		285	88
	Avg Length (cm)		28.8	50.4		30	34.6

1996			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish				821	299	
	Avg Length (cm)				26.1	33.2	
2nd Half	Number of Fish		601	56	274	698	100
	Avg Length (cm)		27.9	38.3	27	28.6	39.1

1997			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish				1426	3034	1553
	Avg Length (cm)				27.9	29.9	34.3
2nd Half	Number of Fish	209	207		533	236	157
	Avg Length (cm)	27.2	27.3		24.2	30.2	33.3

1998			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish				1117	3143	736
	Avg Length (cm)				26.6	28.7	36.2
2nd Half	Number of Fish		710	42	434	1615	410
	Avg Length (cm)		28.7	42.5	26.2	27	33.3

1999			Northern Area			Southern Area	
Half of Year		Small	Unclassified	Large	Small	Unclassified	Large
1st Half	Number of Fish		170		1347	3055	626
	Avg Length (cm)		29		26	27.7	36.6
2nd Half	Number of Fish		147	113	895	932	291
	Avg Length (cm)		31.6	50.1	26.3	27.8	37.9

Table C4. Silver hake landings (millions of fish) at age for combined stock area.

Number of Fish Landed by Age (millions)

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+	Total
1955	34.4	29.5	70.2	90.9	39.1	28.0	292.1
1956	78.1	59.3	56.9	76.4	31.8	19.4	321.9
1957	55.2	41.7	90.1	107.4	51.2	33.0	378.6
1958	41.5	48.0	64.9	73.1	33.8	29.2	290.5
1959	21.9	41.4	94.8	78.9	35.5	26.2	298.7
1960	16.4	54.7	88.9	63.8	25.7	19.7	269.2
1961	1.5	29.4	85.9	73.0	24.4	17.8	232.0
1962	3.1	40.1	158.9	157.4	57.5	25.9	442.9
1963	21.4	82.1	308.6	299.2	82.7	31.1	825.1
1964	19.8	111.9	419.9	394.9	135.3	75.5	1157.3
1965	50.9	227.6	985.9	607.0	93.4	41.4	2006.2
1966	24.0	380.1	590.2	360.6	97.6	55.0	1507.5
1967	16.4	126.8	248.8	209.8	51.1	21.4	674.3
1968	11.0	28.5	169.2	140.3	65.5	39.2	453.7
1969	4.9	30.6	127.8	121.9	56.9	45.5	387.6
1970	66.6	41.1	49.7	66.7	36.5	30.0	290.6
1971	12.0	65.6	166.1	128.8	64.2	62.8	499.5
1972	212.2	218.6	130.1	37.2	7.2	4.1	609.4
1973	106,2	416.5	137.1	33.8	6.7	2.5	702.8
1974	95.3	255.0	163.6	83.3	19.9	13.5	630.6
1975	14.2	166.7	212.7	71.3	27.7	7.4	500.0
1976	9.3	105.8	167.4	103.9	13.3	3.0	402.7
1977	4.4	42.7	155.2	83.7	14.2	6.3	306.5
1978	4.9	35.0	27.5	38.8	26.0	6.5	138.7
1979	8.8	25.5	19.6	9.4	12.2	10.8	86.3
1980	4.7	29.2	31.5	11.5	4.9	7.6	89.4
1981	22.5	32.4	35.8	20.1	5.6	4.1	120.5
1982	18.3	41.8	15.1	12.3	10.3	4.7	102.5
1983	11.0	37.1	20.7	7.8	6.0	4.5	87.1
1984	10.2	67.0	32.8	8.7	1.9	1.5	122.1
1985	18.0	32.9	37.0	11.5	1.9	1.2	102.5
1986	14.4	42.2	26.4	9.1	2.1	1.1	95.3
1987	6.1	38.3	28.9	7.5	5.4	0.3	86.5
1988	4.1	28.2	40.1	10.3	1.8	0.2	84.7
1989	6.0	32.0	49.0	12.0	1.0	0.0	100.0
1990	4.2	38.8	39.3	16.0	2.7	0.2	101.2
1991	2.6	24.6	36.0	19.7	2.8	0.5	86.2
1992	3.5	29.9	37.6	12.8	0.7	0.0	84.5
1993	8.7	36.9	31.7	16.5	2.3	0.1	96.1
1994	2.0	37.0	37.8	10.8	0.4	0.0	88.1
1995	5.5	22.8	26.6	11.9	1.0	0.2	67.9
1996	3.5	34.6	41.9	11.9	0.7	0.0	92.6
1997	6.8	37.7	36.3	6.1	0.3	0.0	87.3
1998	8.0	41.6	32.6	5.9	0.4	0.1	88.5
1999	12.7	43.0	27.0	5.0	0.4	0.2	88.4

Combined Silver hake average landings at age by time period (millions)

	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+	Total
Avg 55-59	46.2	44.0	75.4	85.3	38.3	27.2	316.4
Avg 60-64	12.4	63.6	212.4	197.7	65.1	34.0	585.3
Avg 65-69	21.4	158.7	424.4	287.9	72.9	40.5	1005.9
Avg 70-74	98.5	199.4	129.3	70.0	26.9	22.6	546.6
Avg 75-79	8.3	75.1	116.5	61.4	18.7	6.8	286.8
Avg 80-84	13.3	41.5	27.2	12.1	5.7	4.5	104.3
Avg 85-89	9.7	34.7	36.3	10.1	2.4	0.6	93.8
Avg 90-94	4.2	33.4	36.5	15.2	1.8	0.2	91.2
Avg 95-99	7.3	35.9	32.9	8.2	0.6	0.1	84.9
Avg 55-92	24.6	76.3	121.2	83.1	25.8	15.1	346.1

Table C5. Silver hake biomass indices from NEFSC fall and spring surveys for northern, southern, and combined stock areas.

	Northern Area Fall		Northern Area Spring		Southern Area Fall		Southern Area Spring		Combined Area Fall		Combined Area Spring	
Year	Mean Weight (kg) Per Tow	Stderr	Mean Weight (kg) Per Tow	Stderr	Mean Weight (kg) Per Tow	Stderr	Mean Weight (kg) Per Tow	Stderr	Mean Weight (kg) Per Tow	Stderr	Mean Weight (kg) Per Tow	Stderr
1963	25.418	6.200			3.418	0.840			12.081	2.528		
1964	4.415	0.878			2.908	0.525			3.499	0.471		
1965	6.475	1.802			3.773	0.653			4.834	0.818		
1966	4.124	0.765			1.760	0.274			2.688	0.346		
1967	2.158	0.576			2.186	0.303			2.175	0.291		
1968	2.048	0.546	0.036	0.017	2.693	0.341	3.756	1.615	2.439	0.298	2.296	0.981
1969	2.635	0.583	0.192	0.053	1.256	0.171	2.202	0.430	1.797	0.251	1.413	0.262
1970	3.034	0.798	14.133	13.352	1.332	0.174	1.233	0.176	2.000	0.331	6.297	5.243
1971	2.466	0.498	0.406	0.125	2.210	0.363	2.192	0.301	2.310	0.295	1.491	0.190
1972	6.085	0.947	1.702	0.649	2.000	0.437	1.399	0.209	3.603	0.457	1.518	0.285
1973	4.150	0.575	3.126	0.980	1.699	0.297	4.968	0.710	2.661	0.289	4.245	0.578
1974	3.764	1.034	2.682	0.504	0.862	0.177	3.474	0.552	2.001	0.420	3.163	0.389
1975	8.234	1.127	9.720	2.769	1.840	0.299	6.486	1.372	4.350	0.478	7.768	1.375
1976	12.632	2.762	8.829	1.702	2.062	0.279	4.110	0.724	6.211	1.097	5.963	0.800
1977	7.593	2.474	3.699	0.626	1.773	0.431	4.553	0.713	4.058	1.006	4.217	0.498
1978	7.072	0.970	0.813	0.145	2.931	0.698	5.307	0.932	4.556	0.570	3.542	0.569
1979	6.651	0.974	1.617	0.314	1.741	0.205	2.342	0.562	3.669	0.402	2.058	0.363
1980	6.655	1.205	4.151	0.638	2.122	0.734	2.779	0.474	3.903	0.650	3.318	0.382
1981	4.057	1.024	2.269	0.380	1.166	0.166	3.761	0.557	2.301	0.415	3.174	0.369
1982	5.450	3.063	1.346	0.272	1.651	0.329	2.018	0.459	3.143	1.219	1.754	0.299
1983	9.205	1.884	1.507	0.332	3.200	1.124	1.376	0.241	5.558	1.006	1.428	0.196
1984	3.621	0.783	1.090	0.174	1.558	0.470	2.209	0.549	2.369	0.419	1.770	0.340
1985	8.583	1.406	2.645	0.742	3.907	1.926	2.642	0.464	5.743	1.294	2.643	0.405
1986	14.194	2.324	3.247	0.802	1.388	0.240	2.672	0.475	6.415	0.924	2.898	0.427
1987	9.836	1.375	3.802	0.675	1.619	0.381	3.617	0.881	4.848	0.588	3.690	0.597
1988	6.312	1.229	1.256	0.217	1.830	0.421	1.709	0.340	3.590	0.546	1.531	0.223
1989	12.549	3.221	3.566	0.861	2.120	0.539	2.316	0.554	6.214	1.306	2.806	0.477
1990	15.246	3.805	1.623	0.443	1.645	0.277	3.869	2.400	6.994	1.506	2.985	1.465
1991	11.889	3.480	1.381	0.200	0.907	0.197	1.459	0.355	5.219	1.371	1.428	0.230
1992	14.245	5.407	5.655	1.722	0.978	0.137	0.528	0.185	6.200	2.130	2.549	0.688
1993	8.117	1.565	2.497	0.601	1.329	0.254	1.362	0.493	3.996	0.634	1.809	0.381
1994	6.925	0.977	7.319	3.849	0.799	0.129	2.278	0.793	3.204	0.391	4.263	1.590
1995	13.161	1.953	3.485	0.821	1.641	0.561	0.999	0.400	6.164	0.839	1.975	0.404
1996	7.886	1.233	3.463	1.121	0.431	0.070	6.216	5.698	3.358	0.486	5.135	3.489
1997	5.638	1.113	1.188	0.185	0.842	0.160	0.684	0.113	2.725	0.448	0.883	0.100
1998	21.966	6.752	4.446	0.763	0.620	0.110	0.686	0.190	9.000	2.652	3.435	0.743
1999	11.636	1.142	4.234	0.837	0.870	0.352	1.774	0.679	5.097	0.497	2.415	0.696
2000			10.002	1.583			1.049	0.369			4.909	0.885
Average	8.274		3.348		1.813		2.718		4.351		2.996	

Table C6. Silver hake combined area number per tow at age, autumn survey, delta-distribution.

Year	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+	Age-2+	Age-3+
1963	9.050	70.097	34.382	15.339	3.973	1.414	0.417	55.525	21.144
1964	0.218	15.596	9.763	2.894	0.997	0.350	0.108	14.112	4.349
1965	0.594	15.472	24.784	6.498	1.135	0.388	0.241	33.045	8.261
1966	0.000	12.859	27.095	17.811	4.448	1.707	0.724	51.785	24.690
1967	0.972	9.066	3.099	0.439	0.135	0.069	0.026	3.768	0.670
1968	5.923	14.892	12.396	4.342	1.430	0.535	0.099	18.802	6.406
1969	16.782	3.450	1.952	0.231	0.036	0.009	0.002	2.231	0.279
1970	3.041	14.910	6.660	0.645	0.143	0.048	0.043	7.539	0.879
1971	24.403	10.200	9.255	1.715	0.378	0.138	0.028	11.514	2.260
1972	4.845	30.489	15.654	1.347	0.312	0.137	0.053	17.503	1.849
1973	9.510	4.596	5.566	2.203	0.453	0.249	0.084	8.556	2.989
1974	49.134	22.469	18.078	4.780	1.674	0.750	0.458	25.740	7.662
1975	36.131	14.267	9.579	3.598	1.287	0.466	0.328	15.259	5.679
1976	62.159	5.383	12.602	9.556	3.463	0.672	0.776	27.068	14.466
1977	79.725	6.061	4.626	7.662	4.110	0.836	0.217	17.450	12.825
1978	46.105	10.660	4.900	3.124	3.590	3.546	0.888	16.048	11.148
1979	12.983	13.317	7.233	1.732	0.861	0.781	1.001	11.607	4.375
1980	27.857	5.308	6.353	8.717	2.268	0.922	2.182	20.443	14.089
1981	31.545	6.210	2.582	3.228	2.540	0.462	0.547	9.357	6.775
1982	40.194	9.059	5.557	1.908	1.292	0.948	0.290	9.995	4.438
1983	17.891	25.662	13.715	1.696	0.579	0.495	0.302	16.786	3.071
1984	18.214	5.838	4.794	1.596	0.400	0.093	0.053	6.935	2.141
1985	75.643	28.159	3.897	4.960	1.314	0.183	0.126	10.480	6.583
1986	11.598	35.081	10.083	1.712	1.203	0.198	0.000	13.196	3.114
1987	21.144	2.330	4.331	3.503	0.266	0.028	0.013	8.141	3.810
1988	2.454	13.078	38.834	8.183	1.214	0.736	0.084	49.052	10.217
1989	17.897	22.804	11.819	7.062	0.694	0.054	0.030	19.660	7.841
1990	24.994	7.312	24.781	6.370	2.428	0.425	0.033	34.037	9.256
1991	49.547	12.946	13.839	5.362	0.867	0.050	0.000	20.118	6.279
1992	54.518	19.480	20.854	5.236	0.221	0.000	0.000	26.311	5.457
1993	5.066	23.488	15.037	2.120	0.448	0.023	0.000	17.627	2.591
1994	12.818	8.164	18.670	1.488	0.078	0.000	0.000	20.236	1.566
1995	52.622	39.939	19.031	4.066	0.162	0.000	0.000	23.259	4.228
1996	2.139	6.880	15.011	3.696	0.351	0.022	0.008	19.090	4.078
1997	43.196	9.704	12.301	2.898	0.219	0.014	0.007	15.438	3.137
1998	23.942	99.721	22.674	2.461	0.328	0.015	0.015	25.493	2.819
1999	62.057	24.966	16.780	0.797	0.157	0.031	0.021	17.786	1.006
Average	25.862	18.376	13.205	4.351	1.228	0.454	0.249	19.486	6.282

Table C7. Silver hake combined area number per tow at age, spring survey, delta distribution.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6+	Age-2+	Age-3+
1968	13.458	5.335	2.745	0.626	0.166	0.038	8.910	3.575
1969	4.492	4.580	2.665	0.945	0.283	0.086	8.560	3.980
1970	19.558	2.994	2.000	1.197	0.457	0.214	6.862	3.868
1971	9.405	5.857	2.331	0.513	0.163	0.066	8.930	3.073
1972	18.621	3.507	1.133	0.379	0.124	0.043	5.185	1.678
1973	6.859	10.711	3.282	0.920	0.134	0.092	15.139	4.428
1974	39.916	3.706	3.701	1.896	0.627	0.301	10.230	6.524
1975	33.037	41.183	10.718	2.589	0.742	0.080	55.311	14.128
1976	14.000	16.416	8.850	2.150	0.558	0.279	28.253	11.837
1977	3.687	3.421	5.443	2.735	0.549	0.399	12.547	9.127
1978	4.638	3.107	1.521	1.992	1.086	0.352	8.057	4.950
1979	7.804	6.898	0.884	0.371	0.542	0.446	9.141	2.243
1980	5.208	10.499	4.216	0.715	0.207	0.491	16.127	5.628
1981	7.878	3.825	3.722	2.075	0.722	0.593	10.937	7.112
1982	5.472	4.298	1.180	0.907	0.749	0.465	7.601	3.302
1983	6.212	6.025	0.926	0.510	0.266	0.279	8.005	1.981
1984	3.071	5.709	2.093	0.461	0.129	0.173	8.565	2.857
1985	21.241	4.376	3.868	1.387	0.304	0.194	10.129	5.753
1986	35.614	9.921	1.988	1.686	0.288	0.089	13.972	4.051
1987	4.345	21.487	4.978	1.022	0.542	0.055	28.084	6.596
1988	3.561	2.157	6.137	0.817	0.079	0.022	9.213	7.056
1989	49.274	5.194	4.919	1.695	0.086	0.012	11.906	6.711
1990	9.381	14.843	5.388	0.984	0.225	0.037	21.477	6.634
1991	19.065	3.562	3.325	1.774	0.372	0.104	9.137	5.576
1992	58.078	20.520	3.993	1.233	0.067	0.000	25.814	5.294
1993	18.089	16.362	3.612	0.976	0.141	0.000	21.091	4.729
1994	3.933	35.884	13.688	0.921	0.033	0.005	50.531	14.647
1995	22.590	22.799	5.644	1.277	0.037	0.005	29.762	6.963
1996	2.660	17.345	31.833	1.320	0.043	0.011	50.551	33.206
1997	2.281	3.299	3.056	0.368	0.027	0.007	6.758	3.458
1998	111.241	56.314	1.303	0.322	0.000	0.000	57.939	1.624
1999	5.983	36.378	1.853	0.443	0.098	0.000	38.772	2.394
2000	42.365	78.073	6.120	0.997	0.179	0.051	85.419	7.346
Average	18.576	14.745	4.822	1.158	0.304	0.151	21.179	6.434

Table C8. Silver hake average landed weight at age (kg) for the combined stock area.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age6+
1955	0.045	0.122	0.189	0.249	0.326	0.481
1956	0.038	0.086	0.186	0.253	0.324	0.465
1957	0.064	0.101	0.180	0.252	0.323	0.434
1958	0.052	0.104	0.188	0.268	0.336	0.450
1959	0.042	0.122	0.177	0.256	0.344	0.483
1960	0.052	0.112	0.169	0.230	0.319	0.500
1961	0.068	0.137	0.179	0.233	0.309	0.501
1962	0.069	0.130	0.169	0.226	0.302	0.482
1963	0.079	0.114	0.168	0.216	0.294	0.520
1964	0.058	0.114	0.159	0.216	0.307	0.540
1965	0.063	0.107	0.155	0.202	0.304	0.512
1966	0.060	0.092	0.149	0.211	0.308	0.525
1967	0.046	0.095	0.158	0.220	0.307	0.499
1968	0.049	0.105	0.151	0.224	0.318	0.478
1969	0.064	0.126	0.191	0.251	0.313	0.510
1970	0.053	0.103	0.173	0.221	0.282	0.461
1971	0.064	0.106	0.158	0.207	0.274	0.496
1972	0.091	0.200	0.279	0.378	0.409	0.587
1973	0.103	0.168	0.253	0.315	0.414	0.626
1974	0.077	0.183	0.229	0.303	0.357	0.538
1975	0.105	0.150	0.211	0.340	0.473	0.715
1976	0.071	0.167	0.201	0.234	0.446	0.616
1977	0.088	0.169	0.214	0.261	0.382	0.590
1978	0.099	0.193	0.272	0.325	0.331	0.488
1979	0.083	0.177	0.238	0.283	0.389	0.378
1980	0.101	0.170	0.194	0.253	0.312	0.490
1981	0.072	0.145	0.213	0.247	0.262	0.492
1982	0.110	0.158	0.208	0.252	0.296	0.432
1983	0.117	0.170	0.215	0.265	0.292	0.416
1984	0.068	0.150	0.201	0.326	0.366	0.413
1985	0.120	0.158	0.230	0.344	0.497	0.573
1986	0.092	0.160	0.217	0.313	0.465	0.557
1987	0.117	0.140	0.212	0.237	0.485	0.467
1988	0.068	0.151	0.178	0.316	0.482	0.777
1989	0.098	0.152	0.193	0.243	0.364	0.606
1990	0.112	0.154	0.209	0.263	0.344	0.432
1991	0.089	0.151	0.187	0.224	0.315	0.415
1992	0.067	0.152	0.195	0.250	0.303	0.492
1993	0.037	0.095	0.158	0.263	0.490	0.791
1994	0.032	0.087	0.158	0.249	0.568	0.836
1995	0.037	0.076	0.162	0.318	0.692	0.842
1996	0.041	0.100	0.154	0.349	0.761	0.841
1997	0.040	0.104	0.166	0.298	0.546	0.922
1998	0.047	0.084	0.194	0.299	0.471	0.745
1999	0.030	0.087	0.197	0.341	0.566	0.942
Averages						
1955-1992	0.077	0.139	0.196	0.261	0.349	0.512
1993-1999	0.038	0.091	0.170	0.303	0.585	0.846

Decadal Averages of Mean Weights at Age (kg)

Decade	Age-1	Age-2	Age-3	Age-4	Age-5	Age6+
1955-59	0.048	0.107	0.184	0.256	0.331	0.462
1960-69	0.061	0.113	0.165	0.223	0.308	0.507
1970-79	0.083	0.162	0.223	0.287	0.376	0.550
1980-89	0.096	0.155	0.206	0.280	0.382	0.522
1990-99	0.053	0.109	0.178	0.285	0.506	0.726

Table C9. Estimates of average instantaneous total mortality (Z) and fishing mortality (F) for combined area silve hake based on NEFSC survey numbers-at-age data and an assumed natural mortality of 0.4.

	Spring Survey		Fall Survey	
Time Period	Z	F	Z	F
1964-1967	-	-	1.40	1.00
1969-1972			2.03	1.63
1974-1977	1.13	0.73	0.63	0.23
1979-1982	0.83	0.43	0.66	0.26
1984-1987	1.09	0.69	1.11	0.71
1989-1992	1.41	1.01	1.45	1.05
1994-1998	2.87	2.47	1.80	1.40

Estimates for 1964-1972 are based on survey numbers-at-age data computed with an average of age-length keys for 1973-1975. Survey Z for the fall is computed as the natural logarithm of the ratio of the sum from year j-1 to k-1 of age 2+ abundance to the sum from year j to k of age 3+ abundance. Survey Z for the spring is computed as the natural logarithm of the ratio of the sum from year j to k of age 3+ abundance to the sum from year j+1 to k+1 of age 4+ abundance. The estimate of spring survey Z during 1969-1972 was not feasible

Table C10. Amendment 12 criteria for determining whether northern and southern silver hake are overfished based on NEFSC autumn survey biomass indices, delta-distribution.

Northern Silver Hake Overfishing Status Evaluation

Year	Autumn Index	Autumn Index 3-Year Moving Average	3-Year Average Index Above BMSY?	3-Year Average Index Above Biomass Threshold?	BMSY Proxy	Biomass Threshold
1990	15.246	11.369	Yes	Yes	6.626	3.313
1991	11.889	13.228	Yes	Yes		
1992	14.245	13.793	Yes	Yes		
1993	8.117	11.417	Yes	Yes		
1994	6.925	9.762	Yes	Yes		
1995	13.161	9.401	Yes	Yes		
1996	7.886	9.324	Yes	Yes		
1997	5.638	8.895	Yes	Yes		
1998	21.966	11.830	Yes	Yes		
1999	11.636	13.080	Yes	Yes		

Southern Silver Hake Overfishing Status Evaluation

Year	Autumn Index	Autumn Index 3-Year Average	3-Year Average Index Above BMSY?	3-Year Average Index Above Biomass Threshold?	BMSY Proxy	Biomass Threshold
1990	1.645	1.865	Yes	Yes	1.785	0.892
1991	0.907	1.557	No	Yes		
1992	0.978	1.177	No	Yes		
1993	1.329	1.071	No	Yes		
1994	0.799	1.035	No	Yes		
1995	1.641	1.256	No	Yes		
1996	0.431	0.957	No	Yes		
1997	0.842	0.971	No	Yes		
1998	0.620	0.631	No	No		
1999	0.870	0.777	No	No		

Table C11. Estimates of silver hake biological reference points for combined, northern, and southern stock areas from the Northern Demersal Working Groups preferred Bayesia surplus production models. Table entries are biomass in 1999 (B_{1999}, kt), biomass tha would produce maximum surplus production (B_{MSP}, kt), maximum surplus productio (MSP, kt), exploitation rate to produce maximum surplus production at B_{MSP} (H_{MSP}, fraction of stock biomass), and ratio of exploitation rate in 1999 to H_{MSP} (H_{Ratio} , fraction of H_{MSP}). Northern and southern area values do not sum to combined area values because the input data are not additive and the analytical models are nonlinear

Stock Unit	B_{1999}	B_{MSP}	MSP	H_{MSP}	H_{Ratio}
Combined Area	1,180	603	201	0.34	0.04
Northern Area	202	102	45	0.44	0.05
Southern Area	561	990	17	0.02	1.11

Figure C1. NEFSC survey strata for northern (offshore strata 20-30 and 36-40) and southern (offshore strata 1-19 and 61-76) silver hake in the northwest Atlantic.

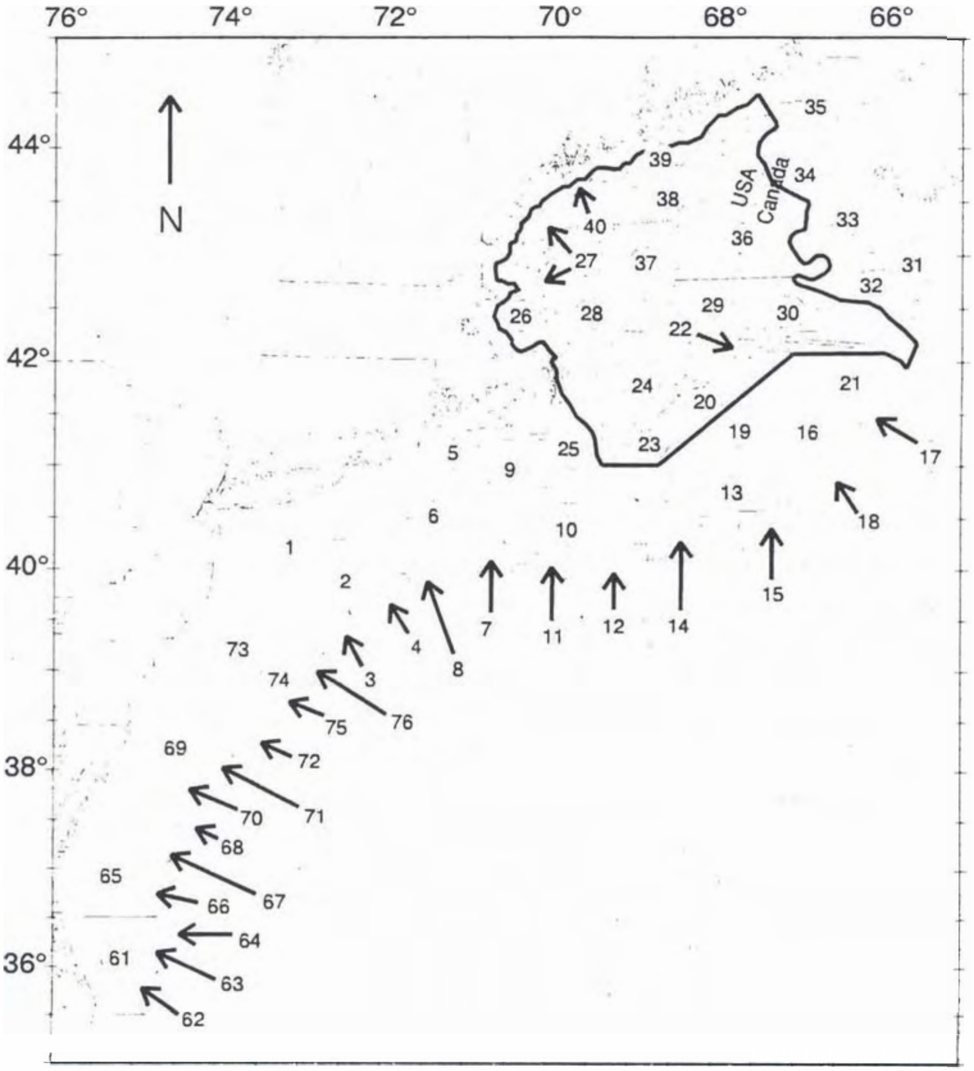


Figure C2. Commercial fishery statistical areas for northern (SA 511-515, 521, 522, 551, and 561) and southern (SA 525, 526, 533-539, 541-543, 552, 562, 611-639) silver hake in the northwest Atlantic.

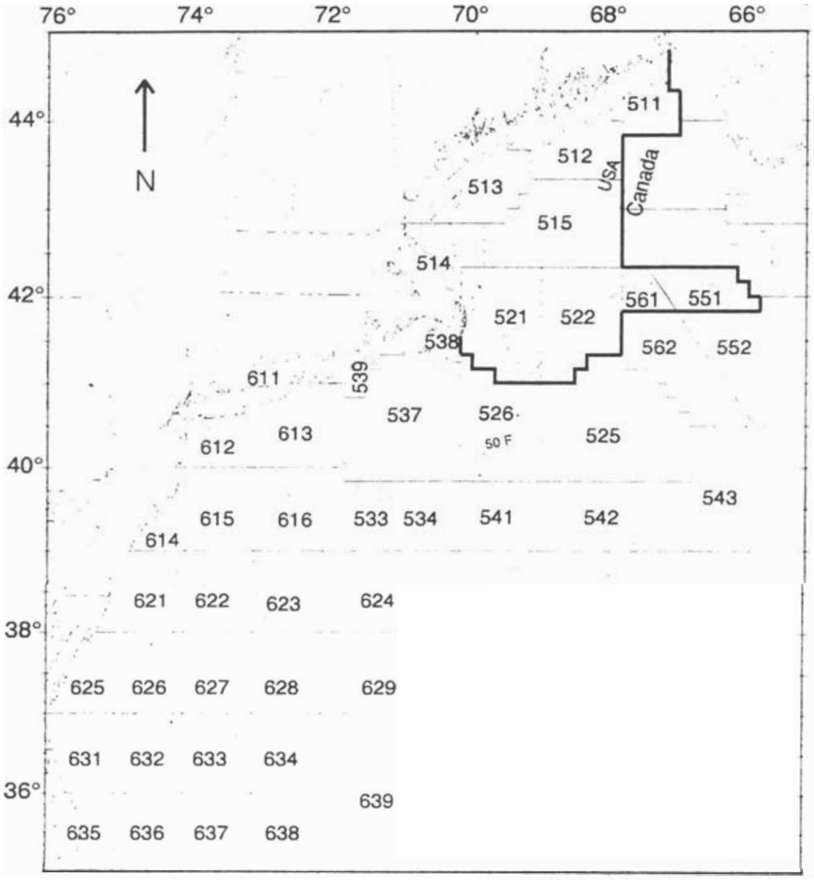
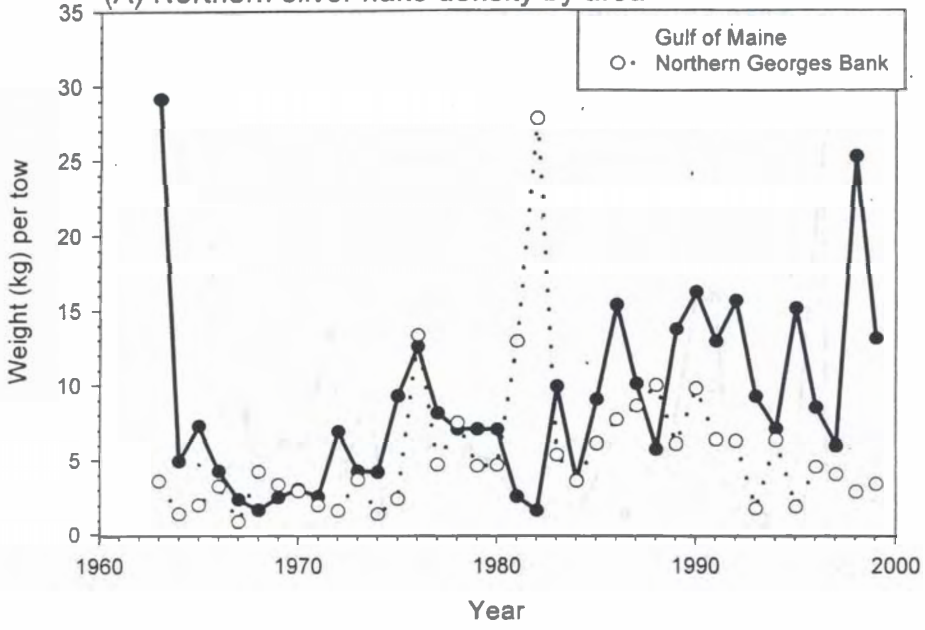


Figure 3. Silver hake density from the NEFSC fall survey.

(A) Northern silver hake density by area



(B) Southern silver hake density by area

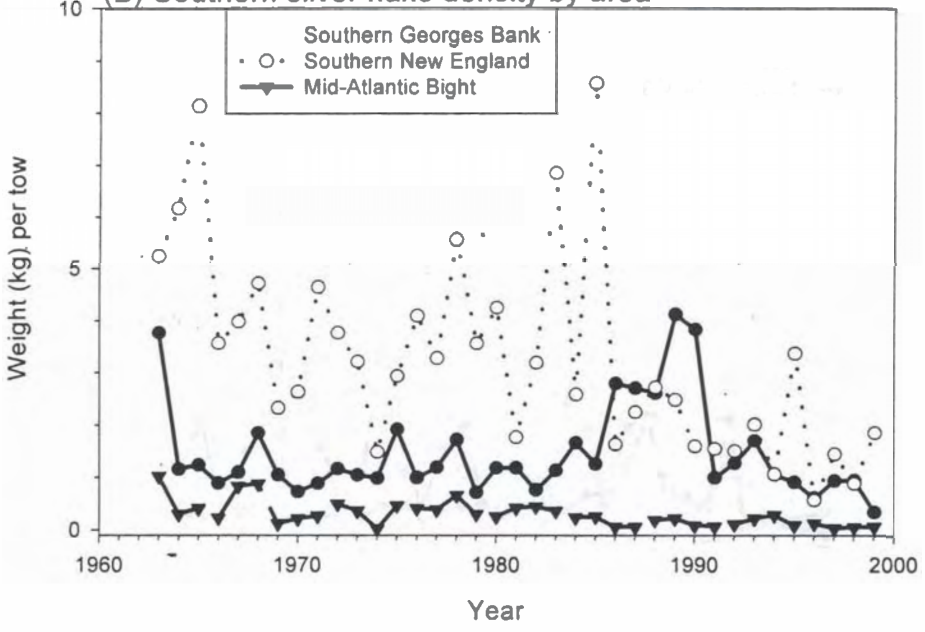
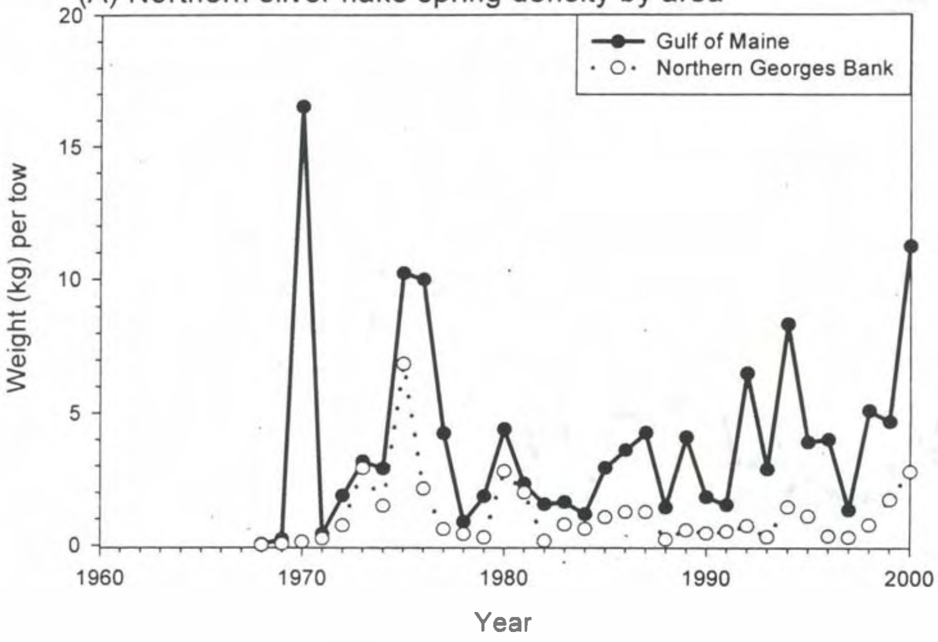


Figure 4. Silver hake density from the NEFSC spring survey.

(A) Northern silver hake spring density by area



(B) Southern silver hake spring density by area

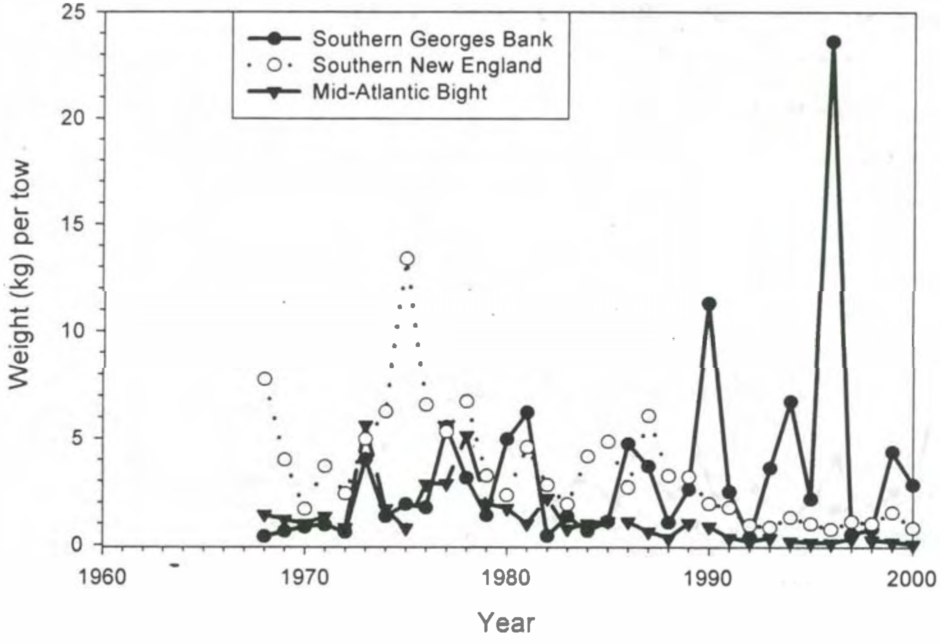
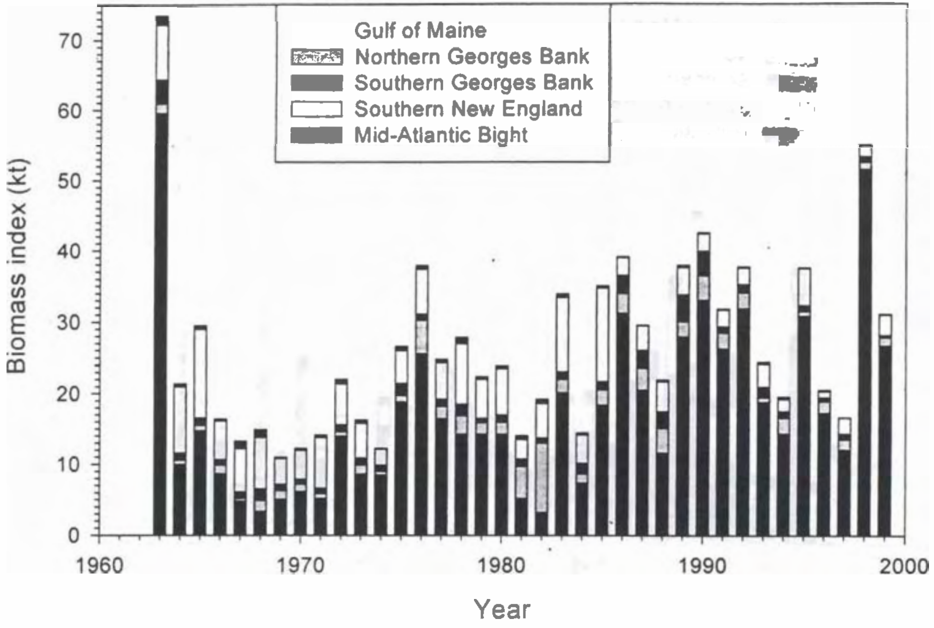


Figure 5. Autumn survey distribution of silver hake biomass by area.

(A) Silver hake autumn survey total biomass indices by area



(B) Autumn survey proportion of biomass by stock area

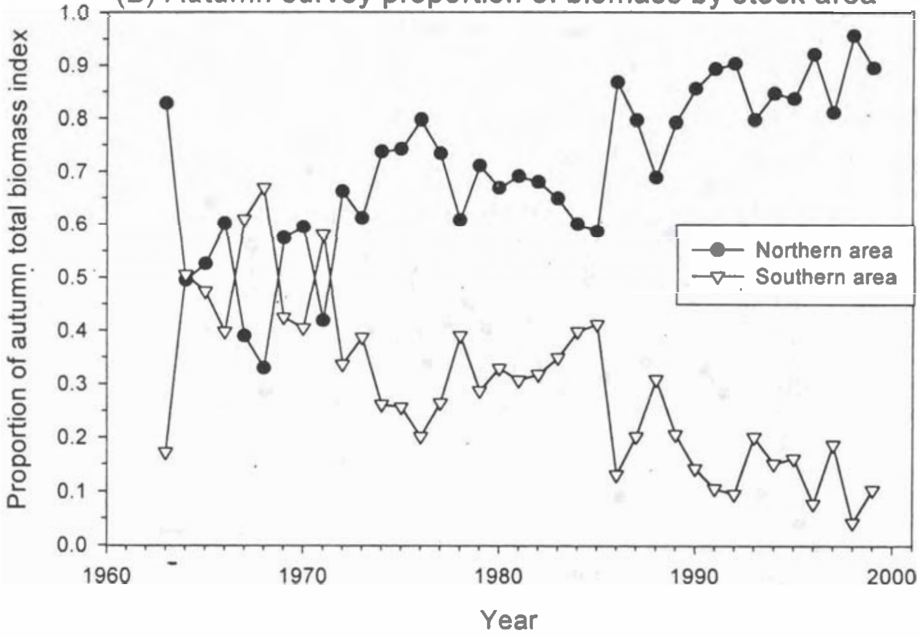
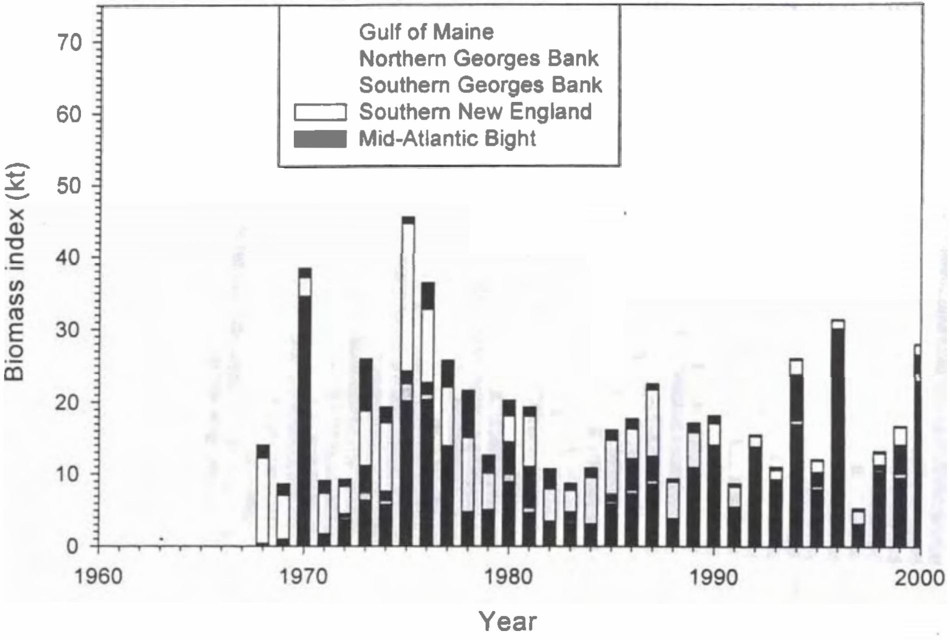
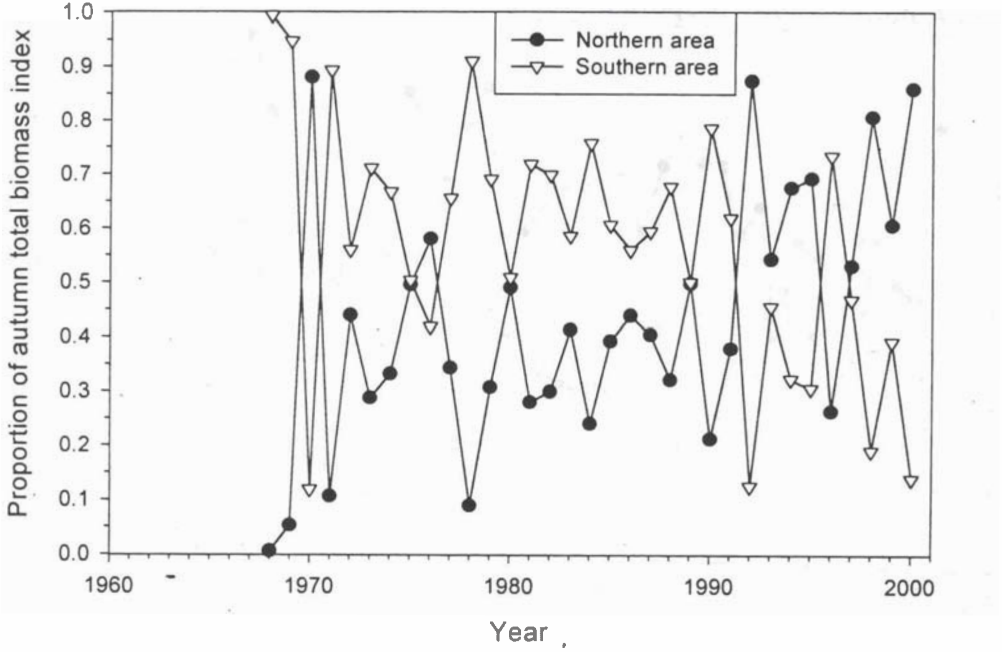


Figure 6. Spring survey distribution of silver hake biomass by area.

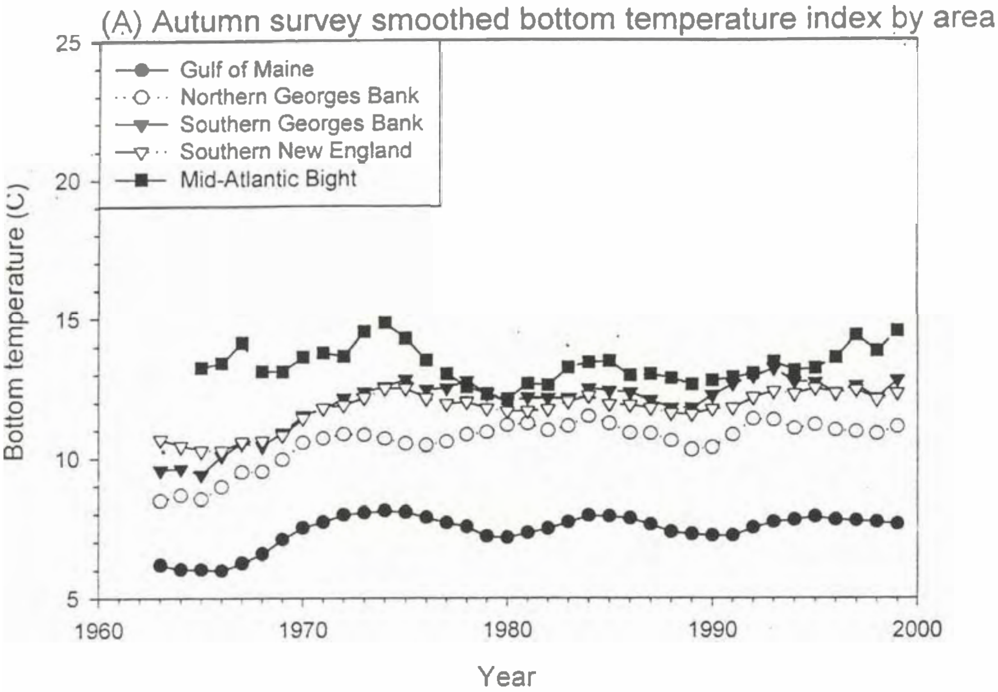
(A) Silver hake spring survey total biomass indices by area



(B) Spring survey proportion of biomass by stock area



igure C7. Trends in near-bottom temperatures by area during autumn and spring.



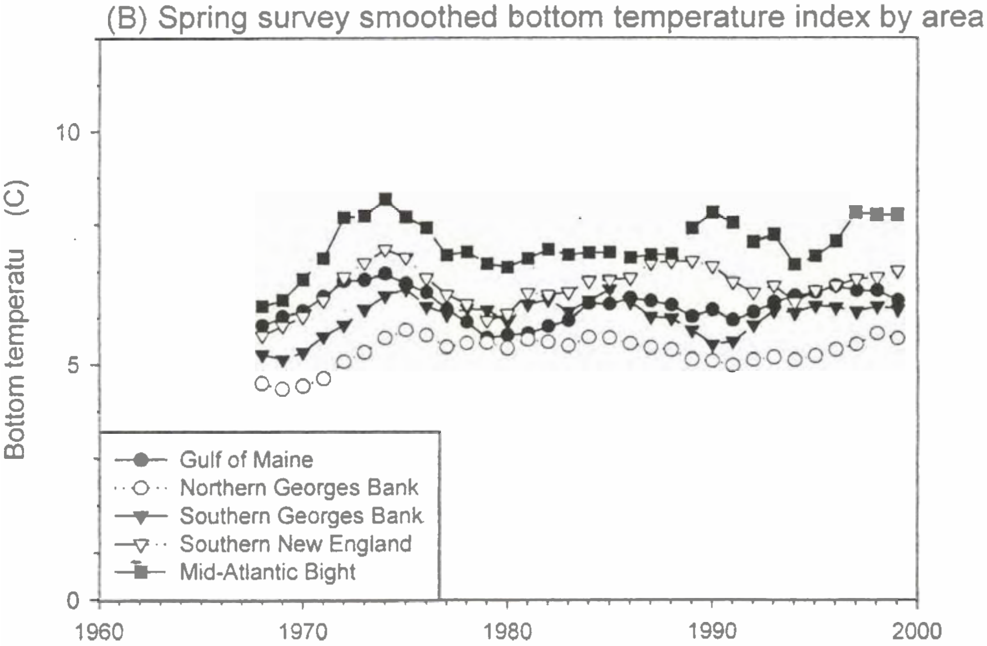
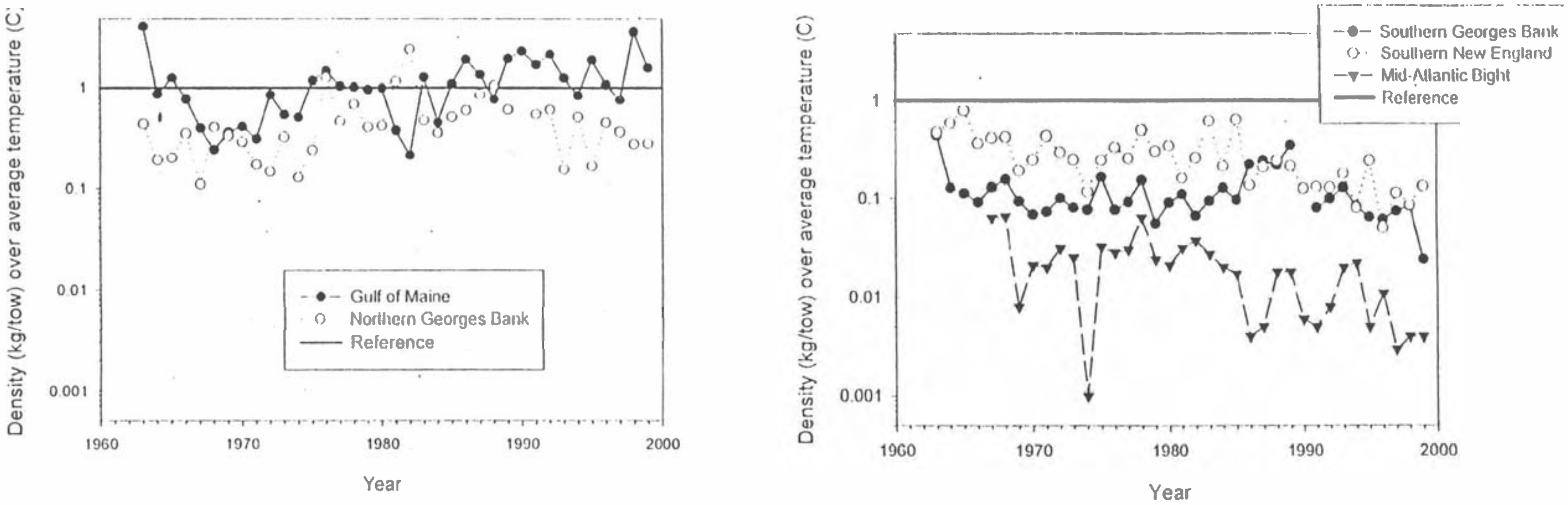
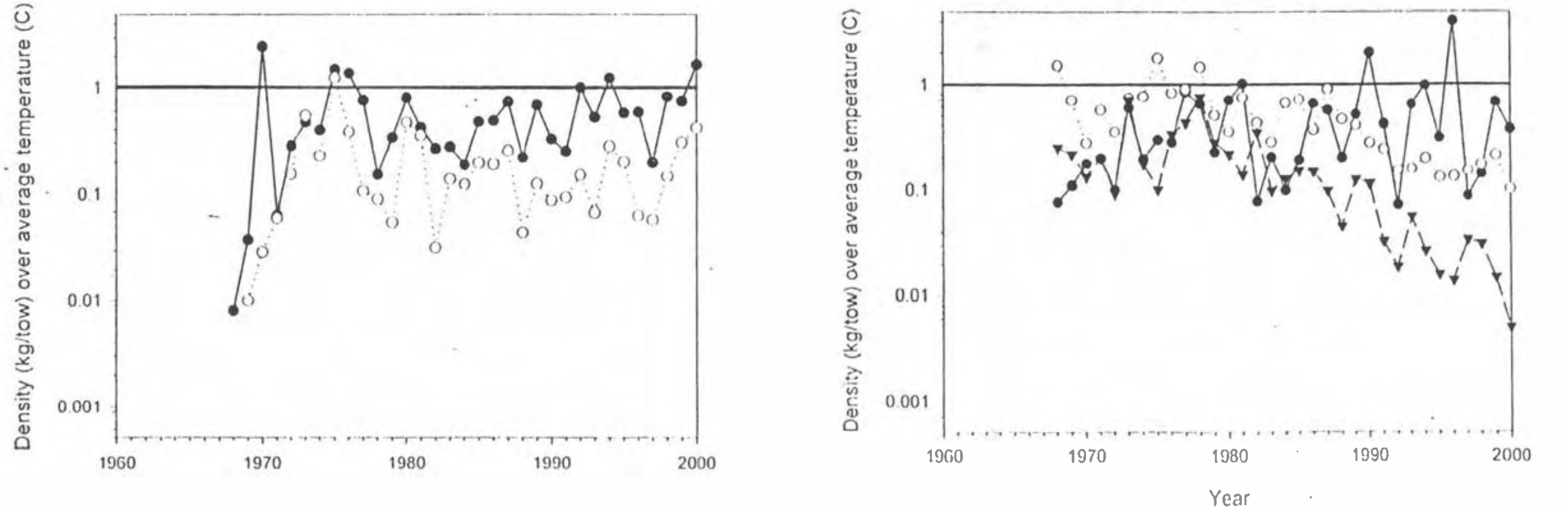


Figure C8. Silver hake density (kg/tow) per degree of bottom temperature by area during the NEFSC autumn and spring surveys.

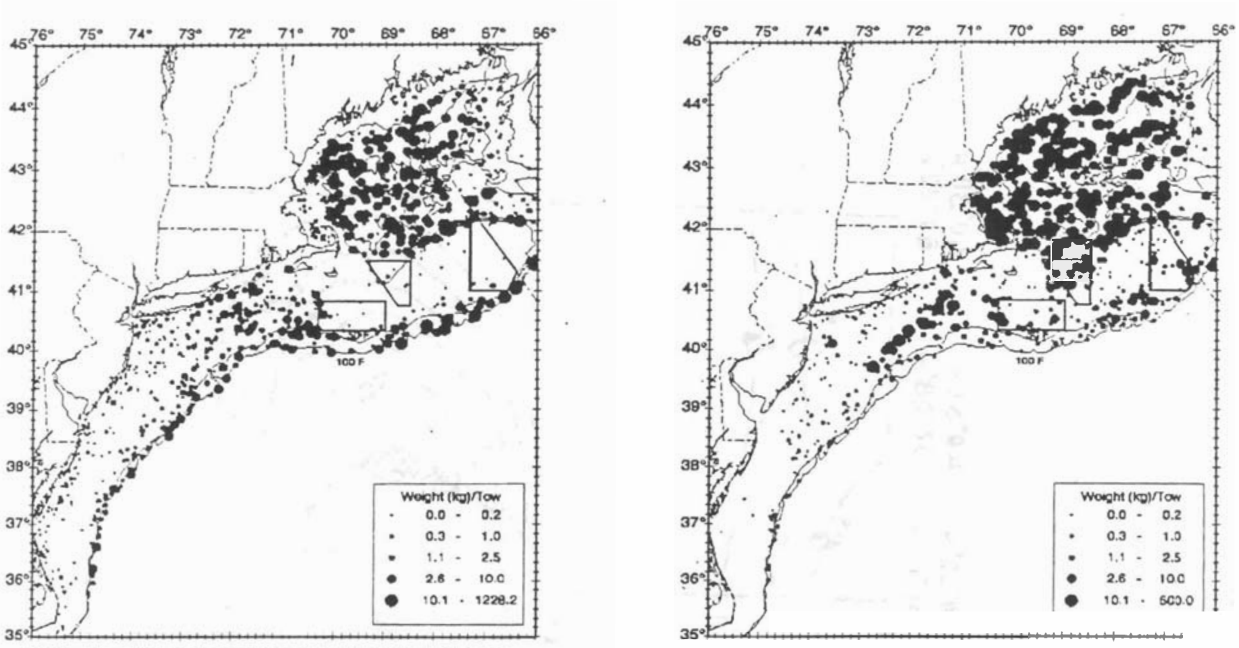

(A) Northern silver hake density to temperature in autumn

(B) Southern silver hake density to temperature in autumn


(C) Northern silver hake spring density to temperature in spring

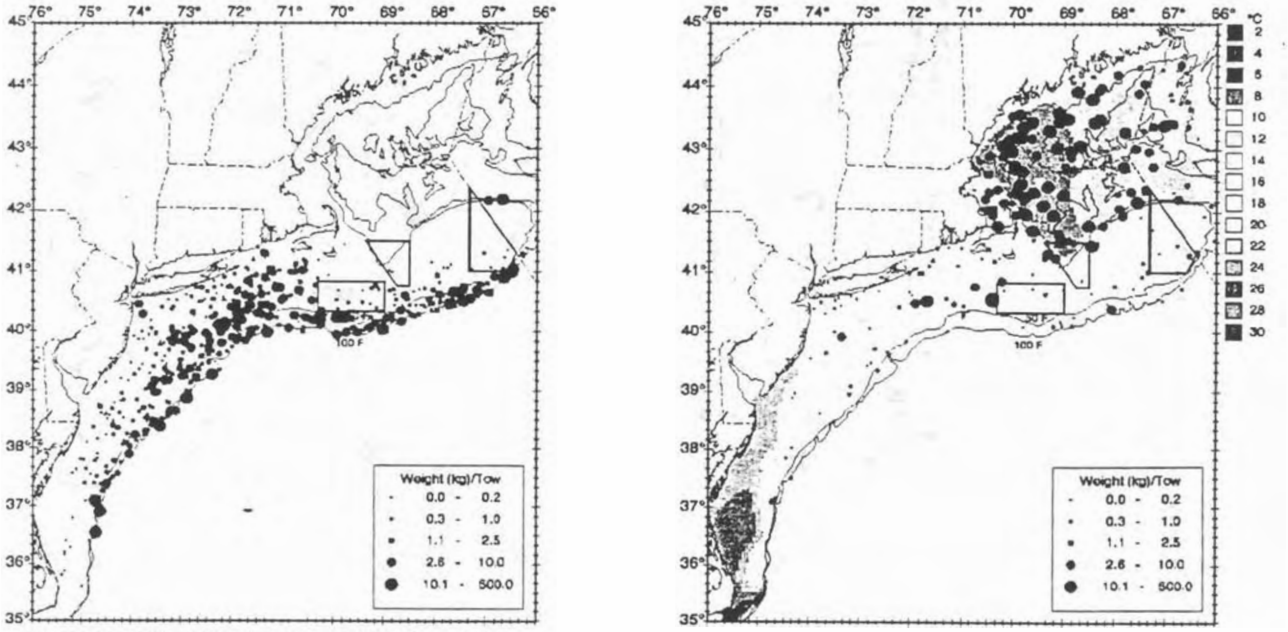
(D) Southern silver hake spring density to temperature in spring

Figure C9. Spatial distribution of silver hake during recent spring, fall, and winter surveys.



Distribution of Silver Hake during the NEFSC Spring Bottom Trawl Surveys, 1995-1999.

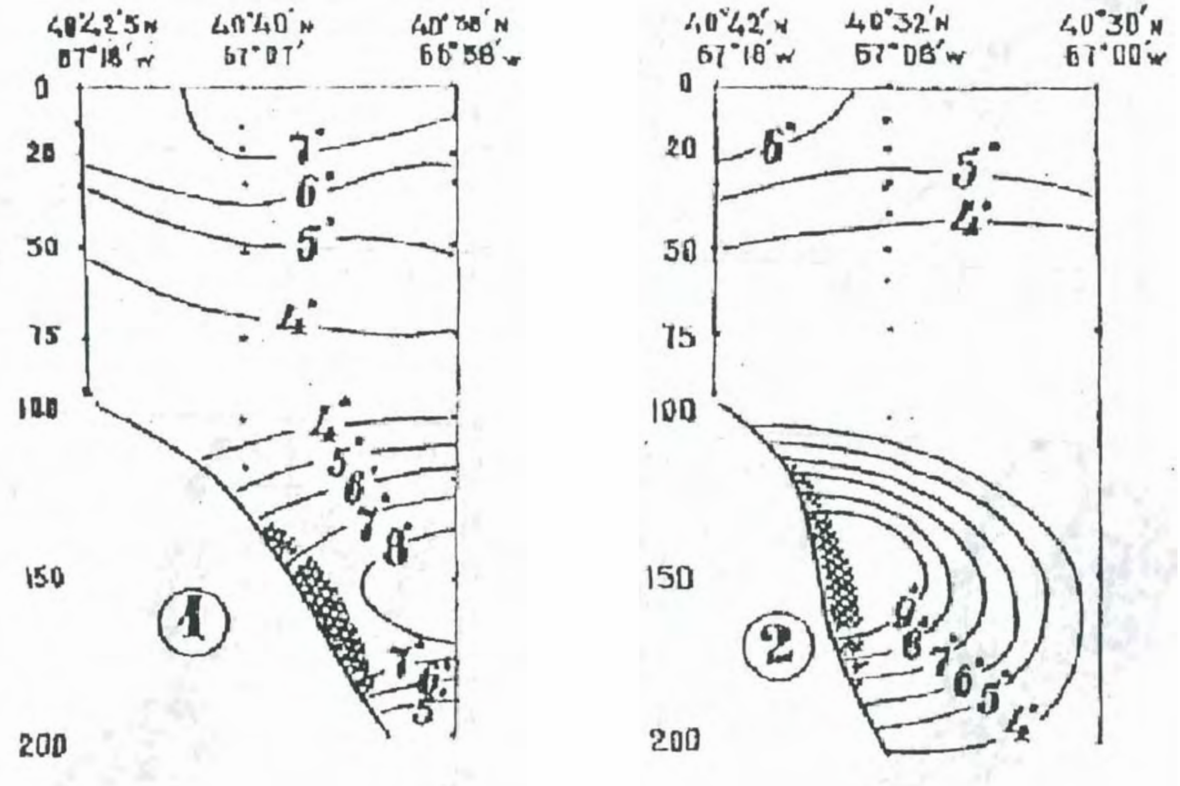
Distribution of Silver Hake during the NEFSC Autumn Bottom Trawl Surveys, 1995-1998.



Distribution of Silver Hake during the NEFSC Winter Bottom Trawl Surveys, 1995-1999.

Distribution of Silver Hake during the NEFSC Autumn Bottom Trawl Surveys, 1999.

Figure C10. Water temperature distribution at depth (m) near silver hake concentrations (dark circles) at Lydonia Canyon during May 1964 from Sarnits and Sauskan (1966).



USSRG4_FIG 8

Figure C11. North Atlantic Oscillation index (A) and smoothed index (B), 1823-1999, derived from Jones et al. (1997)

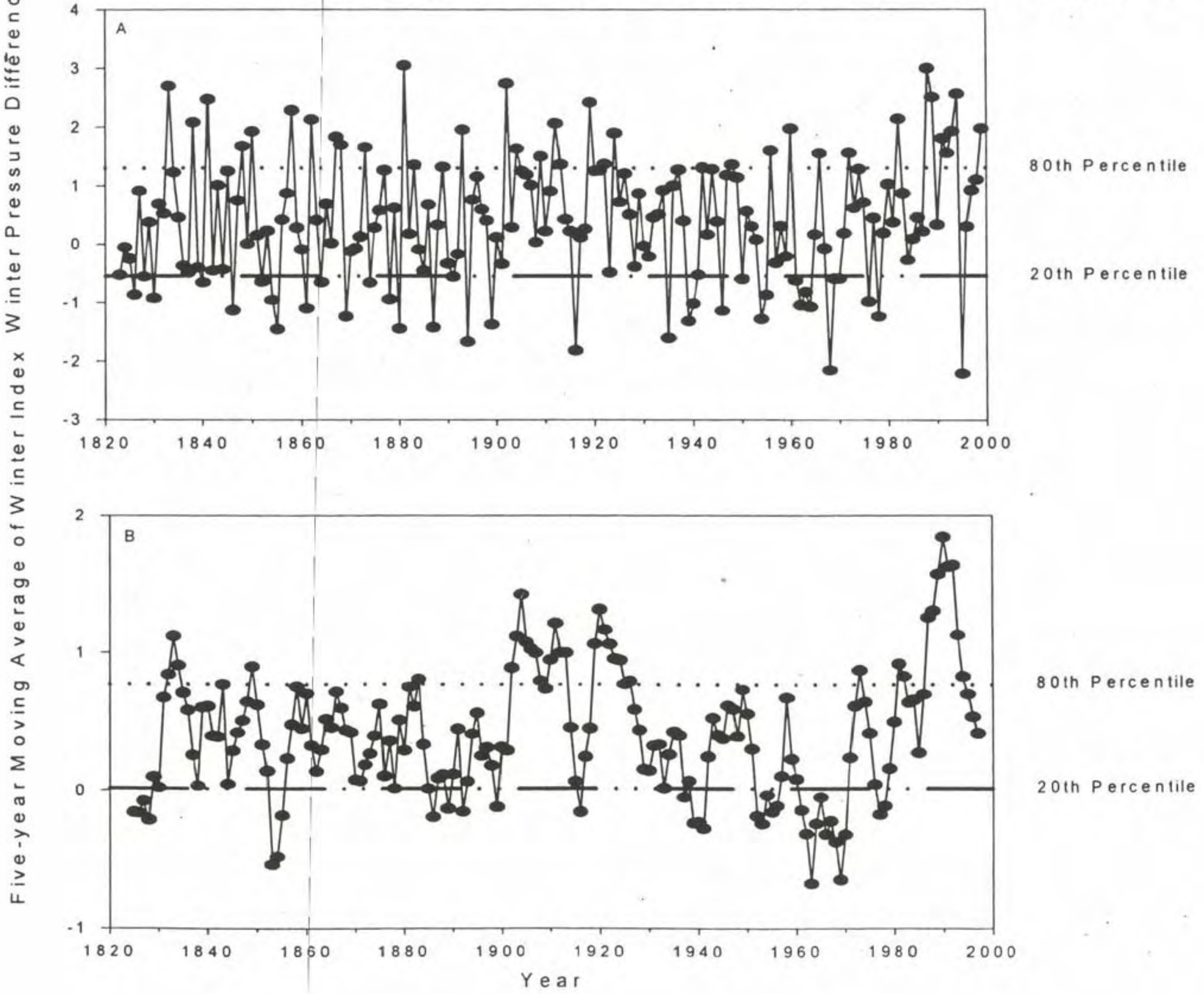


Figure C12. Silver hake fishery yields by stock area, 1955-1999.

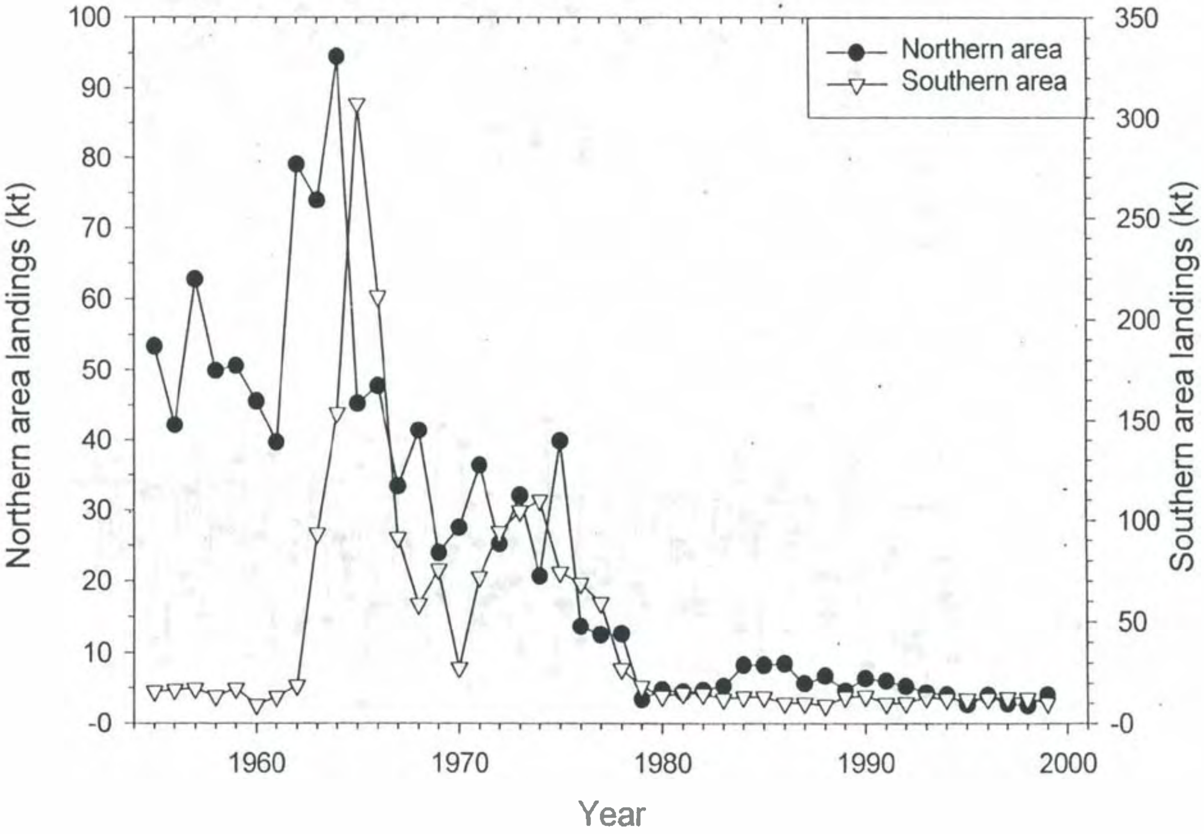
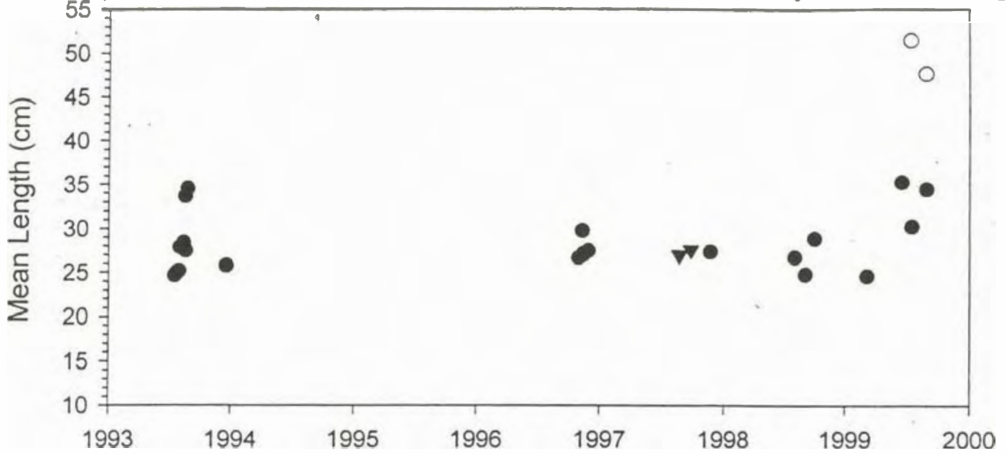
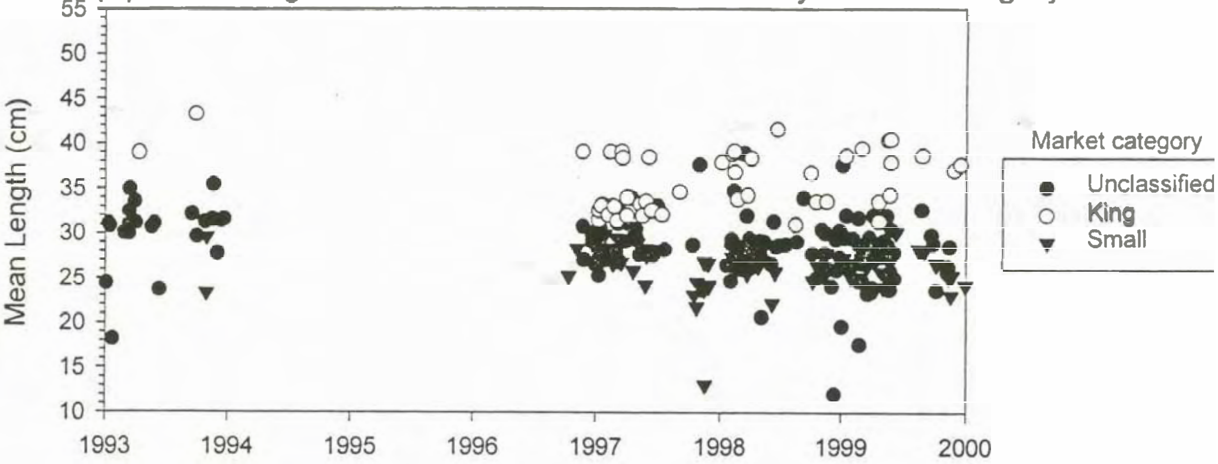


Figure C13. Mean lengths of silver hake in commercial market category samples, 1993-1999.

(A) Mean lengths of northern area silver hake by market category



(B) Mean lengths of southern area silver hake by market category



(C) Mean lengths of unknown area silver hake by market category

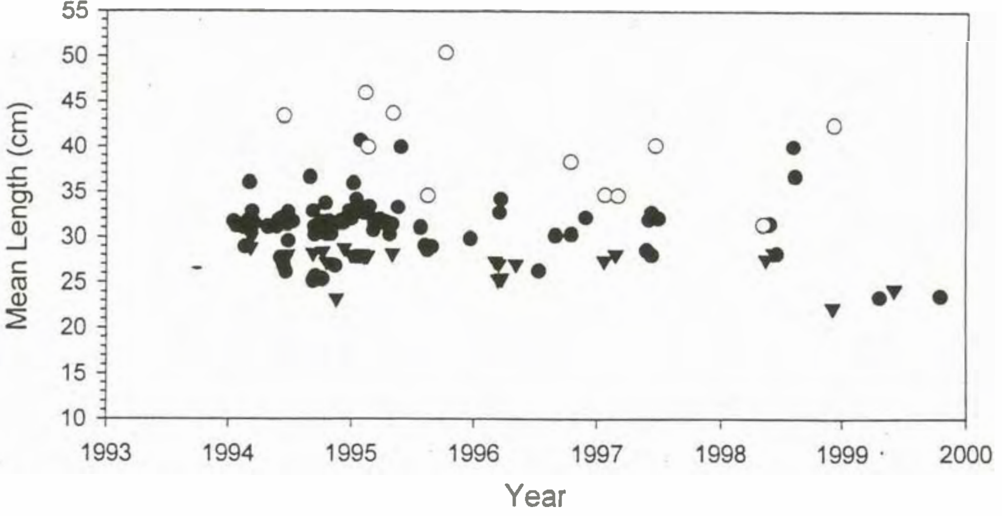


Figure C14. Length frequency distributions of silver hake landings, 1993-1999.

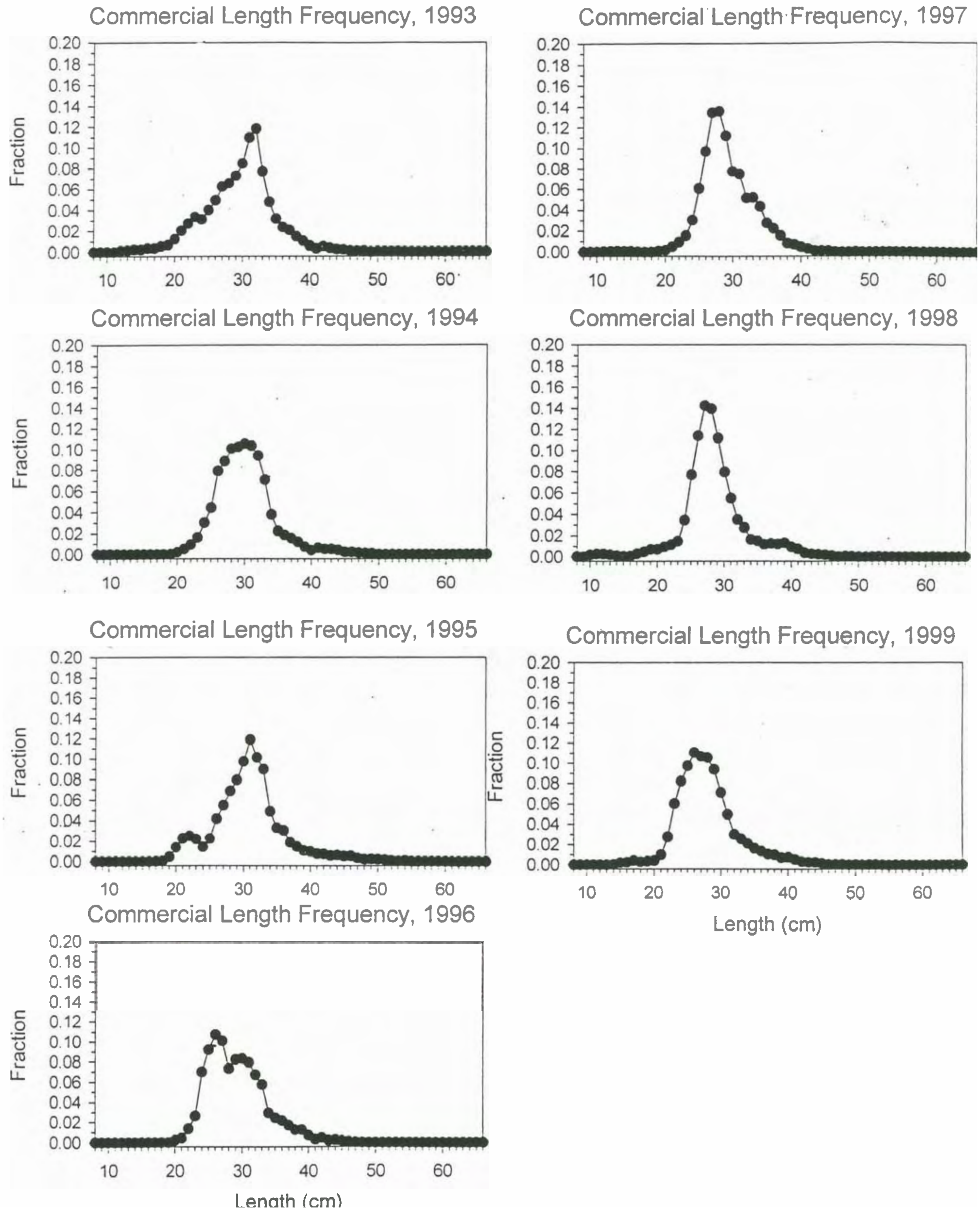
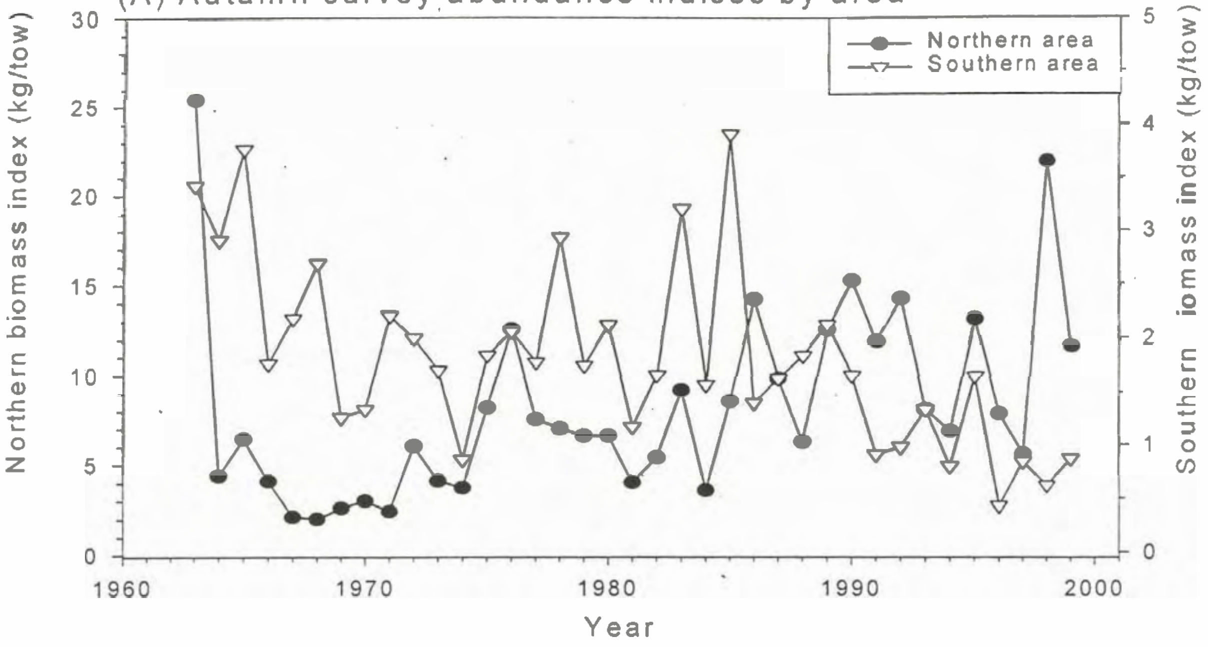


Figure C15. Silver hake survey biomass indices by area

(A) Autumn survey abundance indices by area



(B) Spring survey abundance indices by area

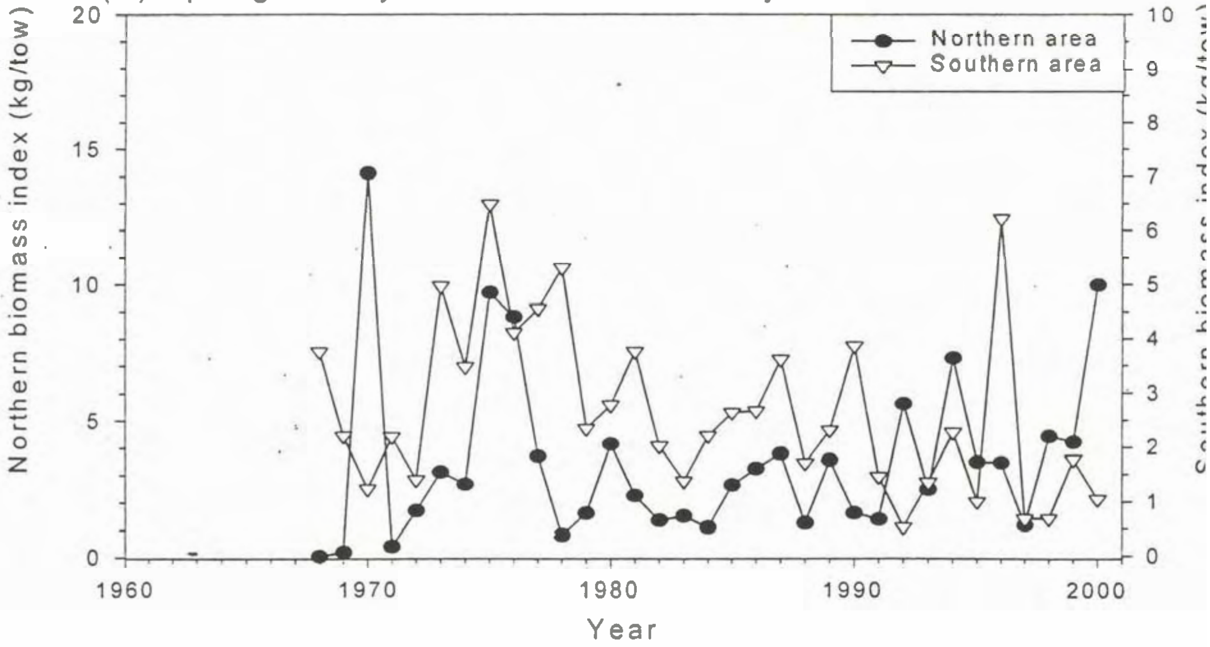
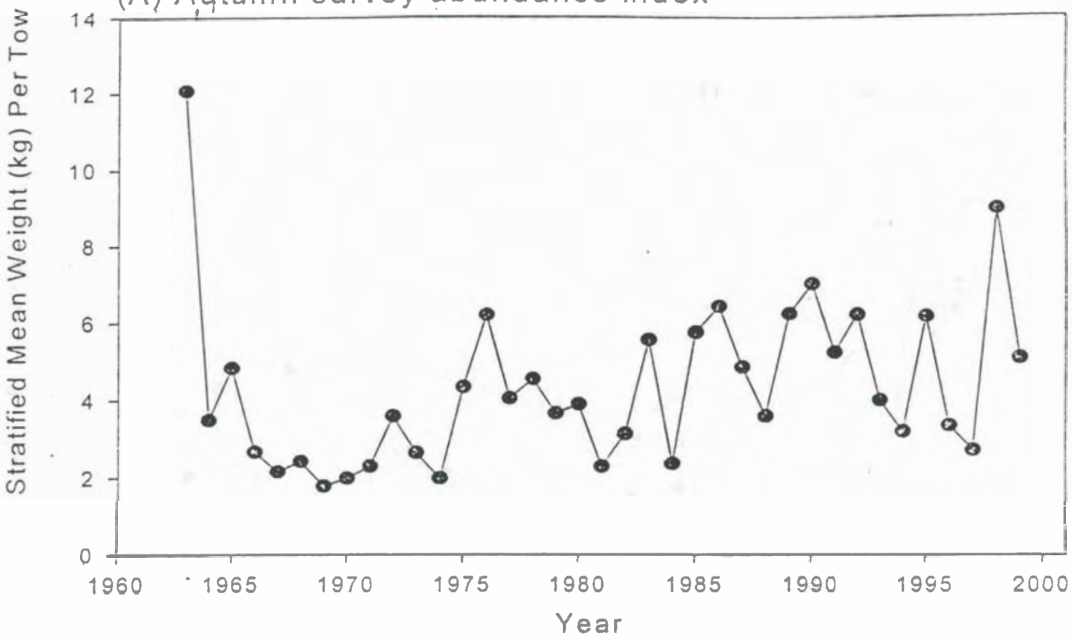


Figure C16. Silver hake survey biomass indices for the combined stock area

(A) Autumn survey abundance index



(B) Spring survey abundance index

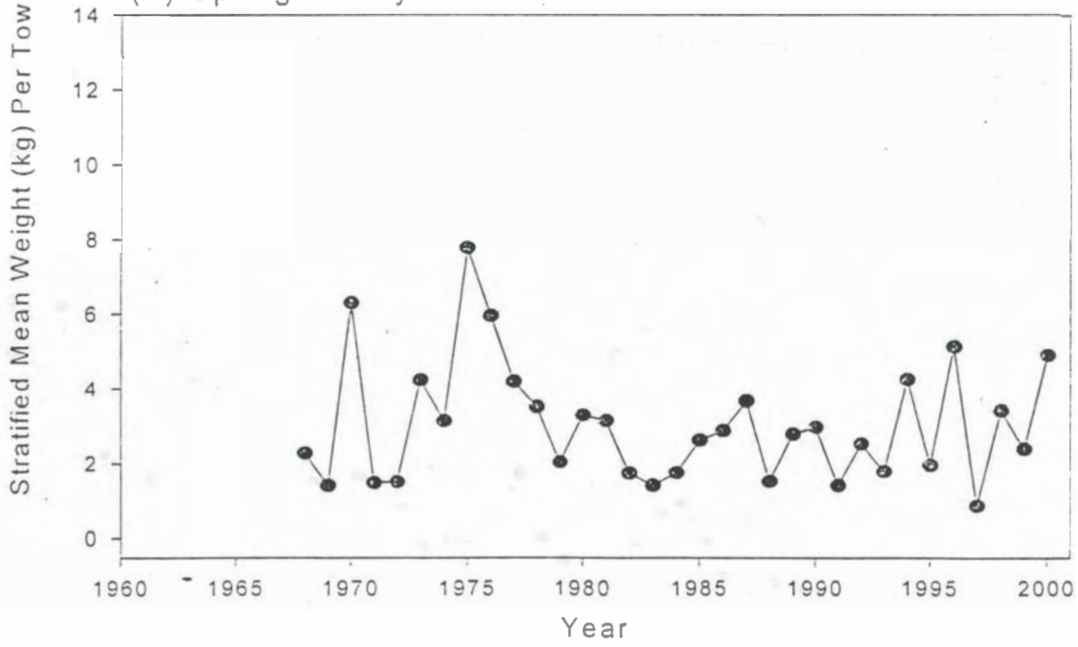


Figure C17. Monthly distribution of silver hake eggs from MARMAP Pichthyoplankton surveys during January through June of 1977-1987 from Berrien and Sibunka (1999).

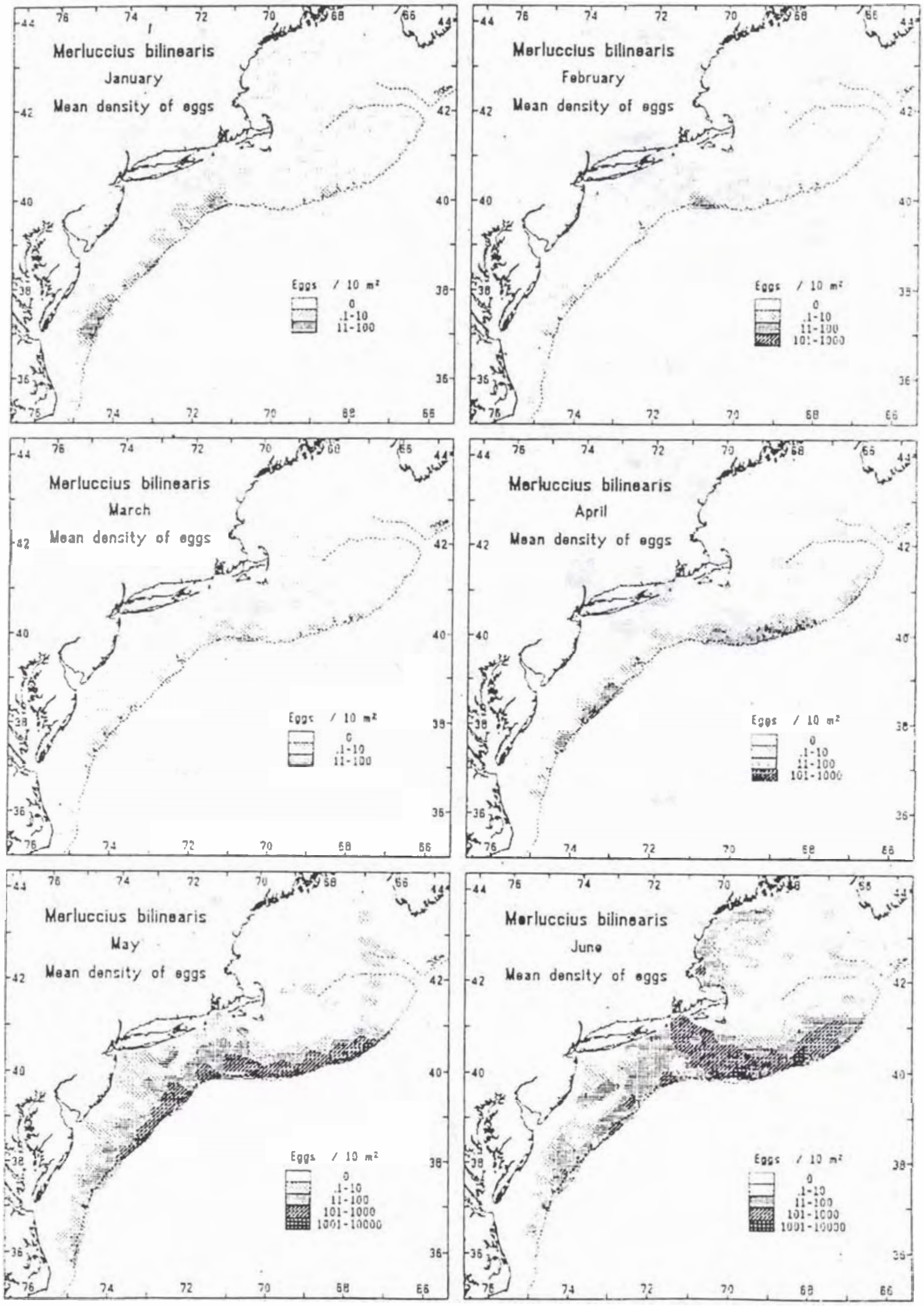


Figure C18. Monthly distribution of silver hake eggs from MARMAP Pichthyoplankton surveys during July through December of 1977-1987 from Berrien and Sibunka (1999

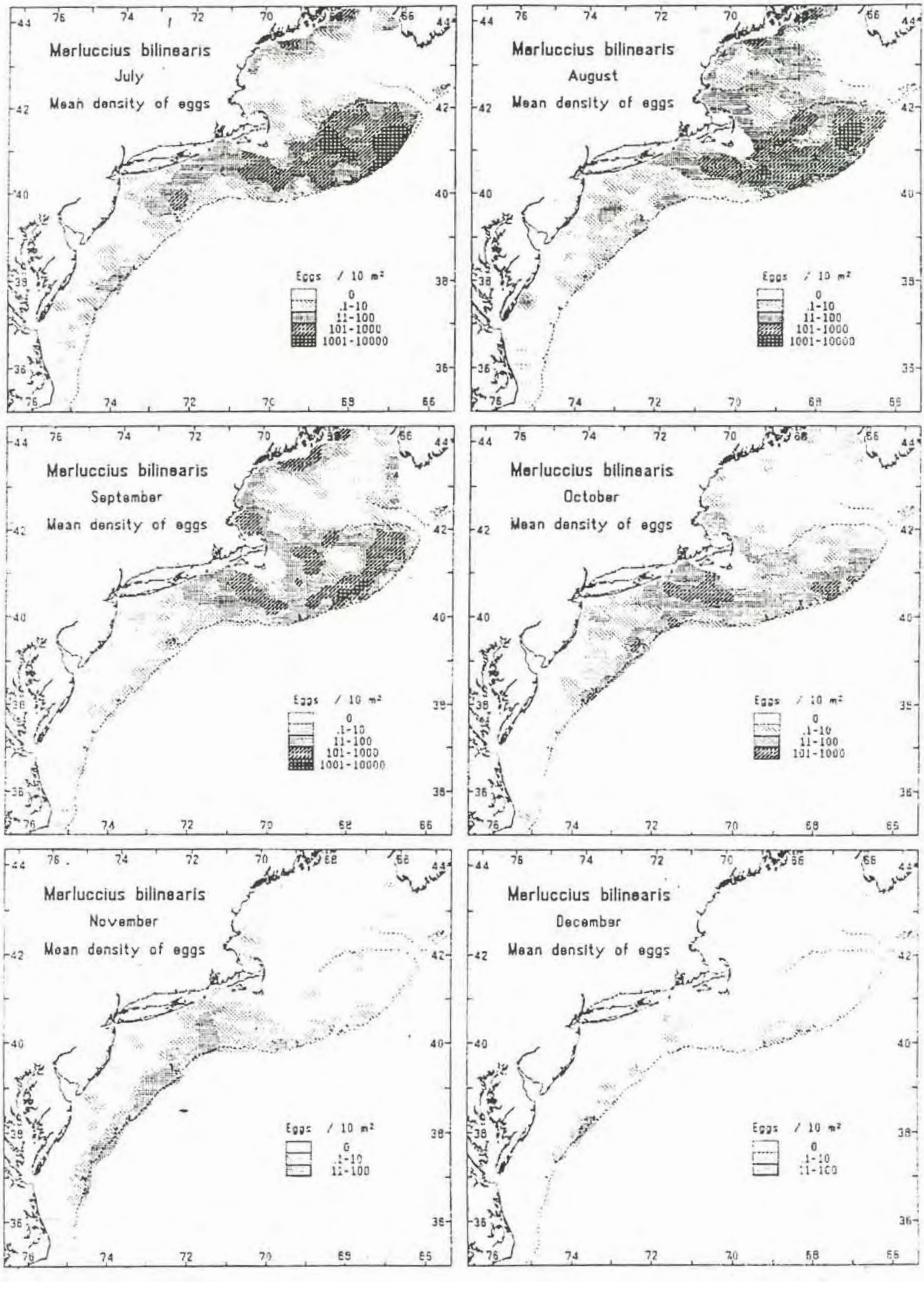
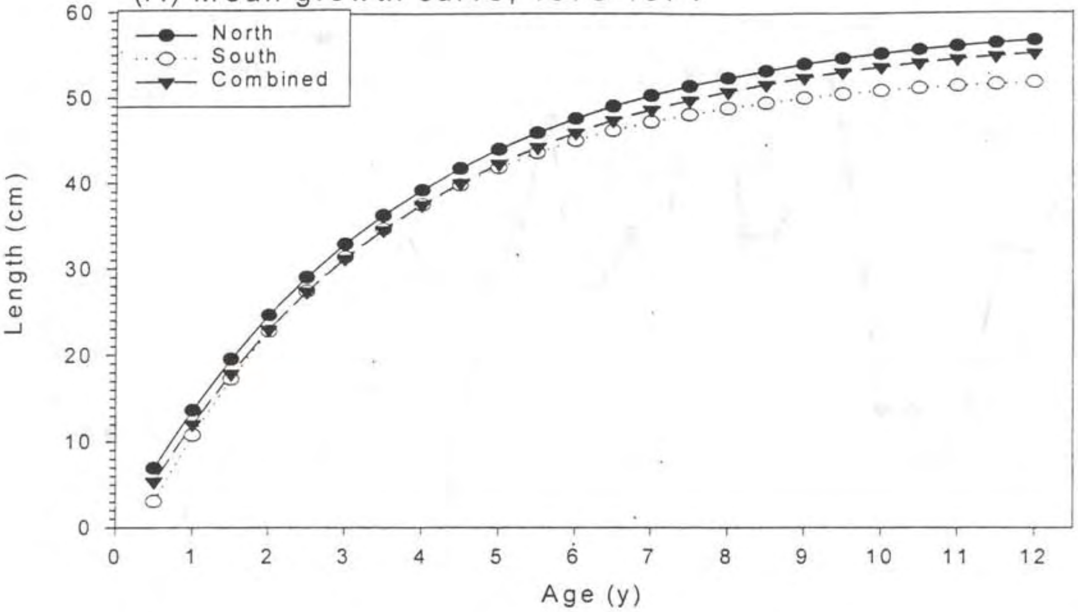


Figure C19. Silver hake growth curves for the early 1970s and the 1990s calculated from NEFSC spring and fall survey size-at-age data.

(A) Mean growth curve, 1973-1974



(B) Mean growth curve, 1993-1998

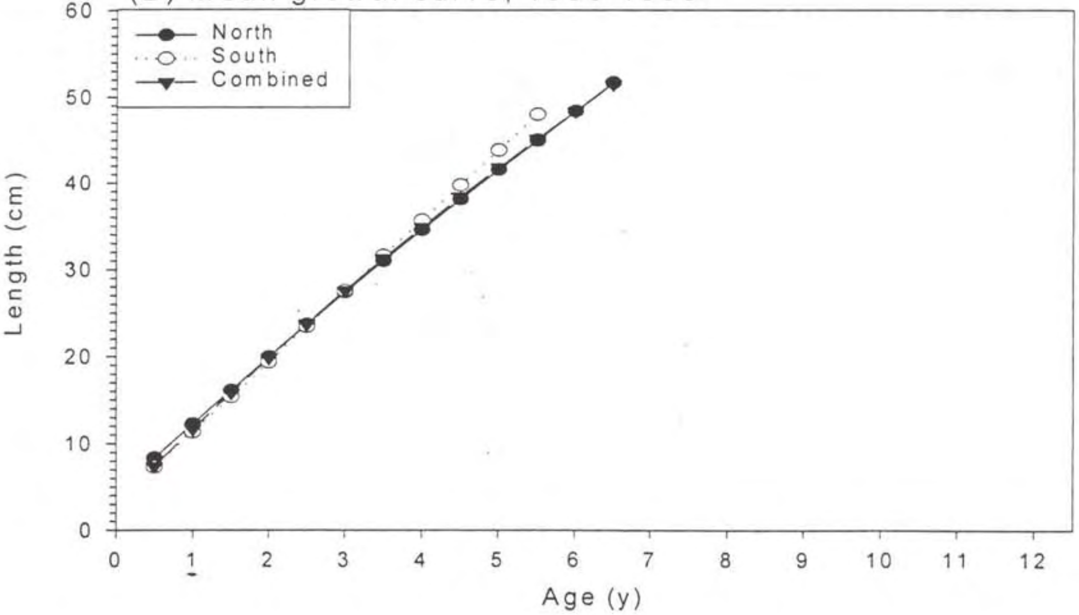


Figure C20. Maximum ages of silver hake from NEFSC survey data.

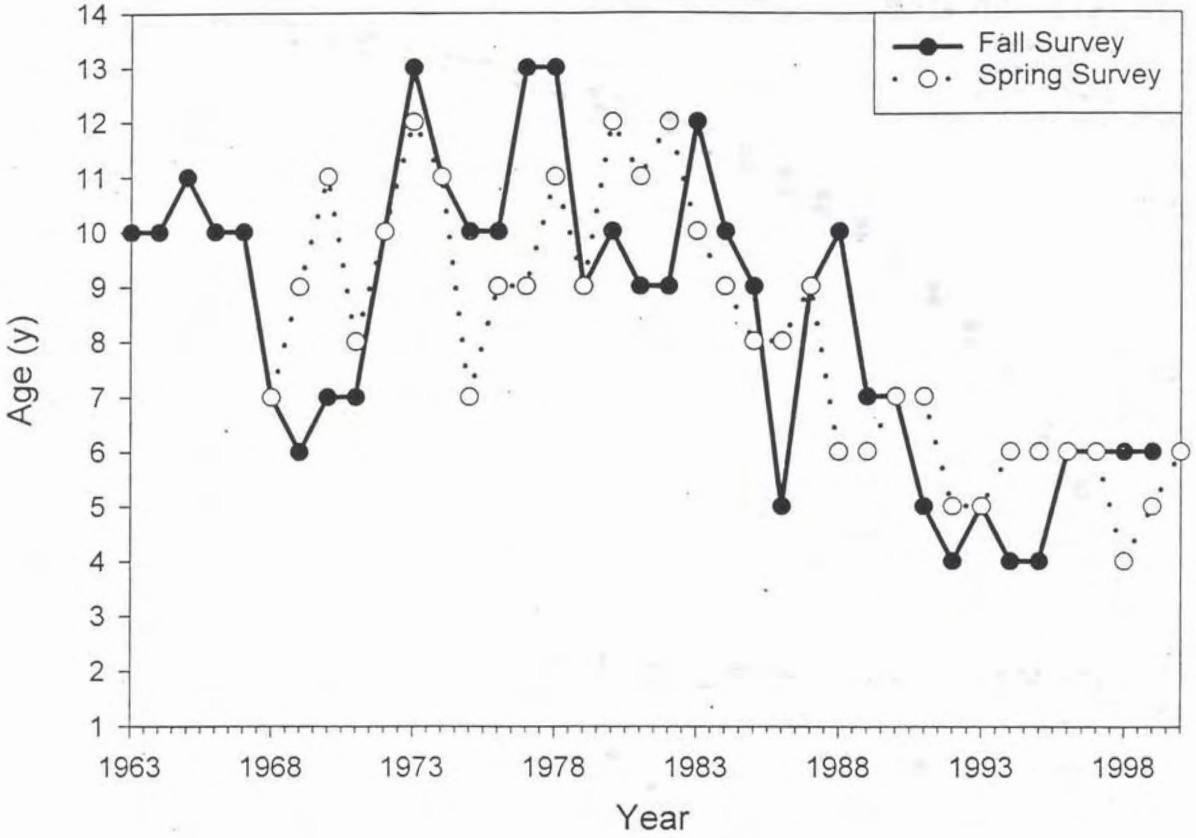


Figure C21. Silver hake condition factor during NEFSC surveys by stock area, 1992-2000.

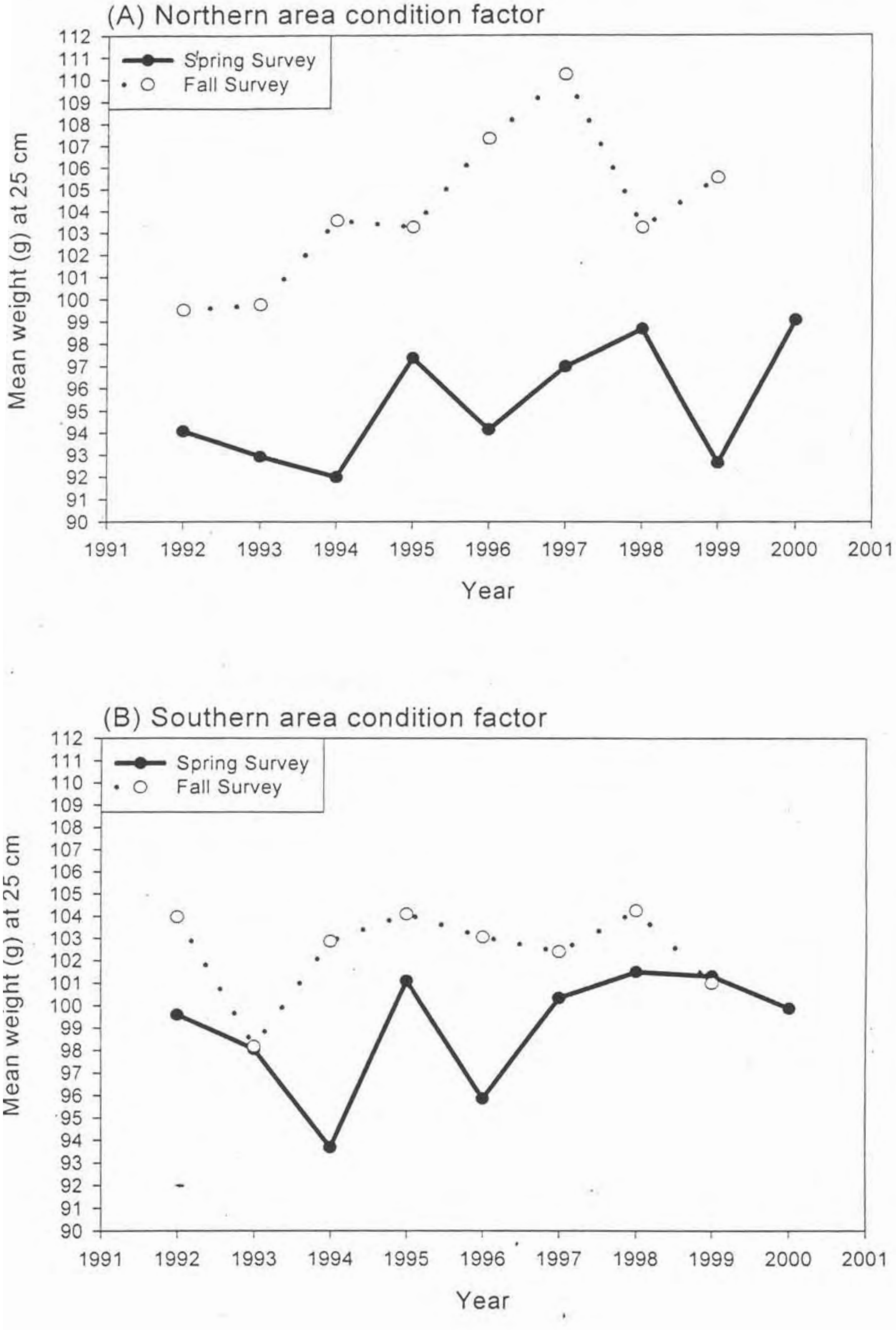


Figure C22. Silver hake exploitation rate indices by stock area, 1963-1999.

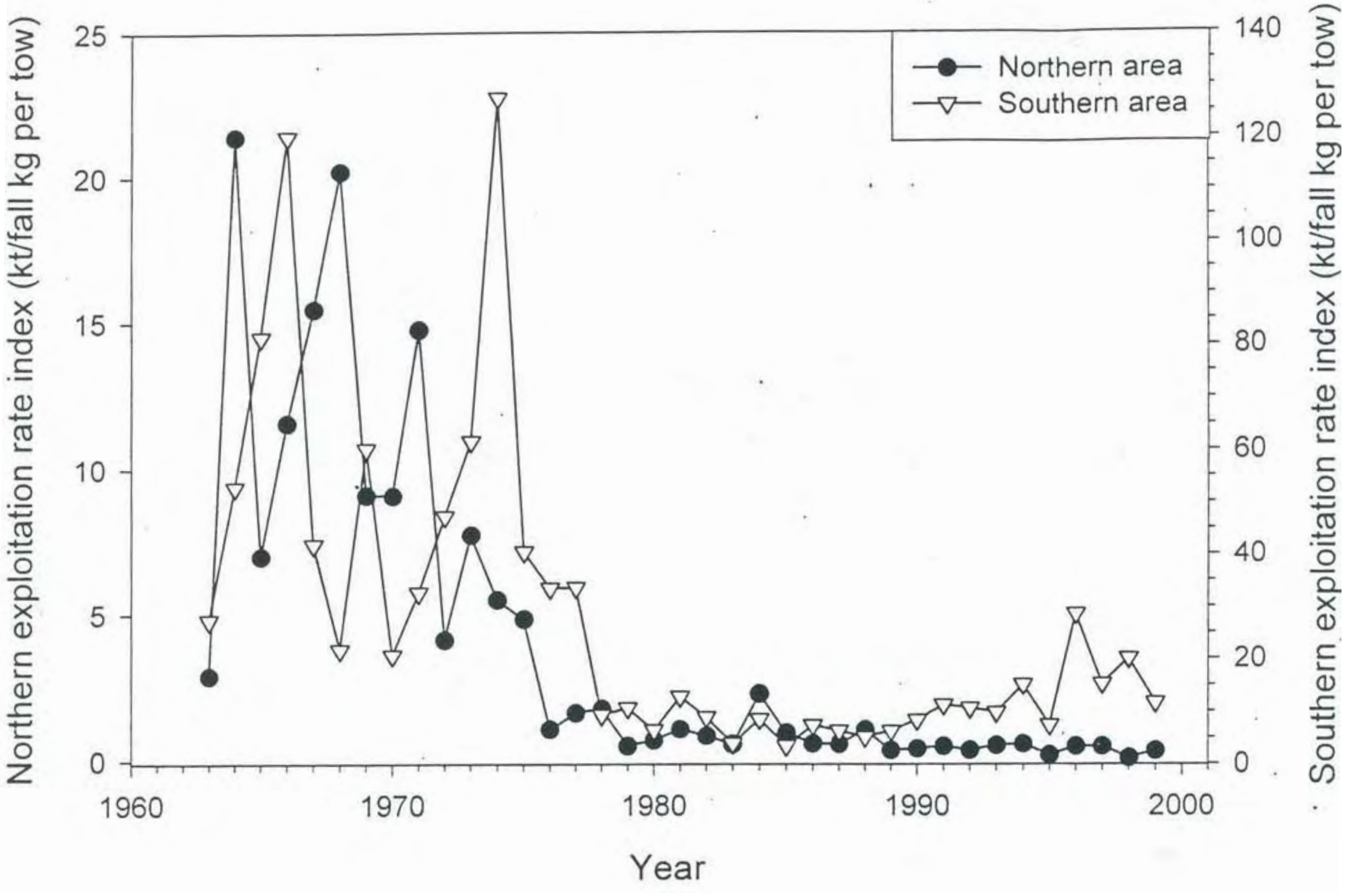
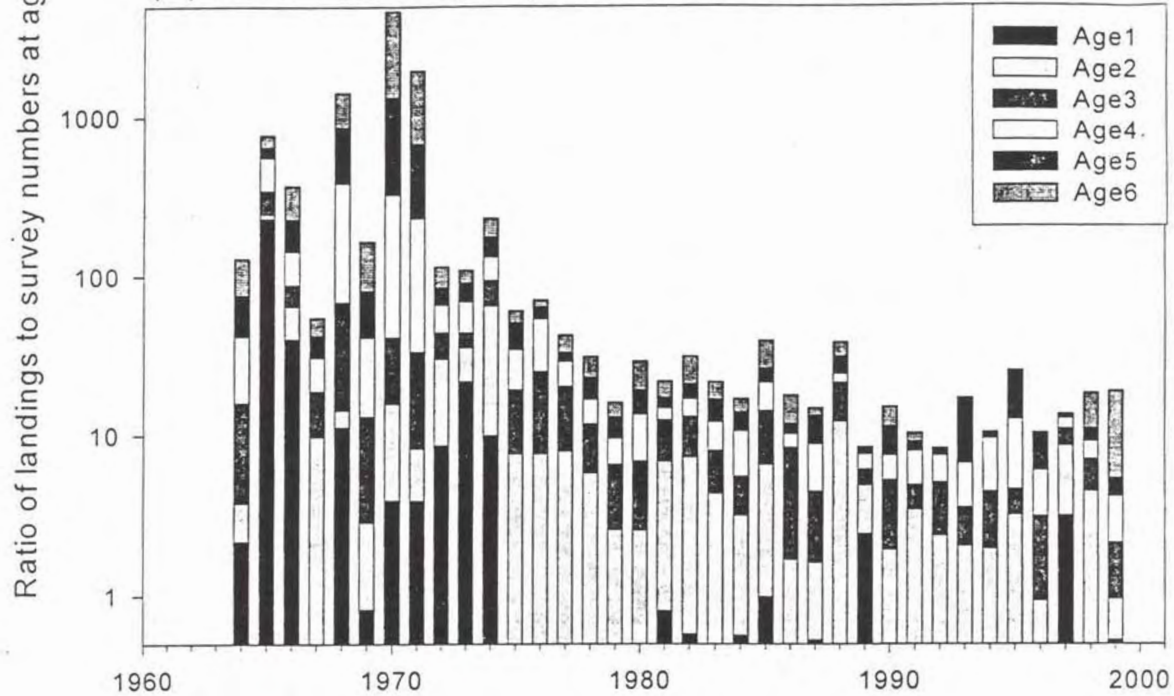


Figure C23. Age-specific exploitation rate indices for combined area silver hake from NEFSC autumn and spring surveys.

(A) Autumn survey exploitation rate indices by age



(B) Spring survey exploitation rate indices by age

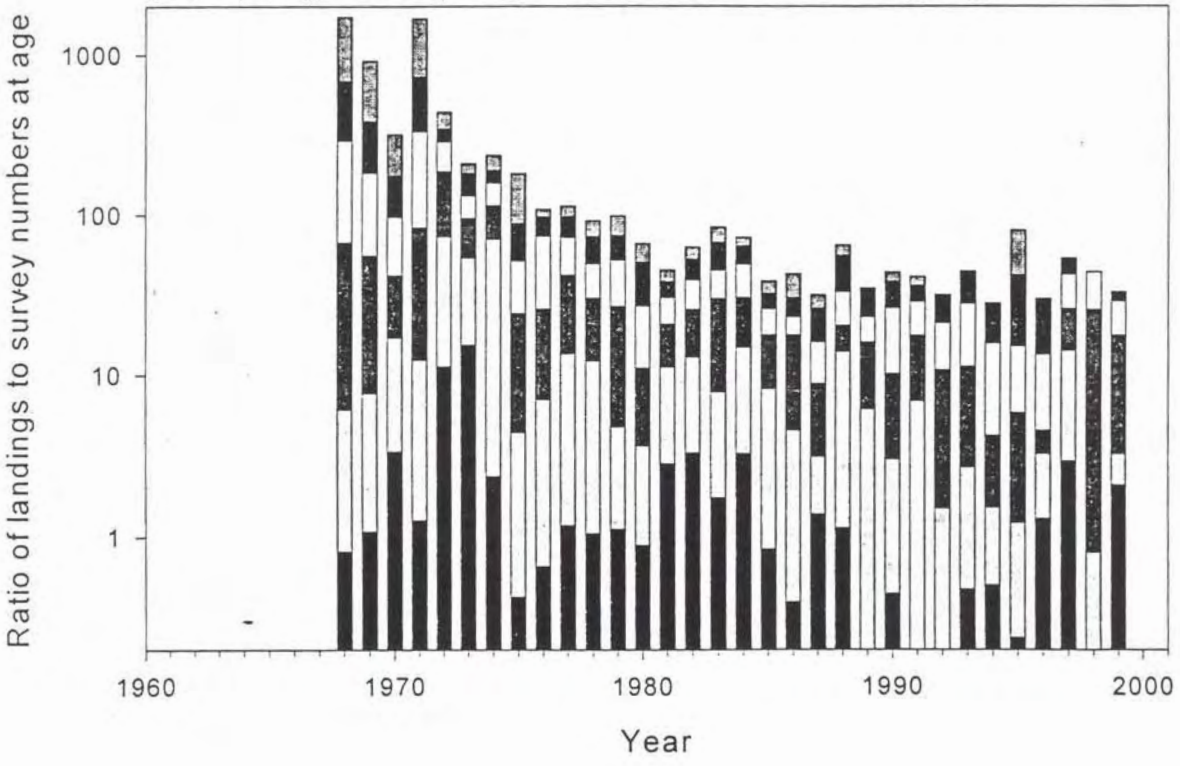


Figure C24. Silver hake average total mortality for the combined stock area from NEFSC spring and autumn survey data, using Heincke's method.

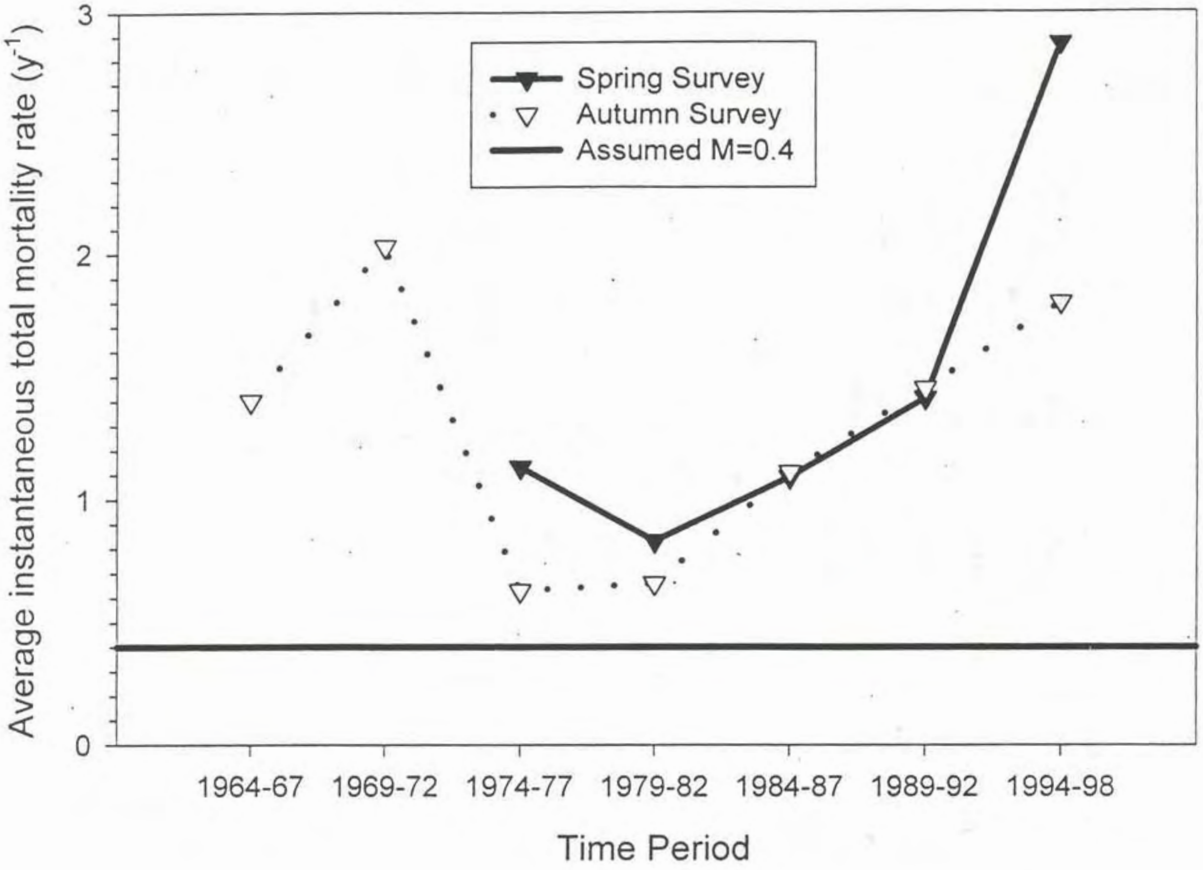


Figure C25. Trends in silver hake survey catchability at age for the best fit ADAPT model.

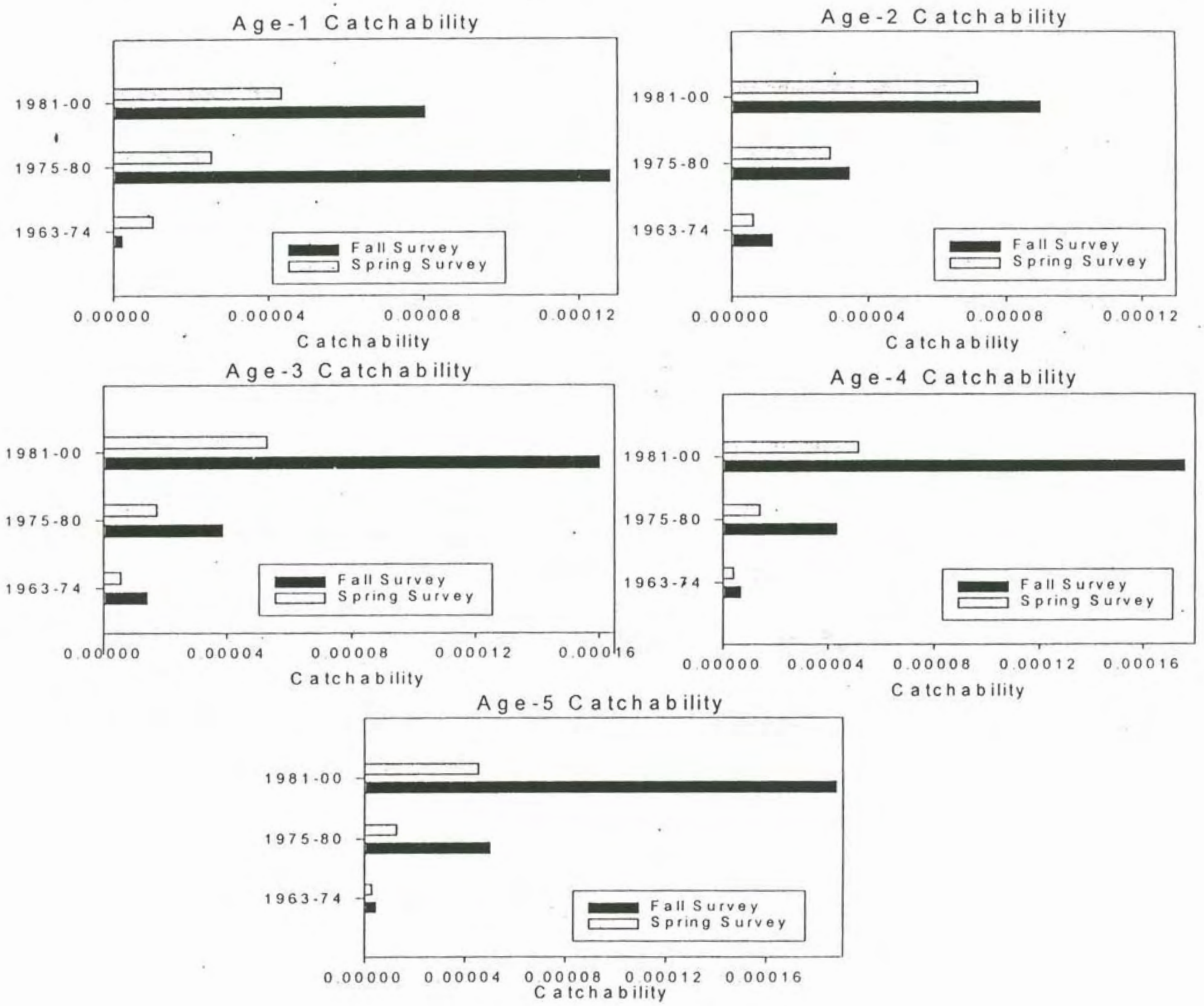
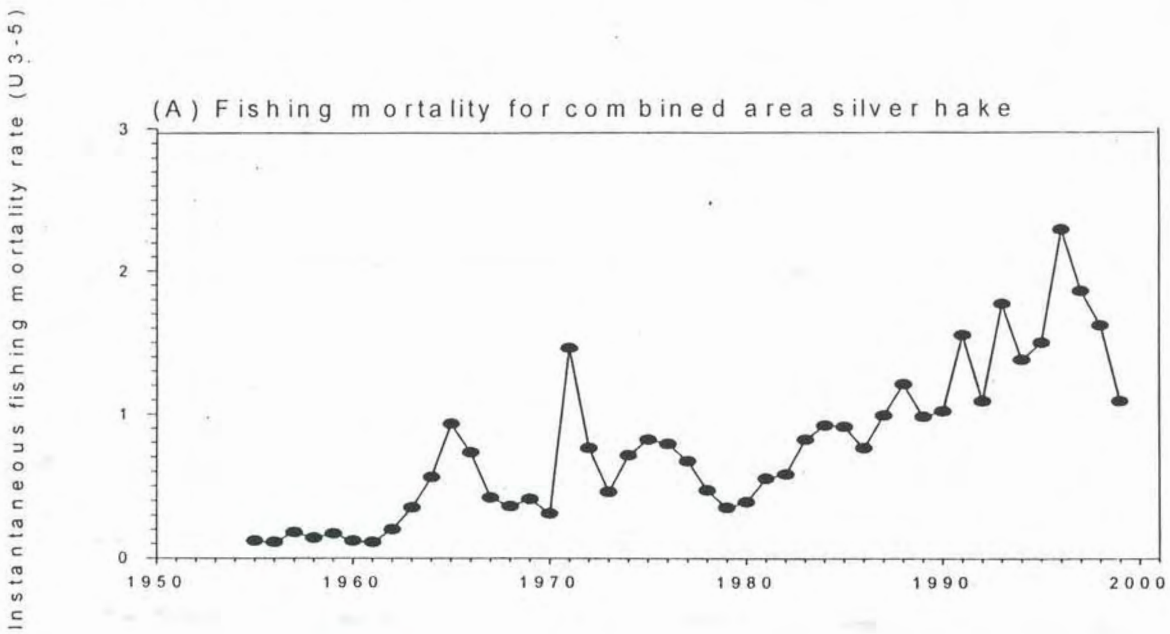
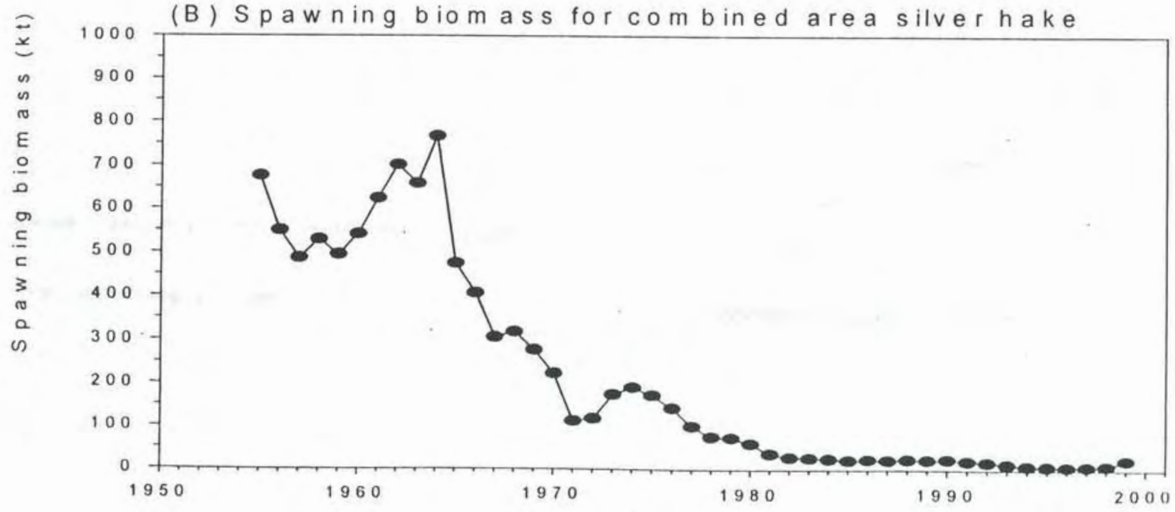


Figure C26. Estimated fishing mortality and spawning biomass for combined area silver hake from best fit ADAPT model.



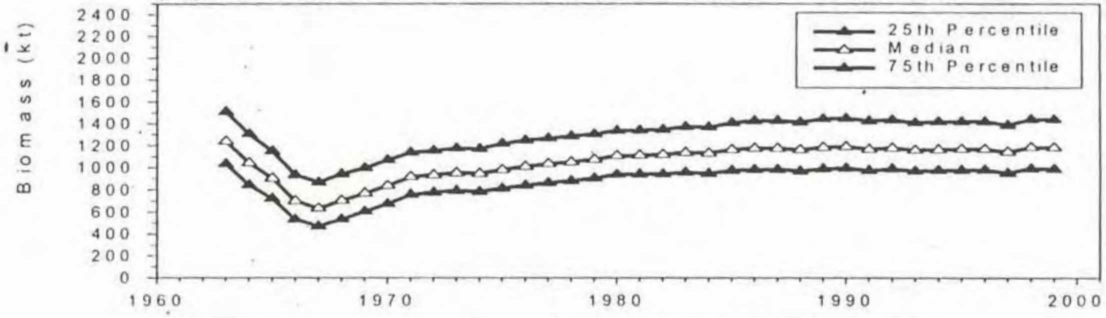
(A) Fishing mortality for combined area silver hake



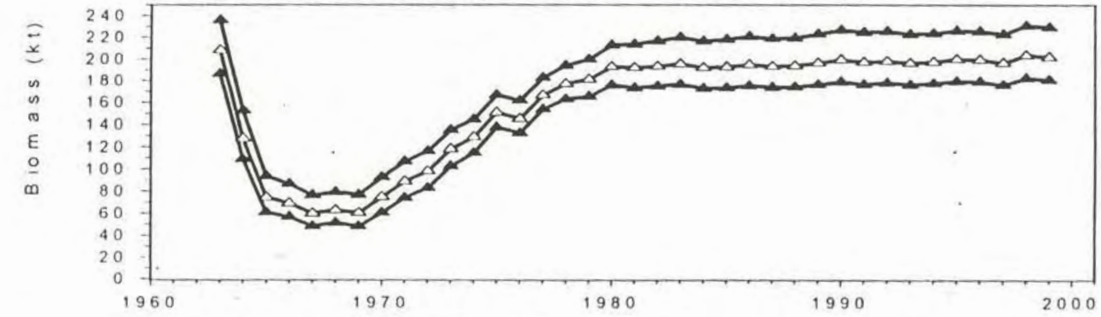
(B) Spawning biomass for combined area silver hake

Figure C27. Biomass estimates for combined northern and southern silver hake from Bayesian surplus production model.

(A) Combined area silver hake biomass estimates



(B) Northern area silver hake biomass estimates



(C) Southern area silver hake biomass estimates

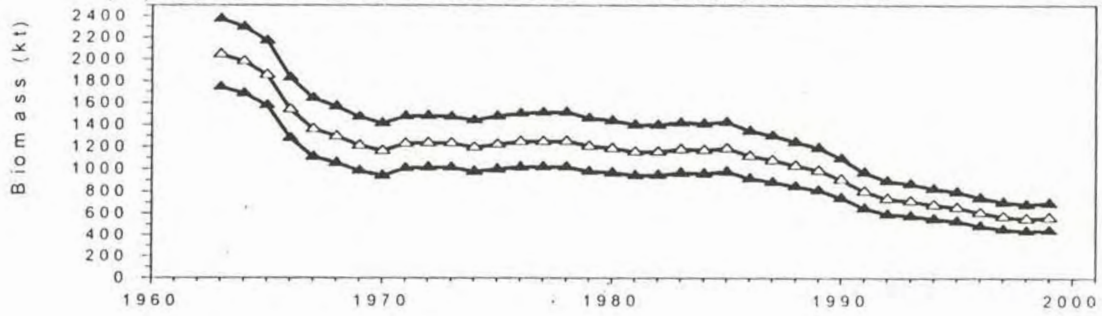
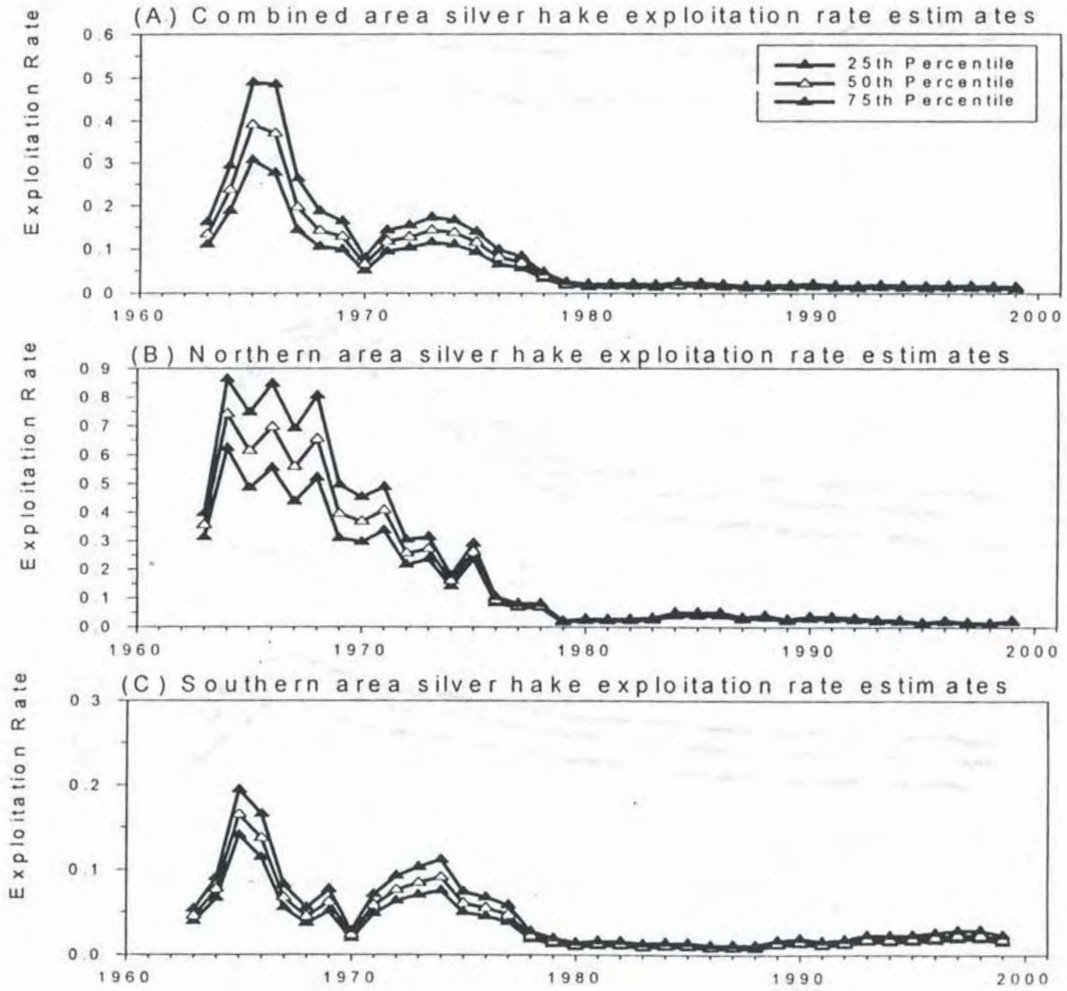


Figure C28. Exploitation rate estimates for combined northern and southern silver hake from Bayesian surplus production model.



D. GULF OF MAINE HADDOCK

TERMS OF REFERENCE

a. Update the status of Gulf of Maine haddock, based on indices of abundance and biomass from research vessel surveys.

b. Characterize population dynamics of Gulf of Maine haddock resource (size/age composition and recruitment), and update catches.

c. Consider current biological reference points for the Gulf of Maine haddock resource and recommend changes, as appropriate.

d. Provide recommendations for enhanced biological monitoring of the stock and other research as needed.

INTRODUCTION

Haddock (*Melanogrammus aeglefinus*) resources within U.S. waters are assessed and managed as two separate stocks, one on Georges Bank and south (NAFO Division 5Z and Subarea 6), and a second in the Gulf of Maine (NAFO Division 5Y; Figure D1). These stock definitions are based on tagging and movement studies, meristic data, age composition, growth and recruitment data (Needler 1930, Schroeder 1942, Schuck and Arnold 1951, Herrington 1948, Walford 1938). Haddock caught in Division 5Y represent the Gulf of Maine stock, while haddock caught in Division 5Z and Subarea 6 comprise the Georges Bank stock (Figure D1). The Gulf of Maine haddock stock was formerly an international resource exploited primarily by U.S. and Canadian fishers. Once the EEZ was established and the international border between the United States and Canada was clarified, the United States established exclusive fishing and management rights to the haddock resources in the Gulf of Maine.

The U.S. haddock fishery is currently managed under the Northeast Multispecies Fishery Management Plan administered by the New England Fishery Management Council. Commercial landings are the most significant form of fishery removals from this stock. Significant levels of regulatory discarding have been produced by U.S. trip limit regulations during several years analyzed for this assessment including the period since 1994. Recreational catch occurs for this stock primarily from party and charter boats targeting other species (cod and pollock), although some targeted fishing for haddock does occur. A minimum size limit of 43 cm (17 inches) was implemented in 1983, and was raised to 48.3 cm (19 inches) in the early 1990s (Table 1).

Recently, a series of significant management measures have been implemented by the National Marine Fisheries Service resulting in significant changes in the haddock resource and it's associated fisheries (Table D1). In January 1994, the NMFS implemented a 500 pound/trip landings limit to discourage targeting of haddock by the commercial fishery. Trip limit regulations have been repeatedly adjusted since: raised to 1000 pounds/trip in July 1996; raised to 1000 pounds/day fished with a maximum of 10,000 pounds/trip on September 1, 1997; raised to 3,000 pounds/day with maximum of 30,000 pounds/trip on September 1, 1998; lowered to

2,000 pounds/day with maximum of 20,000 pounds/trip on May 1, 1999; and raised to 5,000 pounds/day with a maximum of 50,000 pounds/trip on November 5, 1999. Most recently, on October 26, 2000 the daily trip limit was removed and the total trip limit remained at 50,000 pounds/trip.

In addition, Days at Sea reductions have been implemented in the U.S. fishery to reduce overall groundfish effort (Table D1). Mesh size was increased to 6 inches in May 1994 and square mesh size was increased to 6 ½" in May 1999. Both seasonal and year round area closures have been implemented in the Gulf of Maine since 1997 to reduce fishing mortality on the Gulf of Maine cod stock. The year round closure in the vicinity of Jeffrey's Ledge incorporates an area of significant haddock densities and spawning activity (Figure D1).

The Gulf of Maine haddock stock was last formally assessed at SAW/SARC 2 in 1986 (NMFS-NEFSC 1986). At the time of the 1986 assessment, landings had declined from 7,600 mt in 1983 to 3,000 mt in 1985. Although no formal analysis of fishing mortality was attempted, fishing mortality was assumed to be relatively high. The fishery in the mid 1980s was being supported by spill over of large year classes from Georges Bank, and research vessel surveys indicated that recruitment in the Gulf of Maine was extremely poor.

Although the last formal SAW/SARC assessment was in 1986, the Status of Stocks section for this stock has been updated on numerous occasions. In the most recent update (Brown 2000), both landings and research survey indices had declined sharply between the mid 1980s and the mid 1990s. Some increases in both landings and survey indices were observed in the late 1990s; however, the stock was determined to be in an overfished condition and that overfishing has been occurring with reference to the MSY-based harvest control rule. A short update of the status of the Gulf of Maine haddock stock was included in a management update for the New England Fishery Management Council's Multispecies Monitoring Committee in August 2000 (NDWG 2000).

THE FISHERY

U.S. Commercial Landings

Historically, the Gulf of Maine haddock stock was exploited primarily by the United States and Canada, although there are several years where landings from other countries (Spain, USSR) were significant (Table D2). Commercial landings averaged 5,600 mt from 1956 to 1967 before declining sharply to less than 600 mt in 1973. Landings increased in the mid-1970s and averaged 5,400 mt from 1977 to 1985. Landings declined during the mid 1980s falling below 900 mt in 1987 and reaching a record low of 112 mt in 1994. In the late 1990s, landings increased again exceeding 1,000 mt in 1998. Gulf of Maine haddock landings declined from 1,018 mt in 1998 to 668 mt in 1999 (Table D2, Figure D2). Management measures designed to reduce mortality on Gulf of Maine cod may have reduced access to the Gulf of Maine haddock resource in 1999.

Commercial Discards

The Sea Sample and Vessel Trip Report databases represent the two primary sources of information on commercial discarding of haddock. The Sea Sampling program, operated by the Northeast Fisheries Science Center continuously since 1989, has produced observations on haddock discarding practices. Information available from the Sea Sampling program includes estimates of the quantity of haddock kept and discarded from sampled gear hauls, and some biological information including length frequencies and some age data. The Vessel Trip Report program has been operated by the Northeast Regional Office of the National Marine Fisheries Service since April 1994. Information from this program is obtained from industry participants who self-report through a mandatory logbook program. Industry participation in the program has improved since the initiation of the program, but compliance is less than 100%. Therefore, logbook data represent a subset of actual industry activity. Industry participants are required to submit a report of estimated weight landed and discarded for all species caught. Reporting of discards by industry participants is known to be incomplete, and filtering of these data are necessary to make sound conclusions concerning discarding practices.

At Sea Sampling

Haddock catches are reported in the Sea Sample database in three primary gears, two gears (otter trawl and gillnet) that account for greater than 90% of Gulf of Maine haddock landings in most years, and in the shrimp trawl fishery where juvenile haddock represent a bycatch species. Sea sampling coverage of otter trawl trips catching haddock has ranged from 3 to 33 trips annually (Table D3). Total reported haddock discards and discard ratios (discarded weight / kept weight) were consistently low for the otter trawl fleet between 1989 and 1993. Although sampling intensity was low for otter trawl trips in 1994, it appears that discarding on otter trawl trips began to increase in 1994 when the 500 pound trip limit was implemented. Discard ratios for otter trawl trips remained high through 1997 before declining sharply in 1998 as trip limits were liberalized. Sampling coverage for otter trawl trips was poor in 1999, but discard ratios in the first two quarters of 2000 remained at low levels.

Sea sampling coverage (22 to 195 haddock trips annually) for the gillnet fleet was generally better than for the otter trawl fleet due to interest in marine mammal bycatch issues. Total reported haddock discards and discard ratios were consistently at low levels between 1989 and the first half of 2000 (Table D3). Because the Gulf of Maine shrimp fishery generally has a bycatch of juvenile haddock, discarding ratios in the shrimp trawl fishery were relatively high compared to the other two primary gears. The Nordmore grate was introduced into the Gulf of Maine shrimp fishery in 1993, likely resulting in a reduction in haddock catch in this fishery. During the 1992 to 1995 period when sampling intensity in the shrimp trawl fishery was high (16 to 33 trips with haddock catch observed annually), low overall levels of haddock were observed indicating that the fishery likely has minimal interactions with the haddock resource (Table D3).

Vessel Trip Reports

Information in the Vessel Trip Report (VTR) database on reported landings and discards was used to evaluate the relative importance of discarding in the otter trawl, gillnet, and hook (longline and handline) fleets from 1994 to 1999. The ratio of discards to landings by area and time period from the VTR database was estimated quarterly for each of the three fleets. Because many operators fail to report discards, it is clear that discard reporting is incomplete in the VTR database. Following methods used previously to estimate discarding rates for Georges Bank haddock

(Delong et al. 1997, Brown and Munroe 2000), only VTR records that report at least one pound of discards for any species are included in the discard ratio calculation. Thus, both trips with haddock landings or discards were included in the ratio calculation, unless the trip reported no discards for any species.

In the Vessel Trip Report database, reported haddock discards and discard ratios by the otter trawl fleet were consistently high from 1994 through the third quarter of 1997 when 500 and 1000 pound trip limits were in effect (Table D4, Figure D3). When trip limit regulations were liberalized to 1000 pounds/day up to a maximum of 10,000 pounds/trip in September 1997, discard ratios and total otter trawl discards fell sharply. Reported discarding remained at relatively low levels from late 1997 through the end of 1999.

Reported discarding by gillnet and hook (longline and handline) operators remained at relatively low levels from 1994 to 1999. Discarding by hook gear appeared to follow a seasonal pattern with high rates of discarding occurring during the 3rd quarter of most years.

Correspondence of Discard Information

Although the sample size was generally low in the Sea Sampling database, information generated by the sampling program was confirmatory of the discarding practices reported by industry operators in logbooks. In both data sources, discarding by otter trawlers was relatively high during the 1994 to 1997 period when restrictive trip limits were in effect and lower once these regulations were liberalized.

Size Distribution of Discards

Date generated by the sea sampling program represents the only source of information available to characterize the size distribution of landed and discarded haddock. However, in most years the sample size and trip coverage was insufficient to characterize the size distribution of landed or discarded haddock (Table D5). For the otter trawl fleet, annual length measurements for discarded haddock were less than 100 fish for 9 of the 11 years of the program. For the gillnet fleet, annual length measurements for discarded haddock were less than 40 fish in all years of the program.

Commercial Port Length Sampling

Haddock landed in the Gulf of Maine area have been sampled for length frequency distributions and age determinations since the late 1960s (Table D6). Data collected since 1969 suggest that haddock are primarily landed in two market categories, scrod and large, which are sampled separately because of differences in size. To accurately characterize the size and/or age composition of the landings, it is important to rely on consistent sampling coverage across market categories and time.

The temporal coverage of sampling has been inconsistent through this period, with the total number of samples ranging from 0 to 46 samples annually (Table D6). Sampling was insufficient to characterize the length or age composition of the stock from 1969 through 1974. Sampling coverage improved in 1975 (25 samples), and with the exception of 1976 and 1979, there appears to be sufficient samples to characterize the size and age composition of the catch from 1975 to 1987. As landings declined to very low levels during the 1990s, sampling coverage deteriorated and was again insufficient to characterize size and age compositions. Although there appears to be periods where sampling information is sufficient to estimate landings at age, sampling is clearly insufficient to reliably estimate parameters needed to support a full analytic assessment for this stock.

STOCK ABUNDANCE AND BIOMASS INDICES

Research Vessel Survey Abundance and Biomass Indices

Abundance (stratified mean number/tow) and biomass (stratified mean weight/tow) survey indices for Gulf of Maine haddock are based on analyses of representative tows occurring in offshore strata 26-28 and 36-40. Indices were adjusted for changes in trawl doors and research vessels that occurred during the time series (Table D7). Abundance and biomass indices were available for the Spring (1968 to 2000) and Autumn (1963 to 1999) surveys (Table D8). Spring survey biomass and abundance indices declined from high levels in the late 1960s to low levels in the early 1970s, demonstrated moderate increases in the late 1970s and early 1980s, and declined to record low levels in the early 1990s (Table D8; Figure D4). The spring surveys in 1987, 1989, 1990 and 1991 approached the level where the survey had difficulty detecting the presence of haddock in Gulf of Maine strata.

Survey indices in the 1990s have remained at chronic low levels, with the exception of 1997, 1999, and 2000 surveys (Table D8; Figure D4). The 1999 and 2000 abundance indices were the highest observed since 1981, and the biomass index in 2000 was the highest observed since 1985. Survey distribution plots show that Gulf of Maine haddock are generally concentrated along the 50 fathom contour in the Jeffreys Ledge and Stellwagon Bank regions of the Gulf of Maine (Figure D5). During periods when haddock abundance was high, there appears to be a continuous distribution of haddock along the 50 fathom contour from Jeffrey's Ledge south into the Great South Channel area.

U.S. autumn survey abundance and biomass indices declined from very high levels in the mid -1960s to low levels in the early 1970s (Table D7, Figure D4). The indices increased during the late 1970s and early 1980s in response to recruitment of the 1975 and 1978 year classes, and subsequently declined steadily to historic low levels in 1991. The autumn surveys in 1990 and 1991 approached the level where the survey had difficulty detecting the presence of haddock in Gulf of Maine strata. Abundance and biomass indices increased moderately in the mid 1990s and sharply beginning in 1996. The 1999 autumn survey abundance index (6.73 haddock/tow) and biomass index (4.91 kg/tow) were the highest observed since 1980 and 1985, respectively. However, these indices are less than 50% of levels observed during the mid 1960s. Survey distribution plots for the autumn survey exhibit a more scattered distribution for haddock in the Gulf of Maine area with some haddock occurring the deeper water in the central Gulf of Maine (Figure D6).

Survey Catch at Age

Collection and processing of age samples collected from U.S. research vessel surveys has been consistent since the initiation of each survey, allowing for an estimate of size and age composition from the survey. Spring and autumn survey abundance at age indices show the remnants of strong 1962 and 1963 year classes, as well as strong cohorts in 1972 and 1975, with several large cohorts occurring in the late 1970s and early 1980s (Tables D9 & D10; Figures D7 & D8). Recruitment appears to collapse beginning with the 1984 year class, and abundance declines sharply in the late 1980s and early 1990s. In addition the age structure of the population becomes extremely truncated with no fish older than ages 4 and 5 detected in several surveys conducted between 1990 and 1995. Recruitment appears to improve beginning with the 1991 year class and the age structure of the population appears to have broadened since 1996. Survey indices corresponding to the 1998 year class are the largest observed since the early 1980s (Tables D9 & D10).

Maturity Ogives

Maturation and reproductive stage data have been collected on NEFSC research vessel surveys and incorporated into survey databases since 1982. Some maturation data were collected as early as the mid-1970s; however, these data are not currently assessable. Maturity observations collected for female haddock sampled during the spring survey were analyzed to determine trends in maturation using a logistic regression approach (O'Brien et al. 1993). Maturity data were insufficient in most years to estimate annual maturity ogives, so data were pooled into multi-year blocks to estimate maturity-age relationships. Maturity observations were very sparse during the 1986-1995 period resulting in tenuous estimates of the maturity relationship even when estimated for 5 year blocks.

Maturity relationships for most 4-5 year blocks and for the entire sampling period (1982-2000) show similar patterns with approximately 50% maturity at age 2 and near full maturity at age 3 (Table D11). During the 1986-1990 period, the maturity ogive estimates near full maturity at age 2; however, the ogive is estimated from a very small sample size with only 12 fish sampled in the first three age classes (ages 1-3) where the maturity ogive is determined.

ESTIMATES OF RELATIVE EXPLOITATION

Survey Total Mortality Estimates

Estimates of instantaneous total mortality (Z) were derived for individual years from the NEFSC spring and autumn surveys as follows:

Spring Survey:ln ($\sum$ age 4+ for year i / $\sum$ age 5+ for year i+1)
Autumn Survey:ln ($\sum$ age 3+ for year i-1/ $\sum$ age 4+ for year i)

The severe truncation of the age structure of the stock during the late 1980s and early 1990s did not allow for estimation of instantaneous mortality for 6 years in the spring survey (1986, 1989, 1990, 1991, 1993, and 1994) and 1 year in the autumn survey (1992). Annual mortality estimates were quite variable and negative values were estimated for 6 of the 32 years in the spring survey and 8 of the 36 years in the autumn survey (Table D12; Figure D9). This is indicative of the high interannual variability in the survey catchability of older age classes of haddock. The spring mortality estimates appear to indicate a decline in total mortality since the late 1980s with the exception of an extremely high estimate of total mortality in 1997. This high estimate results from very low catches of haddock in the spring 1998 survey which appear to represent a strong year effect for this particular survey. In addition, there is no indication in the landings data that fishing mortality increased sharply during 1997. Mortality estimates from the autumn survey appear to vary without trend throughout the time period (Figure D9).

Exploitation Indices

Exploitation indices (catch (1000's mt) /

autumn survey biomass index) were calculated for the Gulf of Maine haddock stock. Because of variability in the autumn survey indices, a three year unweighted moving average approach was used to estimate exploitation indices as follows:

$$[(\text{Catch}_{\text{Year}-1} / \text{Survey}_{\text{Year}-1}) + (\text{Catch}_{\text{Year}} / \text{Survey}_{\text{Year}}) + (\text{Catch}_{\text{Year}+1} / \text{Survey}_{\text{Year}+1})]/3$$

The exploitation index remained stable and at relatively low levels from 1963 through the late 1970s, increased to higher levels in the early 1980s and declined to lower levels by the late 1980s (Table D13; Figure D10). The exploitation index rose sharply during the early 1990s reaching its highest levels in 1992 and 1993. Beginning in 1994, the exploitation index declined sharply and has remained at low levels during the late 1990s.

BIOLOGICAL REFERENCE POINTS

The MSY-based harvest control rule for Gulf of Maine haddock is based on estimates of B_{MSY} and F_{MSY} derived from surplus production modeling and expressed in research vessel survey units (ODRP 1998). The MSY-based harvest control rule for Gulf of Maine haddock is outlined as follows:

A maximum sustainable yield of 2,700 mt can be produced when relative stock biomass is 8.25 kg/tow (B_{MSY} proxy) and the relative exploitation index (catch/autumn biomass index) is 0.29 (f_{MSY} proxy). The maximum fishing mortality rate should be less than f_{MSY} when stock biomass exceeds B_{MSY}, and less than the fishing mortality that would allow rebuilding in five years when biomass is below B_{MSY}. Since the intrinsic rate of population growth ($r=0.20$) is less than other stocks where a 10 year rebuilding schedule was recommended, it is recommended that the minimum biomass threshold should be the biomass that can be rebuilt to B_{MSY} in five years with no fishing ($F = 0.00$). This biomass level is slightly greater than ½ B_{MSY} (average autumn survey biomass index of 4.38 kg /tow).

The current harvest control rule is shown graphically in Figure D11. Based on three year (1997- 1999) average autumn survey results, using the 3-year averaging technique outlined by the overfishing definition panel, the current biomass proxy (kg/tow) is less than $B_{threshold}$ (4.38 kg/tow), and the F proxy (0.246) is greater than 1999 F_{Target} proxy of 0.00.

In its 1998 report, the Overfishing Definition Review Panel (ODRP) warned that the F_{MSY} estimate from surplus production modeling was unstable and had an 80% confidence interval ranging from 0.20 to 0.42. Given that there has been significant increases in both the catch and survey indices since surplus production modeling was conducted for this stock, the surplus production model was updated to include survey and catch data for 1997 to 1999 using ASPIC (Prager 1994, Prager 1995). This updated model, as well as several sensitivity model runs revealed that parameter estimates, particularly the estimate of FMSY, were sensitive to small changes in model inputs, especially estimates of catch. Given the uncertainty in model parameter estimates produced by updated surplus production models, continued use of the current harvest control rule is recommended until alternate approaches are more thoroughly explored.

SARC COMMENTS

Stock structure
The SARC commented that recruitment dynamics and exploitation patterns are similar for Gulf of Maine and Georges Bank haddock stocks, unlike other gadoids such as cod. Observed synchrony among Gulf of Maine, Georges Bank and Brown's Bank stocks have been noted over time, especially associated with large recruitment events. Research on stock structure for haddock suggest that there may be a common larval source; however, after settlement occurs, growth rates are different. The question of whether these two stocks could be treated as a unit stock complex for management purposes was raised. The SARC suggested the topic of stock structure be explored further, and perhaps haddock movement patterns dove-tailed into proposed tagging and movement studies for cod.

Exploitation Index
The SARC discussed possible methods of calculating an exploitation index noting the importance of using averaging techniques to account for variability in survey indices. A revised approach for averaging was considered, however, the SARC accepted the current averaging procedure for stock determination. The SARC recommended further exploration before a change in methodology could be accepted, especially given the volatility in model results and the implication of changing methods for other species using an exploitation index as a proxy for fishing mortality. The SARC also remarked that an evaluation of the general performance of the exploitation index was needed. It was suggested that these tasks may be appropriate for the Methods Working Group to undertake since these issues pertain to many stocks.

The SARC noted that there may be a bias if an aggregate survey biomass index was used in deriving an exploitation index for this stock. The SARC suggested that the younger fish be removed from the survey biomass index so that the biomass index would reflect the population segment exploited by fisheries. Additional analyses were conducted using age 3+ and 4+ fish in the survey biomass. Results revealed that the three exploitation trends (using total, age 3+ and 4+ biomass) were generally similar; however, in years of good recruitment the magnitude of the peaks differed. The SARC concluded that removing the non-exploitable component of the survey biomass may be appropriate, and suggested that the Methods Working Group investigate methods to separate the survey biomass into exploitable and non-exploitable components. The SARC suggested comparing the Georges Bank haddock exploitation index trend with the VPA fishing mortality trends to gain insight into using an exploitation index for the Gulf of Maine stock.

Biological Reference Points
The SARC considered an updated surplus production model that incorporated minor revisions in earlier landings and three additional years of survey and landings data. The results from the updated model raised several questions regarding how and why the estimates of r and K would change with the addition of the 3 most recent data points. The SARC noted that the survey q's changed between the two analyses, yet this was unexpected given that both catch and survey indices were within the range of observed values, and it was unlikely that productivity had changed. Although r and K may be highly correlated when there is insufficient contrast in the data set, the SARC considered the estimates obtained from the revised analysis to be useful given that the most recent data

contain an additional cycle of stock rebuilding. It was suggested that more diagnostics would be useful such as correlation matrix for the parameters, frequency of MSY and a graph of the observed and predicted values. Additional analyses were conducted during the SARC. Results from these analyses indicate that the biological reference points for this stock were sensitive to minor changes in landings (i.e. r increased from .3 to .4); this decreased the Panel's confidence in using this model. Given the concerns stated above, the SARC expressed caution in using the surplus production model for Gulf of Maine haddock. The SARC recommends that other methods, such as a recruitment index model or a statistical catch-at-age model, be explored to calculate biological reference points.

Future Assessment Methods

Biological monitoring and other assessment methods also were discussed by the SARC. Given that Gulf of Maine haddock is a by-catch fishery, commercial biological sampling levels throughout the time series may be insufficient to construct a catch-at-age matrix. However, the SARC noted that there was approximately a decade where sufficient sampling did occur and that other methods, such as statistical age-structured modeling, are available which utilize the age structure of the population observed in the survey and the available commercial sampling which would allow application of analytical assessment procedures.

Sources of Uncertainty

- The fishing mortality rate index is sensitive to the age range from the survey. When stock abundance is low, the fishing mortality rate index is less reliable. It would be desirable to develop more robust estimators of exploitation rate.
- For this stock, the surplus production model used to establish the reference points is very sensitive to historical catches. Furthermore, the addition of a few additional years of data has a large effect on the estimates. The relative biomass reference point seems more robust than the F_{MSY} proxy to this problem. As a result, the basis of the reference point models needs to be evaluated.
- There is insufficient length and age sampling of US commercial landings to reliably estimate catch at age required to complete a VPA-based analytical assessment of this stock.
- The magnitude of discarding due to by-catch and in response to US trip limit regulations is uncertain.
- Recreational catch (landings and discards) occur for this stock, but are not well estimated by the marine recreational fisheries survey.

Research Recommendations

- The topic of stock structure be explored further, perhaps research for haddock could be dove-tailed into proposed tagging and movement work for Gulf of Maine and Georges Bank cod.
- Explore methods for deriving an exploitation index: 1) investigate the appropriate survey biomass component of the population to correspond to the commercial landings; 2) investigate appropriate smoothing techniques for survey

indices and/or catch values; 3) evaluate the performance of the exploitation index; and 4) evaluate implications of the Gulf of Maine closure area on the exploitation index.

- Explore alternate methods such as recruitment index model or statistical catch-at-age model to estimate biological reference points
- Compare Georges Bank haddock exploitation index trends with the VPA fishing mortality trends to gain insight for the Gulf of Maine stock.

CONCLUSIONS

The Gulf of Maine haddock stock is overfished and overfishing is occurring relative to the Amendment 9 control rule. The current exploitation rate (1997-1999 avg) is below the F_{msy} proxy but well above the current F_{target} and $F_{threshold}$ implied by the harvest control rule. Current biomass estimate (3.41 kg/tow, 1997-1999 average) is below the $B_{threshold}$ of 4.39 kg/tow. However, there are concerns about the robustness of reference points and the estimates of current exploitation rates and biomass.

Exploitation rates have declined in the 1990s and are currently among the lowest on record. Survey abundance and biomass indices have increased from record low levels in the early 1990s, and there is evidence of some broadening of the age structure of the stock. Recent recruitment has improved and research vessel surveys indicate strong 1998 and 1999 year classes that can be expected to recruit to the fishery in 2001-2003. However, biomass and landings remain well below historic levels for the stock.

Application of the Amendment 9 harvest control rule implies that fishing mortality should be reduced to zero for this stock. Reductions in fishing mortality will promote further increases in stock biomass and further broadening of age structure needed to rebuild this stock. The core of the stock distribution is in the vicinity of the current Western Gulf of Maine closure area and continued closure will assist in the protection of this stock.

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Table D1. Significant changes in management actions regulating the U.S. commercial fishery for haddock.

1953-1977		ICNAF Era
1953		Minimum mesh in body and codend - 4 1/2".
1977-Present		Extended Jurisdiction and National Management
1977		U.S. Fishery Conservation and Management Act of 1976 (FCMA) effective.
1977-1982		Fishery Management Plan (FMP) for Atlantic groundfish (cod, haddock and yellowtail fl.); mesh size of 5 1/8", quotas established on annual, quarterly and vessel class basis, eventually leading to trip limits.
1982-1985		The "Interim Plan" for Atlantic groundfish; eliminated all catch controls, retained closed area and mesh size regulations, implemented minimum landings sizes.
1983		Mesh size increased to 5 1/2 " minimum landing size - 17" commercial, 15" recreational.
1984	October	Implementation of the 'Hague' line establishing separate fishing zones for U.S. and Canada in the Gulf of Maine and on Georges Bank.
1985		Fishery Management Plan for the Northeast Multispecies Fishery.
1991		Amendment 4 to the Multispecies FMP established overfishing definitions for haddock in terms of F_{med} ($F_{20\%}$) replacement levels.
1994	January	Amendment 5 to the Multispecies FMP implemented.
	January 3	500 pound trip limit regulation implemented.
	May	6 inch mesh restriction implemented (delayed from March 1).
1996	July 1	Amendment 7 implemented: additional Days-at-Sea restrictions, trip limit raised to 1,000 pounds/trip.
1997	May 1	Additional scheduled Days-at-Sea restrictions from Amendment 7.
	September 1	Trip limit raised to 1,000 pounds/day, maximum of 10,000 pounds/trip.
1998	September 1	Trip limit raised to 3,000 pounds/day, maximum of 30,000 pounds/trip.
1999	May 1	Trip limit lowered to 2,000 pounds/day, maximum of 20,000 pounds/trip. Mesh size increased to 6 ½" square, remains at 6" diamond.
	November 5	Trip limit raised to 5,000 pounds/day, maximum of 50,000 pounds/trip.
	November 15	Amendment 9 of the Northeast Multispecies Fishery Management Plan in effect. Establishes new overfishing definitions and harvest control rules to comply with the Sustainable Fisheries Act.
2000	October 26	Daily trip limit (5,000 lbs/day), removed. Total trip limit of 50,000 lbs./trip remains in effect.

Table D3. Total trips, discard weight (mt), total kept weight (mt) and discard ratio (discarded/kept) for Gulf of Maine haddock reported for U.S. trawl trips in the Sea Sample database. Many sea sampled trips fish in multiple stock areas. Data are only reported for hauls occurring in the Gulf of Maine stock area (statistical areas 464, 465, 511-515). NTS indicates that no trips were sampled for the gear-quarter combination. A zero in the trips column indicates that at least one trip was sampled for that gear-quarter combination, but no haddock were observed. ** indicates sampling that was in progress during the current year.

		Otter Trawl					Shrimp Trawl					Gillnet				
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total
	Trips	3	7	8	2	20	0	1	NTS	1	2	NTS	NTS	15	12	27
	Discard (lbs)	67	3	9	22	101	0	1	--	1	2	--	--	8	29	37
1989	Kept (lbs)	309	275	2661	152	3397	0	0	--	0	0	--	--	270	345	615
	Discard Ratio	0.217	0.011	0.003	0.145	0.030	--	--	--	--	--	--	--	0.030	0.084	0.060
	Trips	1	1	2	2	6	2	1	NTS	0	3	6	5	5	6	22
	Discard (lbs)	0	0	0	2	2	2	7	--	0	9	4	8	9	7	28
1990	Kept (lbs)	5	33	91	245	374	0	6	--	0	6	162	170	1054	249	1635
	Discard Ratio	0.000	0.000	0.000	0.008	0.005	--	1.167	--	--	1.500	0.025	0.047	0.009	0.028	0.017
	Trips	1	2	1	8	12	1	1	NTS	1	3	2	33	64	42	141
	Discard (lbs)	0	0	0	26	26	0	3	--	1	4	0	59	100	38	197
1991	Kept (lbs)	8	24	142	674	848	3	0	--	0	3	9	2380	3591	2508	8488
	Discard Ratio	0.000	0.000	0.000	0.039	0.031	0.000	--	--	--	1.333	0.000	0.025	0.028	0.015	0.023
	Trips	11	6	3	4	24	15	0	NTS	1	16	8	34	30	36	108
	Discard (lbs)	58	4	29	92	183	21	0	--	1	22	45	36	35	33	149
1992	Kept (lbs)	8742	673	1031	1305	11751	4	0	--	0	4	303	1206	924	1385	3818
	Discard Ratio	0.007	0.006	0.028	0.070	0.016	5.250	--	--	--	5.500	0.149	0.030	0.038	0.024	0.039
	Trips	3	4	3	3	13	22	0	NTS	1	23	7	48	19	23	97
	Discard (lbs)	8	30	38	53	129	45	0	--	2	47	8	34	44	77	163
1993	Kept (lbs)	1066	639	242	275	2222	0	0	--	0	0	242	914	932	1855	3943
	Discard Ratio	0.008	0.047	0.157	0.193	0.058	--	--	--	--	--	0.033	0.037	0.047	0.042	0.041
	Trips	4	1	2	2	9	19	1	NTS	4	24	5	21	32	99	157
	Discard (lbs)	67	0	92	0	159	35	2	--	10	47	2	1	23	41	67
1994	Kept (lbs)	142	50	93	139	424	0	0	--	0	0	40	483	765	2839	4127
	Discard Ratio	0.472	0.000	0.989	0.000	0.375	--	--	--	--	--	0.050	0.002	0.030	0.014	0.016

Table D3. Total trips, discard weight (mt), total kept weight (mt) and discard ratio (discarded/kept) for Gulf of Maine haddock reported for U.S. trawl trips in the Sea Sample database. Many sea sampled trips fish in multiple stock areas. Data are only reported for hauls occurring in the Gulf of Maine stock area (statistical areas 464, 465, 511-515). NTS indicates that no trips were sampled for the gear-quarter combination. A zero in the trips column indicates that at least one trip was sampled for that gear-quarter combination, but no haddock were observed. ** indicates sampling that was in progress during the current year.

		Otter Trawl					**Shrimp Trawl**					**Gillnet**				
		Qtr 1	**Qtr 2**	**Qtr 3**	**Qtr 4**	**Total**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**	**Total**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**	**Total**
1989	**Trips**	3	7	8	2	20	0	1	NTS	1	2	NTS	NTS	15	12	27
	Discard (lbs)	67	3	9	22	101	0	1	--	1	2	--	--	8	29	37
	Kept (lbs)	309	275	2661	152	3397	0	0	--	0	0	--	--	270	345	615
	Discard Ratio	0.217	0.011	0.003	0.145	0.030	--	--	--	--	--	--	--	0.030	0.084	0.060
1990	**Trips**	1	1	2	2	6	2	1	NTS	0	3	6	5	5	6	22
	Discard (lbs)	0	0	0	2	2	2	7	--	0	9	4	8	9	7	28
	Kept (lbs)	5	33	91	245	374	0	6	--	0	6	162	170	1054	249	1635
	Discard Ratio	0.000	0.000	0.000	0.008	0.005	--	1.167	--	--	1.500	0.025	0.047	0.009	0.028	0.017
1991	**Trips**	1	2	1	8	12	1	1	NTS	1	3	2	33	64	42	141
	Discard (lbs)	0	0	0	26	26	0	3	--	1	4	0	59	100	38	197
	Kept (lbs)	8	24	142	674	848	3	0	--	0	3	9	2380	3591	2508	8488
	Discard Ratio	0.000	0.000	0.000	0.039	0.031	0.000	--	--	--	1.333	0.000	0.025	0.028	0.015	0.023
1992	**Trips**	11	6	3	4	24	15	0	NTS	1	16	8	34	30	36	108
	Discard (lbs)	58	4	29	92	183	21	0	--	1	22	45	36	35	33	149
	Kept (lbs)	8742	673	1031	1305	11751	4	0	--	0	4	303	1206	924	1385	3818
	Discard Ratio	0.007	0.006	0.028	0.070	0.016	5.250	--	--	--	5.500	0.149	0.030	0.038	0.024	0.039
1993	**Trips**	3	4	3	3	13	22	0	NTS	1	23	7	48	19	23	97
	Discard (lbs)	8	30	38	53	129	45	0	--	2	47	8	34	44	77	163
	Kept (lbs)	1066	639	242	275	2222	0	0	--	0	0	242	914	932	1855	3943
	Discard Ratio	0.008	0.047	0.157	0.193	0.058	--	--	--	--	--	0.033	0.037	0.047	0.042	0.041
1994	**Trips**	4	1	2	2	9	19	1	NTS	4	24	5	21	32	99	157
	Discard (lbs)	67	0	92	0	159	35	2	--	10	47	2	1	23	41	67
	Kept (lbs)	142	50	93	139	424	0	0	--	0	0	40	483	765	2839	4127
	Discard Ratio	0.472	0.000	0.989	0.000	0.375	--	--	--	--	--	0.050	0.002	0.030	0.014	0.016

Table D3. Cont. Total trips, discard weight (mt), total kept weight (mt) and discard ratio (discarded/kept) for Gulf of Maine haddock reported for U.S. trawl trips in the Sea Sample database. Many sea sampled trips fish in multiple stock areas. Data are only reported for hauls occurring in the Gulf of Maine stock area (statistical areas 464, 465, 511-515). NTS indicates that no trips were sampled for the gear-quarter combination. A zero in the trips column indicates that at least one trip was sampled for that gear-quarter combination, but no haddock were observed. ** indicates sampling that was in progress during the current year.

		Otter Trawl					Shrimp Trawl					Gillnet				
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total
	Trips	12	4	6	11	33	31	2	NTS	0	33	10	55	58	58	181
	Discard (lbs)	1340	44	273	286	1942	35	1	--	0	36	15	7	18	20	60
1995	Kept (lbs)	2387	277	562	928	4154	0	0	--	0	0	279	616	804	2301	4000
	Discard Ratio	0.561	0.157	0.485	0.308	0.468	--	--	--	--	--	0.053	0.011	0.02	0.009	0.015
	Trips	3	7	4	5	19	4	1	NTS	5	10	8	52	49	36	145
	Discard (lbs)	642	186	2	62	893	2	1	--	7	9	3	101	43	26	173
1996	Kept (lbs)	850	927	0	215	1992	0	0	--	0	0	280	1003	661	1871	3815
	Discard Ratio	0.755	0.201	--	0.290	0.448	--	--	--	--	--	0.011	0.100	0.06	0.014	0.045
	Trips	7	0	1	NTS	8	7	NTS	NTS	NTS	7	4	104	63	24	195
	Discard (lbs)	5185	0	4	--	5189	4	--	--	--	4	0	0	2	0	2
1997	Kept (lbs)	4400	0	449	--	4849	0	--	--	--	0	172	3633	1443	2633	7881
	Discard Ratio	1.178	--	0.009	--	1.070	--	--	--	--	--	0.000	0.000	0.00	0.000	0.000
	Trips	2	1	0	NTS	3	NTS	NTS	NTS	NTS	NTS	2	19	18	13	52
	Discard (lbs)	35	0	0	--	35	--	--	--	--	--	0	50	204	2	256
1998	Kept (lbs)	3363	100	0	--	3463	--	--	--	--	--	50	1191	920	558	2718
	Discard Ratio	0.010	0.000	--	--	0.010	--	--	--	--	--	0.000	0.042	0.22	0.004	0.094
	Trips	NTS	0	2	2	4	NTS	NTS	NTS	NTS	NTS	7	13	10	27	57
	Discard (lbs)	--	0	3	4	7	--	--	--	--	--	0	0	0	37	37
1999	Kept (lbs)	--	0	7	0	7	--	--	--	--	--	354	3334	2385	2259	8332
	Discard Ratio	--	--	0.429	--	1.000	--	--	--	--	--	0.000	0.000	0.00	0.016	0.004
	Trips	6	15	**	**	**	NTS	NTS	NTS	NTS	NTS	32	26	**	**	**
	Discard (lbs)	0	4	**	**	**	--	--	--	--	--	97	32	**	**	**
2000	Kept (lbs)	1810	693	**	**	**	--	--	--	--	--	19389	1476	**	**	**
	Discard Ratio	0.005	0.022	**	**	**	--	--	--	--	--	0.005	0.022	**	**	**

Table D4. Total discard weight (mt), total kept weight (mt) and discard ratio (discarded/kept) for Gulf of Maine haddock Reported for U.S. trawl trips in the Vessel Trip Record database. Only trips reporting haddock catch and discards for any species (haddock or other species) were considered for discard analyses.

		Otter Trawl					Gillnet					Hook (Hand & Longline)				
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total
	Discard (mt)	--	10.70	29.24	7.75	47.70	--	0.04	0.27	0.07	0.38	--	0.01	0.05	0.18	0.24
1994	Kept (mt)	--	11.77	9.53	8.93	30.31	--	0.72	2.32	2.21	5.25	--	0.04	1.30	2.77	4.11
	Discard Ratio	--	0.910	3.069	0.867	1.573	--	0.059	0.116	0.033	0.073	--	0.292	0.036	0.065	0.058
	Discard (mt)	10.97	1.47	18.55	8.60	39.59	0.03	0.20	0.20	0.09	0.52	0.03	0.14	0.36	0.77	1.30
1995	Kept (mt)	13.82	5.62	9.71	8.52	37.67	1.04	1.83	2.68	2.51	8.06	2.62	3.19	6.21	4.18	16.19
	Discard Ratio	0.794	0.262	1.911	1.009	1.051	0.025	0.109	0.076	0.035	0.064	0.013	0.044	0.058	0.183	0.080
	Discard (mt)	11.56	4.18	9.41	14.10	39.25	0.01	0.06	0.33	0.00	0.39	0.13	0.14	0.10	0.17	0.54
1996	Kept (mt)	9.17	11.25	25.98	19.25	65.65	0.68	2.90	2.65	0.52	6.74	3.37	2.83	2.12	5.46	13.78
	Discard Ratio	1.261	0.372	0.362	0.732	0.598	0.018	0.020	0.123	0.000	0.058	0.037	0.050	0.048	0.031	0.039
	Discard (mt)	48.84	2.81	21.84	4.25	77.73	0.00	0.15	0.01	0.03	0.19	0.10	0.20	1.22	0.25	1.77
1997	Kept (mt)	25.28	5.79	32.55	49.92	113.54	0.42	1.38	0.58	3.31	5.69	2.25	7.19	3.93	7.20	20.58
	Discard Ratio	1.932	0.485	0.671	0.085	0.685	0.008	0.109	0.011	0.009	0.034	0.046	0.027	0.310	0.035	0.086
	Discard (mt)	3.17	2.43	1.65	0.39	7.64	0.00	0.07	0.07	0.04	0.19	0.17	0.60	0.16	0.43	1.37
1998	Kept (mt)	54.52	21.27	94.59	63.40	233.82	0.28	2.19	1.19	2.09	5.74	8.39	10.38	1.88	0.86	21.51
	Discard Ratio	0.058	0.114	0.017	0.006	0.033	0.016	0.032	0.059	0.021	0.033	0.021	0.058	0.085	0.498	0.064
	Discard (mt)	0.11	1.39	0.31	4.34	6.14	0.05	0.05	0.09	0.07	0.26	0.27	0.10	0.09	0.01	0.47
1999	Kept (mt)	40.75	10.10	33.64	47.05	131.55	2.83	4.33	6.39	24.12	37.67	4.86	2.04	1.07		8.06
	Discard Ratio	0.003	0.138	0.009	0.092	0.047	0.017	0.012	0.014	0.003	0.007	0.056	0.047	0.084	0.069	0.058

Table D5. Summary of at-sea sampling of U.S. commercial trips and hauls from Georges Bank and south where haddock were measured from 1989-1999. Summaries from major gear groups including otter trawl, shrimp trawl, and gillnet trips are included. NTS indicates that no trips were sampled for the gear-quarter combination. A zero in the trips column indicates that at least one trip was sampled for that gear-quarter combination, but no haddock were observed. ** indicates sampling that was in progress during the current year.

		Otter Trawl					Shrimp Trawl					Gillnet				
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total
	Trips	2	1	4	1	8	0	1	NTS	0	1	NTS	NTS	0	0	0
1989	Hauls	2	1	5	1	9	0	1	–	0	1	–	–	0	0	0
	Discard Lengths	35	1	0	8	44	0	1	–	0	1	–	–	0	0	0
	Kept Lengths	40	0	131	0	171	0	0	–	0	0	–	–	0	0	0
	Trips															
1990	Hauls															
	Discard Lengths	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Kept Lengths	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Trips	0	0	0	0	0	0	0	NTS	0	0	0	4	4	1	9
1991	Hauls	0	0	0	0	0	0	0	–	0	0	0	4	5	1	10
	Discard Lengths	0	0	0	0	0	0	0	–	0	0	0	0	1	0	1
	Kept Lengths	0	0	0	0	0	0	0	–	0	0	0	37	11	24	72
	Trips	2	0	3	1	6	3	0	NTS	0	3	2	9	7	8	26
1992	Hauls	2	0	5	1	8	3	0	–	0	3	4	15	8	8	35
	Discard Lengths	10	0	11	12	33	7	0	–	0	7	0	0	0	1	1
	Kept Lengths	14	0	1	0	15	0	0	–	0	0	12	18	12	9	51
	Trips	0	3	1	2	6	8	0	NTS	1	9	1	15	5	4	25
1993	Hauls	0	8	5	3	16	16	0	–	1	17	1	19	7	12	39
	Discard Lengths	0	5	19	12	36	48	0	–	1	49	0	2	0	1	3
	Kept Lengths	0	93	0	25	118	0	0	–	0	0	1	24	15	30	70
	Trips	4	1	3	3	11	18	1	NTS	4	23	2	4	3	7	16
1994	Hauls	6	1	9	4	20	23	2	–	10	35	2	4	3	16	25
	Discard Lengths	8	0	34	0	42	85	3	–	32	120	0	1	1	17	19
	Kept Lengths	3	1	46	11	61	0	0	–	0	0	2	3	6	9	20
	Trips	18	5	9	7	39	24	0	NTS	0	24	1	7	15	16	39
1995	Hauls	54	18	28	21	121	41	0	–	0	41	5	12	16	21	54
	Discard Lengths	208	15	88	131	442	134	0	–	0	134	7	0	4	0	11
	Kept Lengths	156	34	34	58	282	0	0	–	0	0	0	23	21	59	103
	Trips	5	11	2	5	23	2	1	NTS	3	6	5	19	15	12	51
1996	Hauls	10	15	2	15	42	3	1	–	6	10	9	29	18	14	70
	Discard Lengths	35	44	2	33	114	4	1	–	35	40	1	23	11	1	36
	Kept Lengths	21	61	0	15	97	0	0	–	0	0	19	27	21	79	146
	Trips	17	0	2	NTS	19	5	NTS	NTS	NTS	5	2	10	9	3	24
1997	Hauls	58	0	4	–	62	5	–	–	–	5	2	10	10	3	25
	Discard Lengths	946	0	3	–	949	6	–	–	–	6	1	1	2	0	4
	Kept Lengths	158	0	13	–	171	0	–	–	–	0	1	59	45	5	110
	Trips	4	0	0	NTS	4	NTS	NTS	NTS	NTS	NTS	1	9	2	3	15
1998	Hauls	12	0	0	–	12	–	–	–	–	–	1	12	2	3	18
	Discard Lengths	10	0	0	–	10	–	–	–	–	–	0	3	0	2	5
	Kept Lengths	124	0	0	–	124	–	–	–	–	–	1	31	5	32	69
	Trips	NTS	0	1	2	3	NTS	NTS	NTS	NTS	NTS	2	2	7	11	22
1999	Hauls	–	0	1	2	3	–	–	–	–	–	4	3	11	13	31
	Discard Lengths	–	0	1	6	7	–	–	–	–	–	0	0	10	8	18
	Kept Lengths	–	0	0	0	0	–	–	–	–	–	7	50	21	38	116

Table D6. U.S. sampling of commercial haddock landings for length and age composition by market category from the Gulf of Maine (U.S. statistical areas 464, 465, 511, 512, 513, 514, 515), 1982-1999. Q1, Q2, Q3, and Q4 denote calendar quarters 1-4, respectively. Other samples include snapper and unclassified samples.

	Total	Total	Scrod Samples					Large Samples					Other	Age Determinations				
Year	Samples	Lengths	Q1	Q2	Q3	Q4	Total	Q1	Q2	Q3	Q4	Total	Total	Q1	Q2	Q3	Q4	Total
1969	6	526	0	0	3	1	4	0	1	1	0	2	0	0	20	46	15	81
1970	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	3	269	0	0	0	1	1	1	0	0	1	2	0	0	0	0	0	0
1972	9	792	2	0	1	0	3	2	1	2	1	6	0	0	0	20	20	40
1973	5	931	0	0	0	2	2	1	0	2	0	3	0	20	0	38	40	98
1974	3	354	1	1	0	0	2	1	0	0	0	1	0	40	20	0	0	60
1975	20	2053	5	6	0	0	11	5	3	0	0	8	0	15	25	0	0	40
1976	5	286	0	1	1	2	4	1	0	0	0	1	1	19	15	20	35	89
1977	31	4172	3	5	8	6	22	0	2	4	1	7	0	112	229	443	339	1123
1978	21	1814	6	4	3	2	15	3	1	1	0	5	2	237	135	89	49	510
1979	5	599	1	0	0	1	2	1	0	1	1	3	1	78	0	25	61	164
1980	15	1153	2	2	4	3	11	0	2	1	0	3	0	31	97	88	46	262
1981	23	2253	1	1	2	3	7	0	1	3	6	10	1	14	120	185	227	546
1982	34	3188	4	1	3	3	11	2	0	18	2	22	6	183	14	401	135	733
1983	46	4476	6	6	4	3	19	4	8	8	6	26	1	190	304	302	178	974
1984	27	1994	4	2	3	2	11	1	1	10	4	16	0	85	52	276	125	538
1985	42	3105	7	4	6	2	19	4	6	6	7	23	0	190	204	230	180	804
1986	37	2542	5	6	4	4	19	3	3	9	3	18	0	118	136	232	116	602
1987	25	1837	3	1	2	4	10	2	1	7	5	15	0	76	38	175	199	488
1988	10	746	4	1	1	0	6	1	0	1	2	4	0	104	0	32	39	175
1989	7	603	1	0	0	2	3	2	0	1	1	4	0	91	0	16	42	149
1990	5	275	1	1	0	1	3	1	0	0	1	2	0	43	16	0	37	96
1991	13	1023	1	0	3	3	7	0	2	2	2	6	0	16	32	117	87	252
1992	6	411	1	0	1	2	4	1	0	0	1	2	0	40	0	15	83	138
1993	5	338	0	0	1	0	1	1	1	1	0	3	1	20	42	49	0	111
1994	8	575	0	0	1	2	3	0	1	1	3	5	0	0	26	47	149	222
1995	5	349	1	0	0	1	2	1	1	0	1	3	0	43	22	0	47	112
1996	6	550	0	1	0	1	2	1	0	1	2	4	0	25	13	22	69	129
1997	12	1173	0	1	2	2	5	1	2	4	0	7	0	25	77	119	18	239
1998	20	1788	6	1	2	1	10	4	1	2	3	10	0	127	45	119	147	438
1999	14	953	0	0	5	3	8	2	0	2	2	6	0	33	0	132	122	287

Table D7. Conversion factors used to account for differences in fishing power between research vessels and changes in doors used to conduct the U.S. research vessel bottom trawl surveys (Forrester et al. 1997). Coefficients of 0.82 (Delaware) and 1.49 (BMV door) were applied to numerical abundance indices, and 0.79 (Delaware) and 1.51 (BMV door) were applied to biomass indices.

		Spring		Autumn	
Years	**Door**	**Vessel**	**Conversion**	**Vessel**	**Door**
1963-1967	**BMV**	**—**	**—**	**Albatross IV**	**1.490**
1968-1976	**BMV**	**Albatross IV**	**1.490**	**Albatross IV**	**1.490**
1977-1980	**BMV**	**Albatross IV**	**1.490**	**Delaware II**	**1.222**
1981	**BMV**	**Delaware II**	**1.222**	**Delaware II**	**1.222**
1982	**BMV**	**Delaware II**	**1.222**	**Albatross IV**	**1.490**
1983-1984	**BMV**	**Albatross IV**	**1.490**	**Albatross IV**	**1.490**
1985-1988	**Polyvalent**	**Albatross IV**	**1.000**	**Albatross IV**	**1.000**
1989-1991	**Polyvalent**	**Delaware II**	**0.820**	**Delaware II**	**0.820**
1992	**Polyvalent**	**Albatross IV**	**1.000**	**Albatross IV**	**1.000**
1993	**Polyvalent**	**Albatross IV**	**1.000**	**Delaware II**	**0.820**
1994	**Polyvalent**	**Delaware II**	**0.820**	**Albatross IV**	**1.000**
1995-2000	**Polyvalent**	**Albatross IV**	**1.000**	**Albatross IV**	**1.000**

Table D8. Stratified and standardized mean number and mean weight (kg) per tow of of haddock caught in the NEFSC spring and autumn trawl surveys from 1963-1999.

	Spring Survey		Autumn Survey	
Year	**Number/Tow**	**Weight (kg)/tow**	**Number/tow**	**Weight (kg)/tow**
1963			69.54	50.69
1964			14.17	18.82
1965			17.43	17.64
1966			11.65	13.85
1967	*Spring survey initiated in 1968*		12.186	16.85
1968	6.00	7.88	7.64	15.48
1969	3.78	7.37	5.45	12.85
1970	0.90	1.72	2.91	7.35
1971	0.87	2.52	2.87	8.13
1972	0.86	0.86	1.98	3.03
1973	1.20	1.57	4.16	8.58
1974	1.43	1.05	2.68	3.34
1975	2.77	3.48	5.53	8.61
1976	8.32	6.35	6.03	8.04
1977	6.79	6.72	8.29	8.75
1978	1.35	1.43	9.16	20.93
1979	3.33	4.63	5.52	13.72
1980	2.69	3.38	7.15	9.83
1981	4.40	4.48	3.86	9.34
1982	2.04	2.55	2.62	4.16
1983	3.67	3.56	2.59	5.21
1984	1.09	1.14	1.69	3.89
1985	1.77	1.88	4.07	6.14
1986	0.70	1.28	0.62	1.39
1987	0.09	0.06	1.03	2.64
1988	0.18	0.30	0.33	1.47
1989	0.08	0.12	0.28	0.63
1990	0.02	0.00	0.14	0.43
1991	0.07	0.06	0.14	0.12
1992	0.19	0.27	0.21	0.09
1993	0.45	0.20	0.86	0.47
1994	0.40	0.25	0.32	0.21
1995	0.80	0.35	0.97	1.09
1996	0.30	0.33	2.40	3.54
1997	1.93	1.22	2.68	2.42
1998	0.19	0.11	3.13	2.91
1999	4.26	1.10	6.73	4.91
2000	3.61	1.81	**Data Not Available**	

Table D9. Stratified mean catch per tow (numbers) for haddock in NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine (Strata 01260-01280, 01360-01400), 1968-2000. Indices have been adjusted to account for changes in catchability due to changes in research vessels and doors (Forrester et al. 1997).

Year	0	1	2	3	4	5	6	7	8	9+	Total
1963											
1964											
1965											
1966											
1967			*NEFSC Spring Survey Initiated in 1968*								
1968	0.00	0.00	0.00	0.00	0.34	4.43	0.94	0.08	0.03	0.21	6.01
1969	0.00	0.00	0.00	0.08	0.02	0.19	2.67	0.70	0.04	0.08	3.78
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.61	0.09	0.06	0.91
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.65	0.18	0.88
1972	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.86
1973	0.00	0.12	0.72	0.00	0.05	0.00	0.00	0.00	0.00	0.31	1.20
1974	0.00	0.89	0.09	0.33	0.00	0.00	0.00	0.00	0.00	0.13	1.44
1975	0.00	0.01	1.97	0.15	0.37	0.00	0.01	0.00	0.00	0.25	2.77
1976	0.00	5.15	0.07	1.85	0.18	0.91	0.00	0.03	0.00	0.13	8.33
1977	0.00	0.88	3.56	0.03	1.34	0.40	0.58	0.00	0.00	0.00	6.80
1978	0.00	0.09	0.70	0.31	0.06	0.15	0.04	0.00	0.00	0.00	1.36
1979	0.00	0.36	0.00	1.54	1.14	0.09	0.11	0.09	0.00	0.00	3.33
1980	0.00	1.29	0.18	0.21	0.53	0.41	0.03	0.00	0.00	0.04	2.70
1981	0.00	1.32	1.59	0.59	0.19	0.39	0.10	0.07	0.03	0.12	4.41
1982	0.00	0.05	0.40	0.91	0.43	0.16	0.03	0.06	0.00	0.00	2.05
1983	0.15	1.36	0.08	1.10	0.53	0.32	0.00	0.06	0.00	0.09	3.68
1984	0.00	0.02	0.55	0.06	0.31	0.11	0.00	0.00	0.05	0.00	1.10
1985	0.00	0.01	0.31	1.09	0.06	0.17	0.06	0.05	0.02	0.00	1.77
1986	0.00	0.05	0.00	0.14	0.39	0.00	0.04	0.07	0.02	0.00	0.71
1987	0.00	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.09
1988	0.00	0.04	0.00	0.00	0.01	0.12	0.01	0.00	0.00	0.00	0.19
1989	0.00	0.00	0.04	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.08
1990	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
1991	0.00	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.07
1992	0.00	0.08	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.19
1993	0.00	0.26	0.15	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.45
1994	0.00	0.08	0.20	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.40
1995	0.00	0.44	0.24	0.08	0.02	0.00	0.00	0.00	0.02	0.00	0.81
1996	0.00	0.00	0.04	0.15	0.12	0.00	0.00	0.00	0.00	0.00	0.31
1997	0.00	0.77	0.23	0.24	0.59	0.08	0.02	0.00	0.00	0.00	1.94
1998	0.00	0.08	0.05	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.20
1999	0.00	3.73	0.09	0.16	0.03	0.22	0.04	0.00	0.00	0.00	4.27
2000	0.00	1.04	1.19	0.97	0.14	0.08	0.05	0.14	0.00	0.00	3.61

Table D10. Stratified mean catch per tow (numbers) for haddock in NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine (Strata 01260-01280, 01360-01400), 1968-2000. Indices have been adjusted to account for changes in catchability due to changes in research vessels and doors (Forrester et al. 1997).

Year	0	1	2	3	4	5	6	7	8	9+	Total
1963	35.63	12.20	1.70	3.01	6.95	4.93	1.67	1.31	1.04	1.10	69.55
1964	0.03	4.46	2.79	0.72	1.22	2.41	1.43	0.48	0.33	0.31	14.18
1965	0.06	0.37	8.04	5.07	0.25	1.46	1.15	0.66	0.31	0.06	17.43
1966	0.01	0.04	0.55	7.25	2.39	0.27	0.61	0.43	0.06	0.03	11.65
1967	0.00	0.00	0.30	1.24	8.01	1.80	0.49	0.12	0.18	0.04	12.19
1968	0.00	0.00	0.00	0.08	0.17	5.49	1.26	0.23	0.29	0.12	7.65
1969	0.00	0.00	0.00	0.03	0.03	0.03	4.16	0.85	0.13	0.21	5.45
1970	0.00	0.04	0.00	0.00	0.00	0.04	0.09	2.09	0.61	0.04	2.92
1971	0.27	0.00	0.06	0.00	0.01	0.00	0.10	0.16	1.99	0.28	2.88
1972	0.00	1.18	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.77	1.98
1973	1.13	0.01	0.95	0.00	0.36	0.03	0.01	0.04	0.01	1.61	4.17
1974	0.01	1.69	0.19	0.43	0.00	0.00	0.00	0.00	0.01	0.34	2.69
1975	0.89	0.22	1.92	0.55	1.38	0.00	0.04	0.04	0.00	0.48	5.53
1976	1.64	1.76	0.07	1.28	0.16	0.78	0.00	0.15	0.00	0.18	6.04
1977	0.04	3.35	3.24	0.12	1.04	0.16	0.26	0.00	0.00	0.09	8.30
1978	0.16	0.01	1.89	4.33	0.44	1.08	0.88	0.14	0.00	0.24	9.16
1979	0.72	0.37	0.01	0.96	2.40	0.50	0.37	0.11	0.06	0.02	5.53
1980	3.97	0.50	0.32	0.00	0.29	1.07	0.67	0.13	0.10	0.10	7.15
1981	0.00	0.50	0.55	0.73	0.40	0.84	0.68	0.02	0.07	0.06	3.87
1982	0.40	0.05	0.58	0.82	0.35	0.05	0.03	0.18	0.03	0.14	2.63
1983	0.00	0.56	0.04	0.68	0.52	0.33	0.19	0.07	0.16	0.03	2.60
1984	0.00	0.21	0.55	0.00	0.26	0.00	0.41	0.00	0.03	0.23	1.70
1985	0.00	0.09	0.47	2.73	0.02	0.18	0.15	0.39	0.00	0.05	4.08
1986	0.00	0.01	0.00	0.07	0.30	0.14	0.02	0.03	0.06	0.00	0.62
1987	0.02	0.00	0.13	0.13	0.17	0.06	0.25	0.16	0.00	0.10	1.04
1988	0.00	0.00	0.00	0.04	0.02	0.08	0.00	0.04	0.15	0.00	0.34
1989	0.00	0.06	0.06	0.02	0.01	0.03	0.05	0.05	0.00	0.00	0.28
1990	0.01	0.03	0.00	0.08	0.00	0.00	0.00	0.02	0.02	0.00	0.15
1991	0.03	0.06	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.14
1992	0.04	0.14	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.21
1993	0.10	0.47	0.22	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.87
1994	0.21	0.03	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04	0.33
1995	0.00	0.09	0.60	0.18	0.04	0.04	0.00	0.00	0.00	0.02	0.98
1996	0.04	0.13	0.20	1.06	0.62	0.07	0.11	0.07	0.04	0.07	2.41
1997	0.21	1.33	0.02	0.38	0.58	0.08	0.07	0.00	0.00	0.00	2.69
1998	1.47	0.24	0.43	0.13	0.42	0.30	0.07	0.05	0.02	0.00	3.13
1999	0.54	3.23	0.62	0.82	0.28	0.48	0.52	0.13	0.05	0.06	6.73

Table D11. Maturity ogives for female haddock sampled during Spring NEFSC research vessel surveys in Gulf of Maine strata from 1982 to 2000.

										Sample Size	
Years	Alpha	Beta	1	2	3	4	5	6	7+	Ages 1-3	Total
1982-1985	-4.2022	2.0412	0.103	0.470	0.872	0.981	0.998	1.000	1.000	83	132
1986-1990	-22.5367	14.7676	0.000	0.999	1.000	1.000	1.000	1.000	1.000	12	33
1991-1995	-17.1760	8.4442	0.000	0.429	1.000	1.000	1.000	1.000	1.000	37	43
1996-2000	-6.0570	3.1757	0.053	0.573	0.970	0.999	1.000	1.000	1.000	79	117
1982-2000	-5.19178	2.54986	0.066	0.477	0.921	0.993	0.999	1.000	1.000	211	325

Table D12. Estimates of instantaneous total mortality (Z) for the Gulf of Maine haddock stock. Annual estimates were derived from NEFSC spring (top panel) and autumn research vessel data (bottom panel). Spring estimates were derived as ln (∑ age 4+ for year i / ∑ age 5+ for year i+1. Autumn estimates were derived as ln (∑ age 3+ for year i-1 / age 4+ for year i. Solid lines represent 3-year moving average. The severe truncation of the age structure of the stock during the late 1980s and early 1990s did not allow for mortality estimates for 6 years in the spring survey (1986, 1989, 1990, 1991, 1993, and 1994) and 1 year in the autumn survey (1992).

	NEFSC Spring Survey			NEFSC Autumn Survey		
Year	Age 4+	Age 5+	Z	Age 3+	Age 4+	Z
1963				20.02	17.01	
1964				6.90	6.19	1.17
1965				8.96	3.89	0.57
1966				11.04	3.79	0.86
1967				11.89	10.65	0.04
1968	6.008	5.673	0.49	7.65	7.57	0.45
1969	3.704	3.686	1.41	5.45	5.42	0.34
1970	0.906	0.906	0.03	2.87	2.87	0.64
1971	0.878	0.878	1.16	2.55	2.55	0.12
1972	0.275	0.275	-0.12	0.80	0.77	1.20
1973	0.365	0.311	1.01	2.07	2.07	-0.95
1974	0.133	0.133	-0.70	0.79	0.36	1.75
1975	0.640	0.268	-0.52	2.50	1.95	-0.90
1976	1.251	1.072	0.24	2.55	1.27	0.68
1977	2.326	0.984	2.49	1.66	1.54	0.50
1978	0.253	0.194	-0.12	7.10	2.77	-0.51
1979	1.429	0.286	1.07	4.43	3.47	0.72
1980	1.022	0.489	0.36	2.37	2.37	0.63
1981	0.905	0.712	1.25	2.82	2.09	0.13
1982	0.689	0.259	0.39	1.60	0.78	1.29
1983	0.995	0.467	1.85	1.99	1.31	0.21
1984	0.469	0.156	0.45	0.93	0.93	0.76
1985	0.361	0.301	1.02	3.52	0.79	0.17
1986	0.518	0.129	Undef	0.61	0.54	1.87
1987	0.009	0.000	-2.69	0.88	0.75	-0.20
1988	0.145	0.135	1.54	0.34	0.29	1.10
1989	0.031	0.031	Undef	0.16	0.15	0.83
1990	0.000	0.000	Undef	0.11	0.03	1.56
1991	0.000	0.000	Undef	0.05	0.04	1.01
1992	0.112	0.000	0.95	0.02	0.00	Undef
1993	0.043	0.043	Undef	0.08	0.04	-0.66
1994	0.032	0.000	0.34	0.08	0.08	0.01
1995	0.046	0.023	Undef	0.28	0.09	-0.16
1996	0.122	0.000	0.22	2.04	0.98	-1.26
1997	0.690	0.098	4.34	1.12	0.74	1.01
1998	0.071	0.009	-1.31	0.99	0.86	0.26
1999	0.290	0.261	0.06	2.34	1.52	-0.43
2000	0.417	0.272				

Table D13. Stratified and standardized mean number and mean weight (kg) per tow of Haddock caught in the U.S. spring and autumn bottom trawl surveys from 1963-1999. An exploitation index has been calculated based on a 3 year moving average of landings (000s mt) / autumn survey biomass index (kg/tow).

		Autumn Survey	Exploitation Index (catch/Autumn survey biomass)	
Year	Landings (000's mt)	Weight (kg)/tow	Annual Estimates	3-Year Moving Average
1963	4.789	50.697	0.094	
1964	5.453	18.829	0.290	0.210
1965	4.363	17.644	0.247	0.316
1966	5.704	13.859	0.412	0.328
1967	5.496	16.853	0.326	0.322
1968	3.557	15.484	0.230	0.256
1969	2.713	12.854	0.211	0.218
1970	1.562	7.354	0.212	0.195
1971	1.306	8.137	0.161	0.227
1972	0.936	3.036	0.308	0.178
1973	0.558	8.583	0.065	0.207
1974	0.829	3.347	0.248	0.153
1975	1.263	8.616	0.147	0.213
1976	1.956	8.040	0.243	0.256
1977	3.322	8.752	0.380	0.290
1978	5.179	20.932	0.247	0.328
1979	4.879	13.723	0.356	0.454
1980	7.473	9.835	0.760	0.594
1981	6.239	9.344	0.668	1.030
1982	6.923	4.164	1.663	1.262
1983	7.597	5.219	1.456	1.385
1984	4.038	3.893	1.037	0.995
1985	3.025	6.149	0.492	0.909
1986	1.668	1.392	1.198	0.668
1987	0.829	2.645	0.313	0.602
1988	0.436	1.476	0.295	0.342
1989	0.264	0.631	0.418	0.572
1990	0.433	0.432	1.002	1.671
1991	0.431	0.120	3.592	2.674
1992	0.312	0.091	3.429	2.476
1993	0.193	0.472	0.409	1.451
1994	0112	0.217	0.516	0.367
1995	0.192	1.099	0.175	0.254
1996	-0.257	3.543	0.073	0.167
1997	0.616	2.424	0.254	0.225
1998	1.018	2.917	0.349	0.246
1999	0.668	4.910	0.136	

Table D14. Parameter estimates and variability from ASPIC surplus production modeling conducted by the Overfishing Definition Review Panel (1998) and used as the basis for the current harvest control rule.

	Overfishing Definition Review Panel (1998)			
Parameter	**Estimate**	**Bias-Corrected Estimate**	**Confidence Interval**	**Relative Interquartile Range**
MSY	2,244 mt	2,372 mt	1,550 - 3,053	0.329
Bmsy	22,740 mt	22,730 mt	1,732 - 2,846	0.241
Fmsy	0.104	0.101	0.059 - 0.168	0.500
K	45,480 mt	45,460 mt	34,630 - 56,930	0.241
r	0.209	0.202	0.119 - 0.337	0.500
q(Autumn)	0.362	0.350	0.254 - 0.498	0.318
q(Spring)	0.107	0.957	0.074 - 0.140	0.360

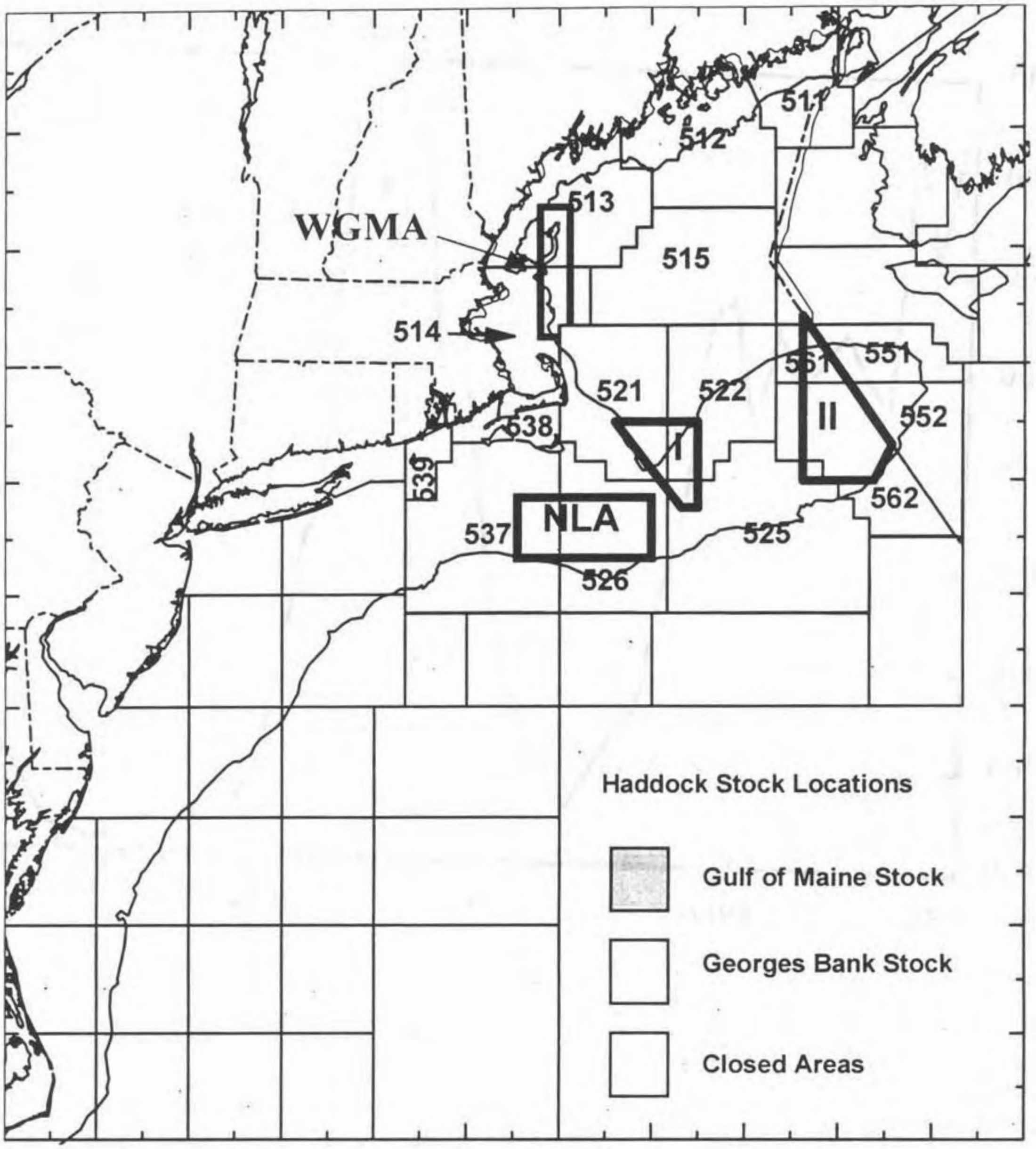
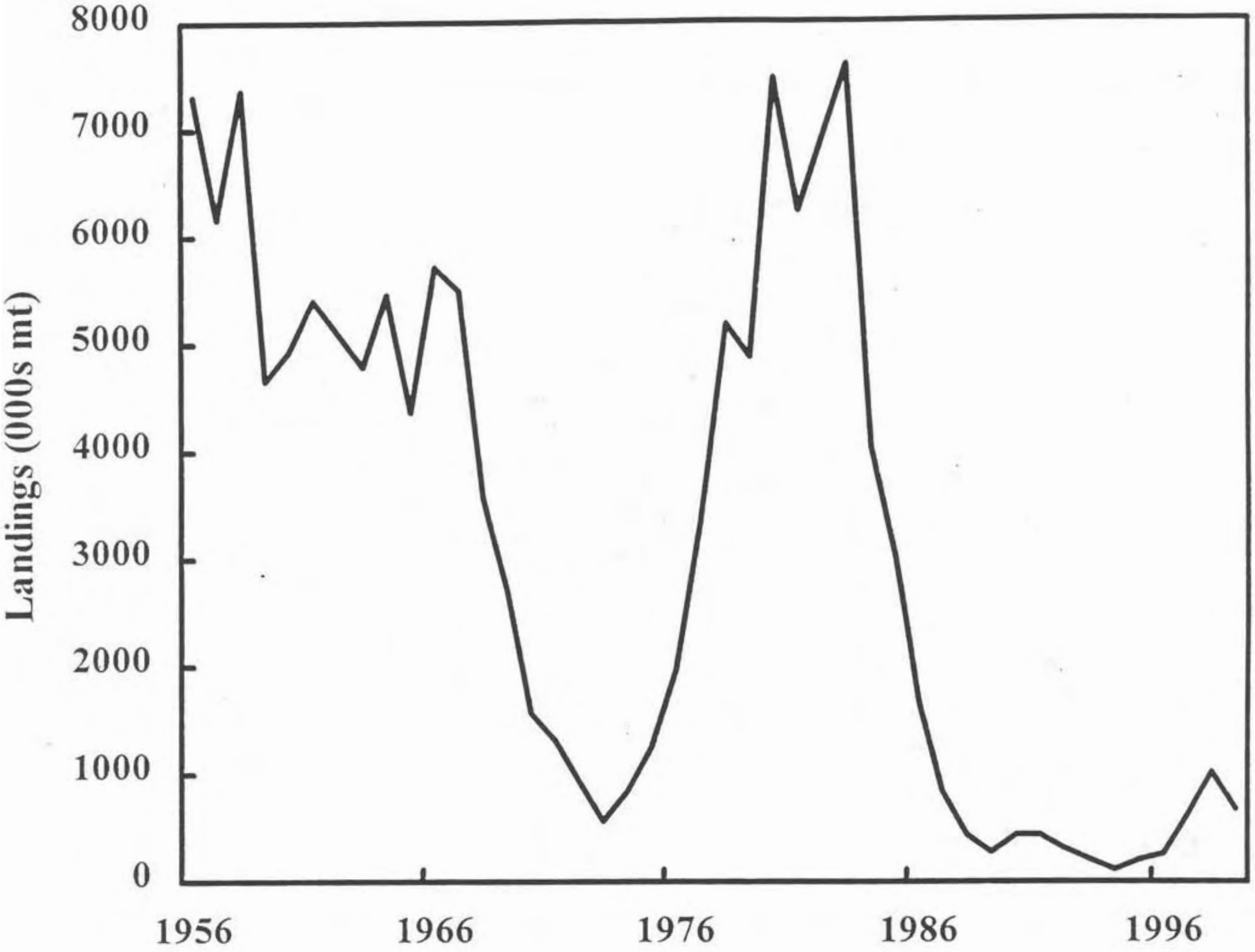


Figure D1. Stock area definitions for U.S. haddock assessments.



gure D2. Total commercial landings (000s mt) of haddock from Gulf of Maine from 1956-1999.

trawl, gillnet and hook (long and hand line) trips. Trips were filtered to include only those trips that reported discards for some species (haddock or any other species.

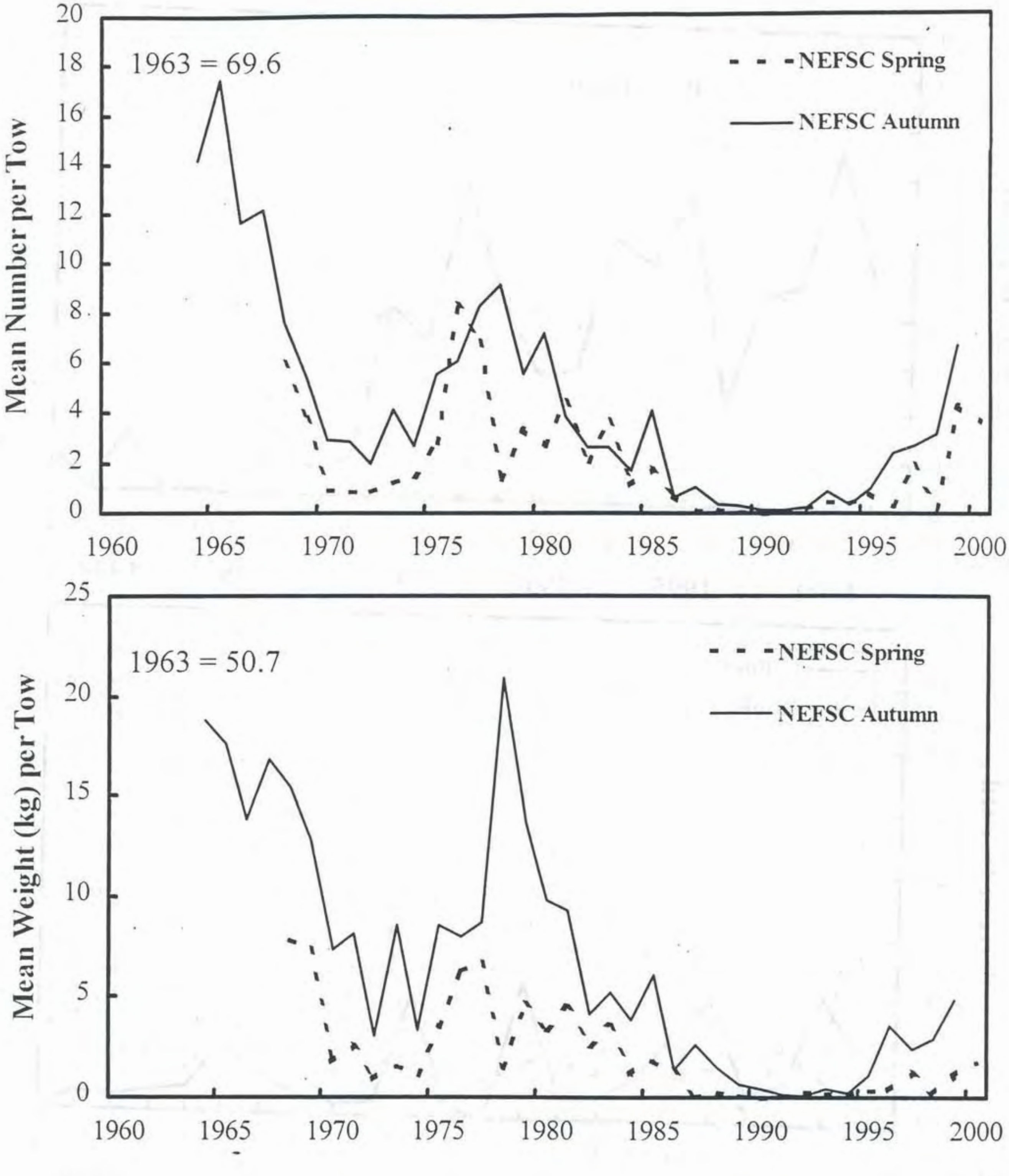
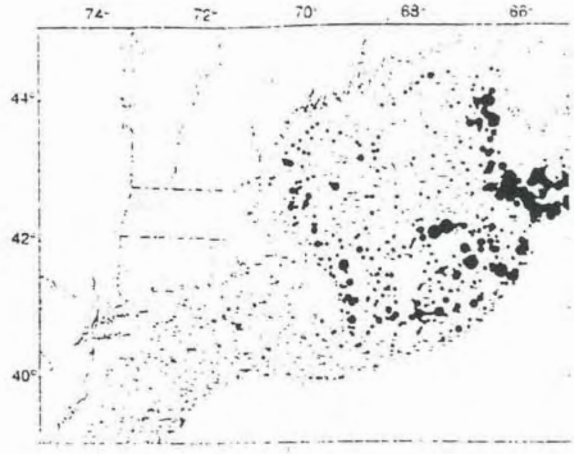
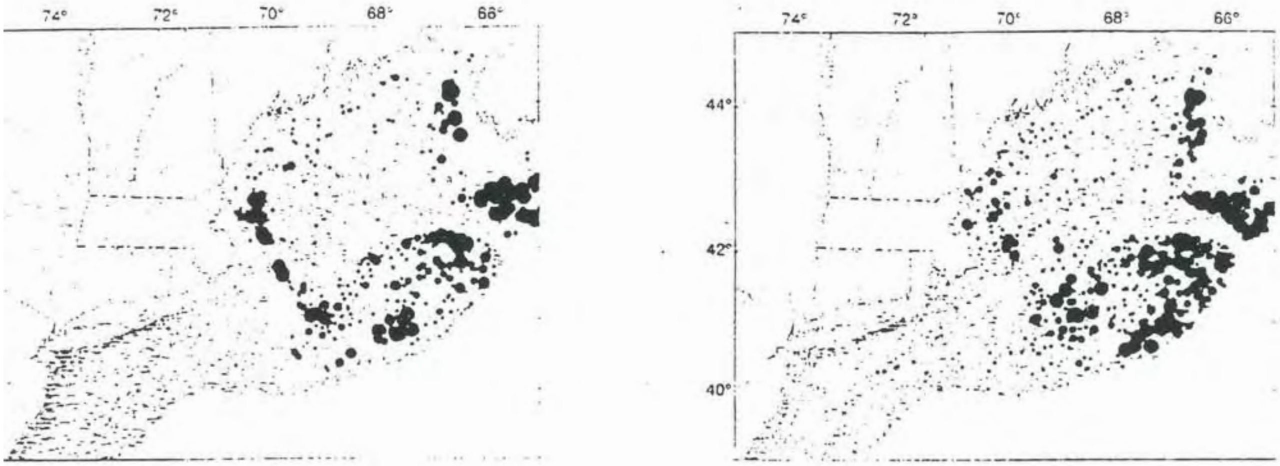


Figure D4. U.S. research vessel survey abundance (stratified mean number per tow (top panel) and biomass (kg per tow, lower panel) indices for the Gulf of Maine from 1963-2000. U.S. survey includes strata 01260-01280 and 01360-01400 .

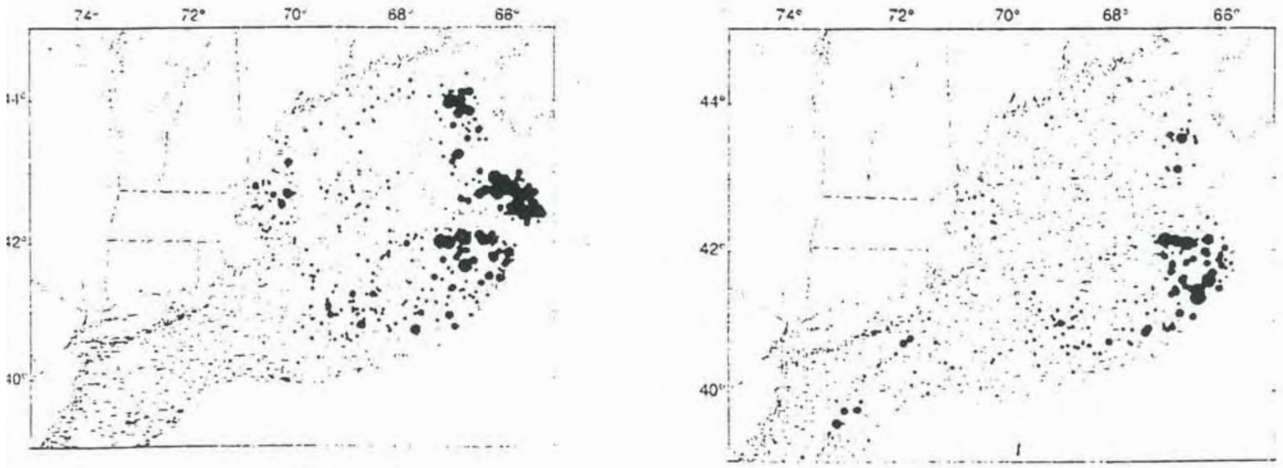


Spring 1968-1972



Spring 1973-1977

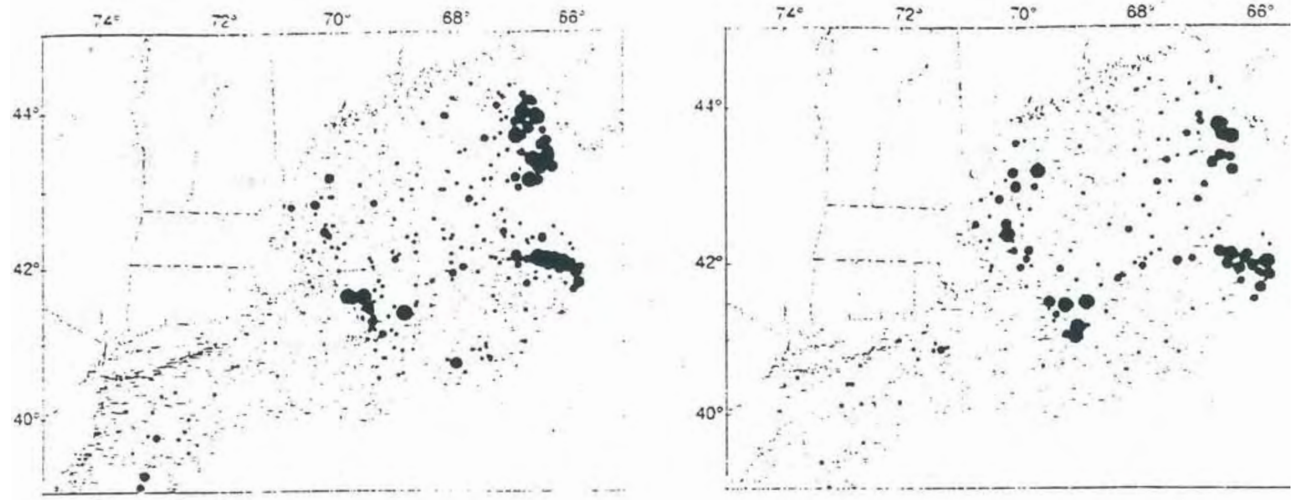
Spring 1978-1982



Spring 1983-1987

Spring 1988-1992

igure D5. Spatial distribution patterns of haddock sampled on NEFSC Spring research vessel surveys from 1968 to 2000. Circles indicate the size of haddock catches, + indicates a tow where no haddock were sampled.



Autumn 1993-1997

Autumn 1998-2000

Figure D6. Spatial distribution patterns of haddock sampled on NEFSC Autumn research vessel surveys from 1963 to 1999. Circles indicate the size of haddock catches, + indicates a tow where no haddock were sampled.

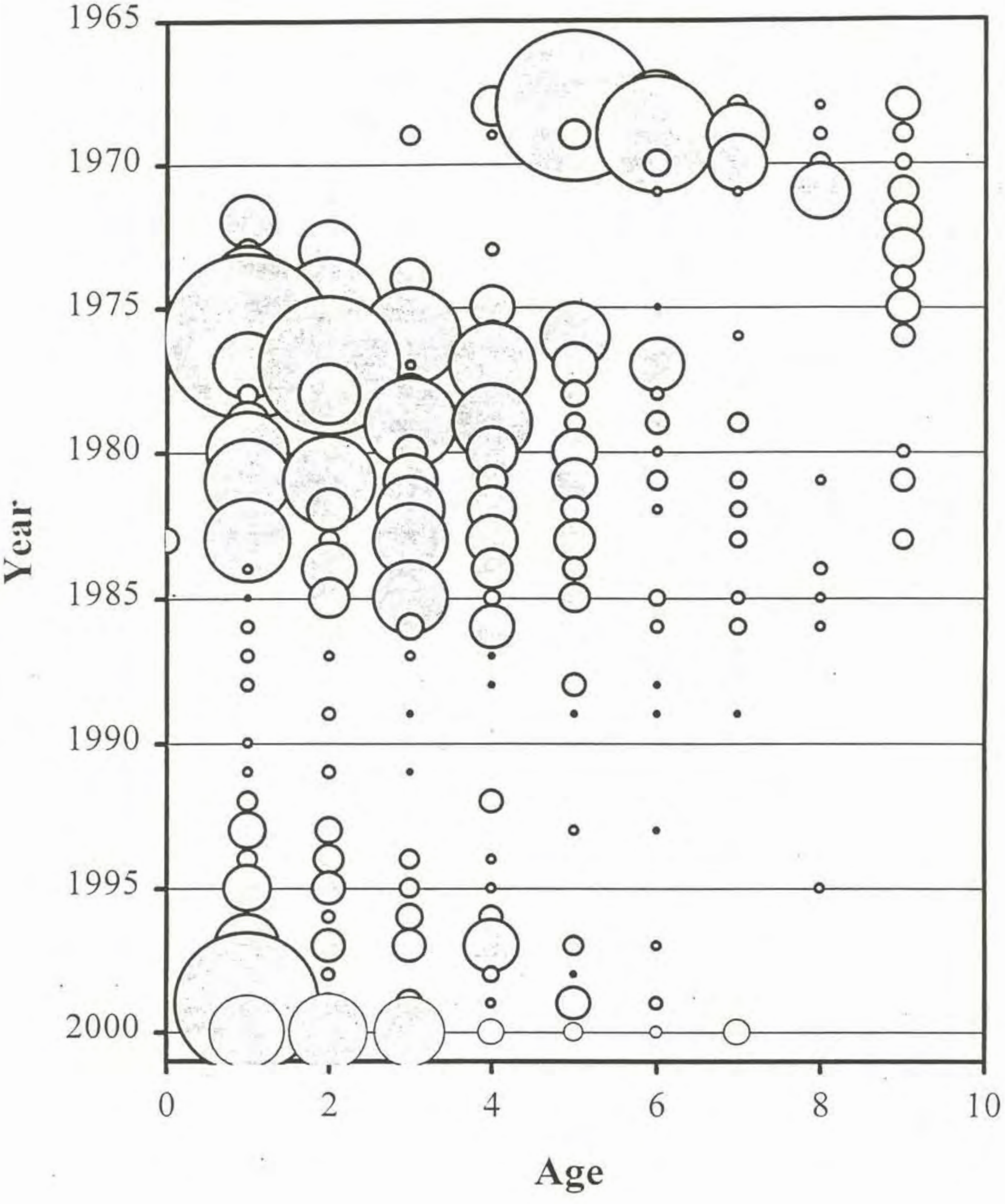


Figure D7. U.S. Spring research vessel survey abundance (stratified mean number at age per tow) for the Gulf of Maine haddock stock from 1968-2000. U.S. survey includes strata 01260-01280 and 01360-01400.

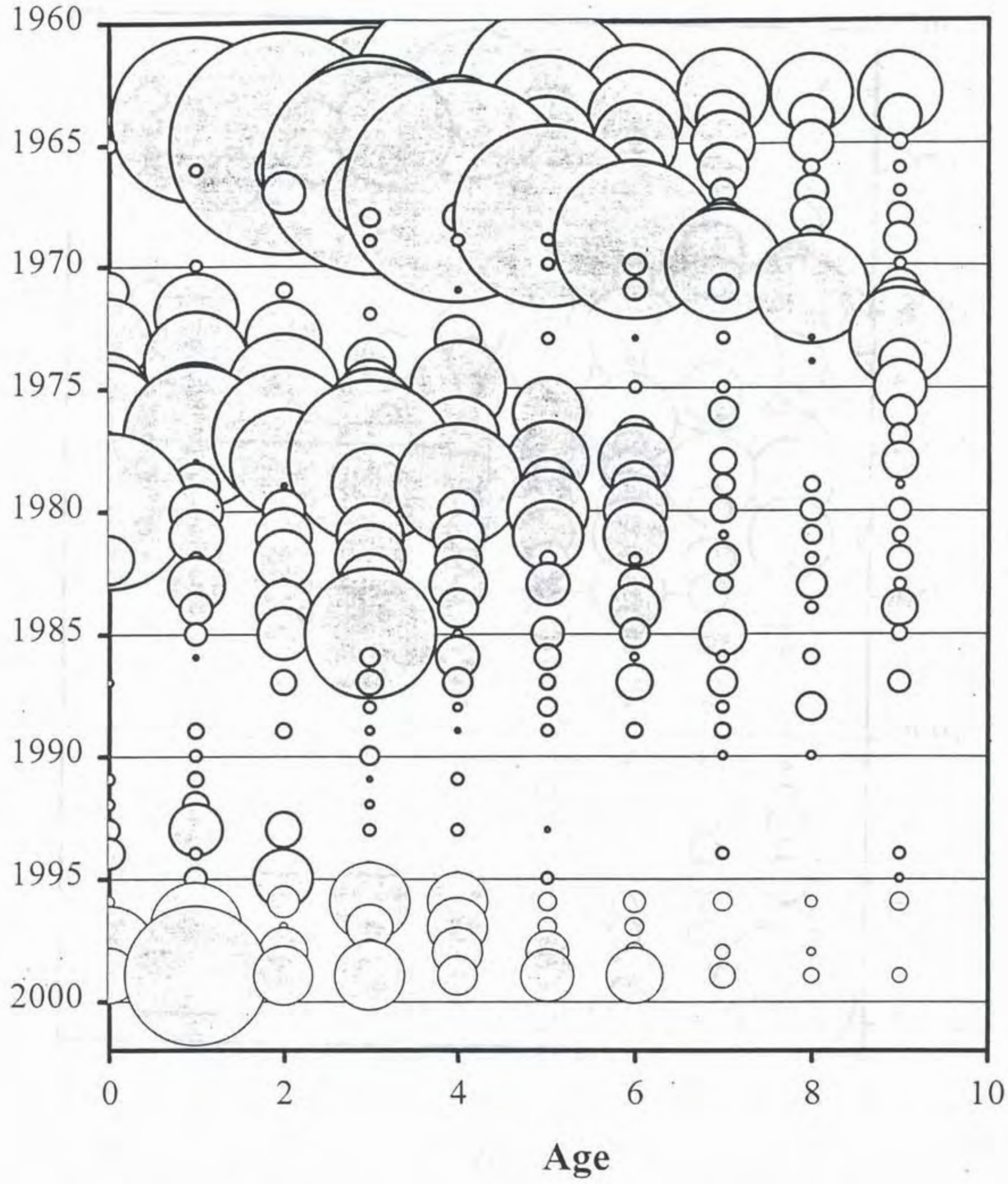


Figure D8. U.S. Autumn research vessel survey abundance (stratified mean number at age per tow) for the Gulf of Maine haddock stock from 1963-1999. U.S. survey includes strata 01260-01280 and 01360-01400. Large age 0 and 1 indices in 1963 corresponding to the1962 and 1963 cohorts were omitted to improve scaling of the figure.

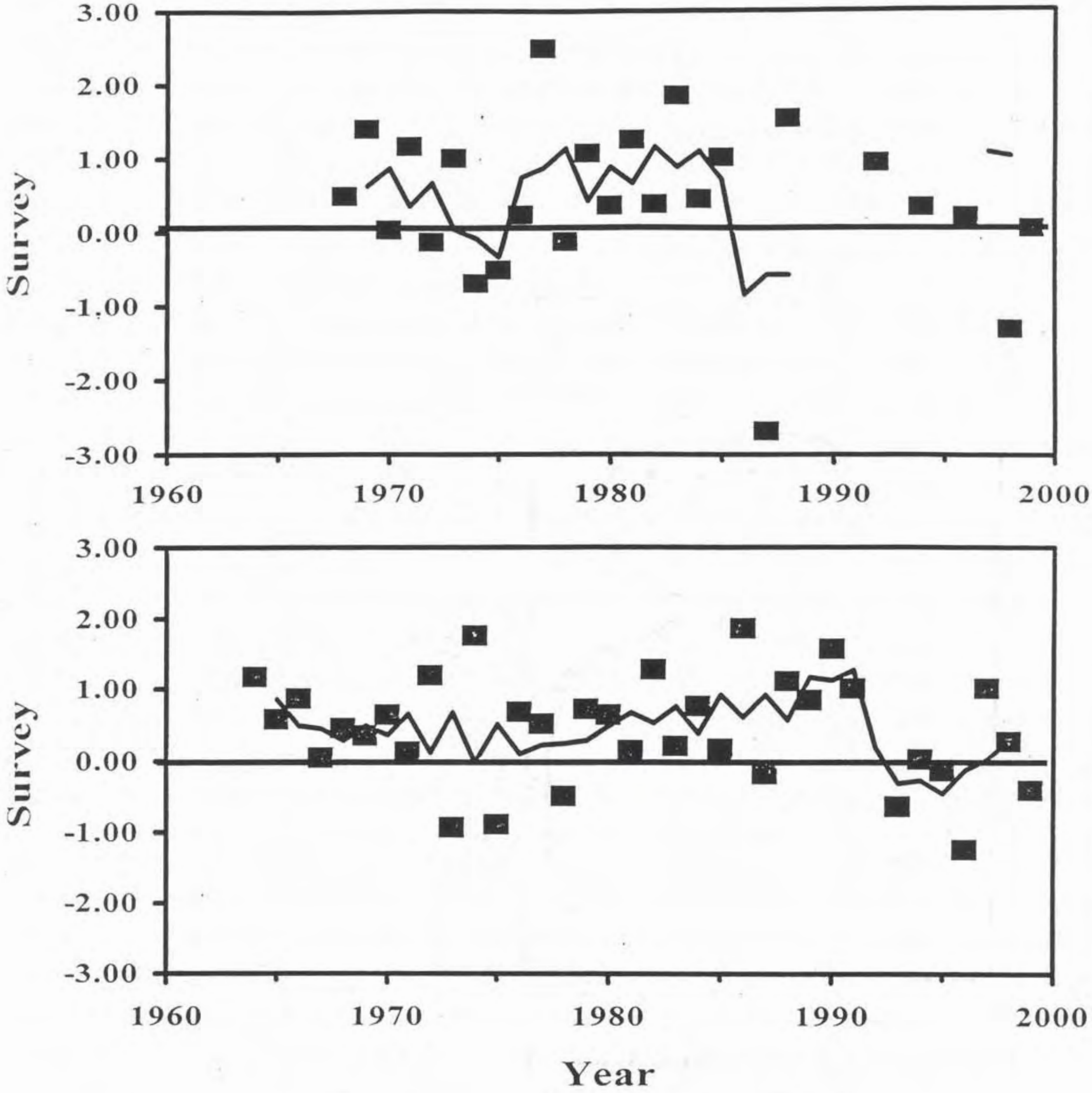


Figure D9. Estimates of instantaneous total mortality (Z) for the Gulf of Maine haddock stock. Annual estimates were derived from NEFSC spring (top panel) and autumn research vessel data (bottom panel). Spring estimates were derived as ln (∑ age 4+ for year i / ∑ age 5+ for year i+1. Autumn estimates were derived as ln (∑ age 3+ for year i-1 / ∑age 4+ for year i. Solid lines represent 3-year moving average. The severe truncation of the age structure of the stock during the late 1980s and early 1990s did not allow for mortality estimates for 6 years in the spring survey (1986, 1989, 1990, 1991, 1993, and 1994) and 1 year in the autumn survey (1992).

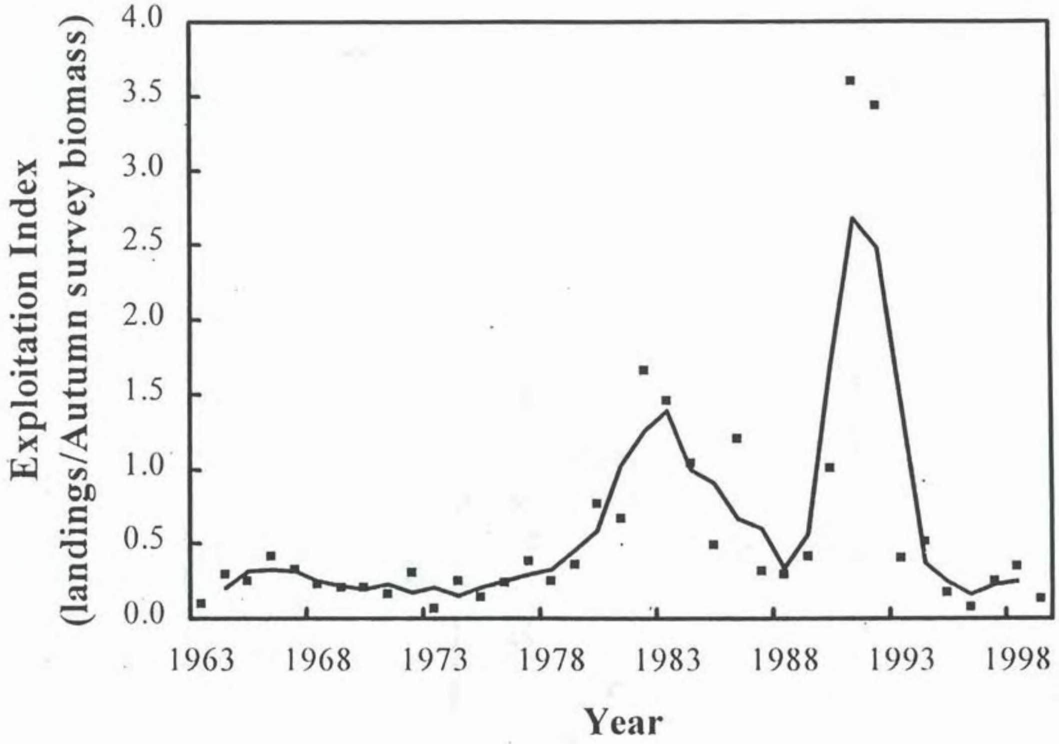


Figure D10. Exploitation index (landings [000s mt] / autumn survey biomass index [kg/tow]) for Gulf of Maine haddock. Because of variability in the autumn survey indices, a three year unweighted moving (line) average approach was used to estimate exploitation indices.

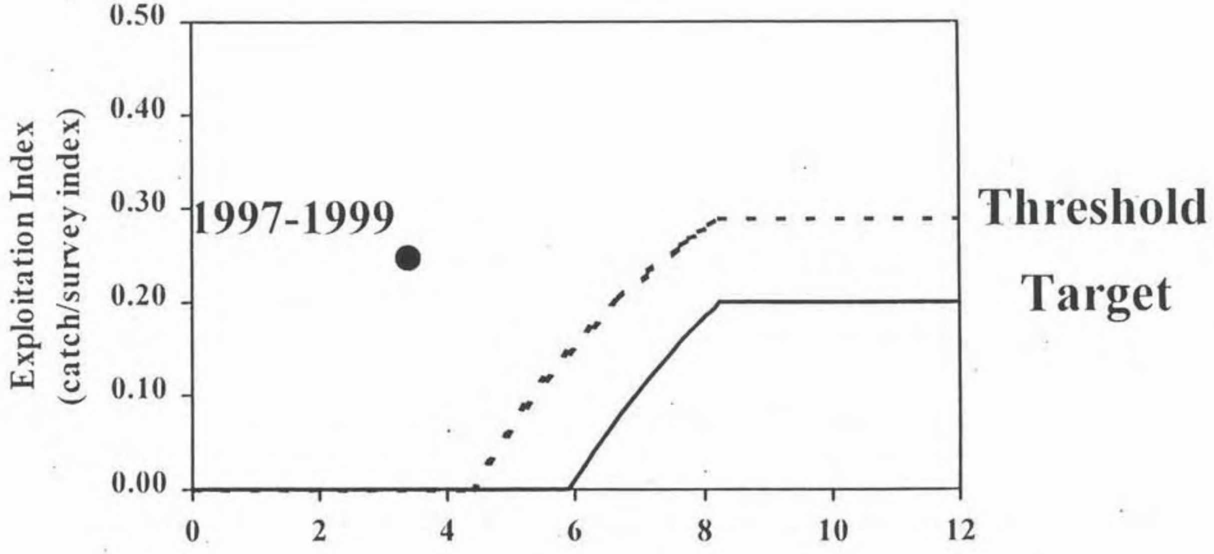


Figure D11. Harvest control rules for Gulf of Maine haddock based on proxies of MSY-based reference points and minimum biomass thresholds.