Northeast Fisheries Science Center Reference Document 99-14

*A Report of the 29th Northeast Regional Stock Assessment Workshop*

# 29th Northeast Regional Stock Assessment Workshop (29th 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

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## MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) meeting of the 29th Northeast Regional Stock Assessment Workshop (29th SAW) was held in the Aquarium Conference Room of the Northeast Fisheries Science Center's Woods Hole Laboratory, Woods Hole, MA during 21-25 June, 1999. The SARC Chairman was Dr. Victor Restrepo, University of Miami (FL). 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 States of Rhode Island and Massachusetts, DFO - Canada, and CEFAS, Lowestoft (UK) (Table 1). In addition, 35 other persons including three Industry Observers, attended some or all of the meeting (Table 2). The meeting agenda is presented in Table 3.

**Table 1.** SAW-28 SARC Composition.

Chairman:
**Victor Restrepo, University of Miami**

Four *ad hoc* experts chosen by the Chair:
**Jon Brodziak, NMFS/NEFSC**
**Loretta O'Brien, NMFS/NEFSC**
**William Overholtz, NMFS/NEFSC**
**Tim Smith**, NMFS/NEFSC

One person from the NMFS Northeast Regional Office:
**John Witzig, NMFS/NERO**

One person from each regional Fishery Management Council:
**Andrew Applegate, NEFMC**
**Richard Seagraves, MAFMC**

Atlantic States Marine Fisheries Commission/State personnel:
**Michael Armstrong, ASMFC**
**Jeffrey Brust, ASMFC**

One or more scientists from:
Academia - **William Macy, University of Rhode Island**
NMFS Pilot Project - **Mark Bravington, CEFAS (UK)**
DFO, Canada - **Samuel Naidu, DFO, St. Johns**

### Opening

Dr. Terrence Smith, Stock Assessment Workshop Chairman, welcomed the meeting participants. In his introductory remarks, he thanked the Working Group members who, he indicated, "worked in the trenches for several weeks" to prepare the documentation for SARC review.

**Table 2.** List of Participants.

**National Marine Fisheries Service**
Northeast Fisheries Science Center

| | |
|---|---|
| Frank Almeida | Ralph Mayo |
| John Boreman | Bill Michaels |
| Steve Cadrin | Steve Murawski |
| Steve Clark | Paul Nitschke |
| Emma Hatfield | Loretta O'Brien |
| Deborah Hart | Paul Rago |
| Lisa Hendrickson | Fred Serchuk |
| Elizabeth Holmes | Gary Shepherd |
| Joe Idoine | Pie Smith |
| Larry Jacobson | Terry Smith |
| Han-Lin Lai | Katherine Sosebee |
| Jason Link | Mark Terceiro |
| | Susan Wigley |

**Massachusetts Division of Marine Fisheries**
Steven Correia

**Mid-Atlantic Fishery Management Council**
Alan Weiss

**National Research Council Postdoctoral Program**
Stuart Whipple

**Rutgers University**
Eric Powell

**Conservation Law Foundation**
Anthony Chatwin

**Industry Observers**
Hugh Hogan
Ray Starvish
James Fletcher

**CMAST**
Kevin Stokesbury
Deqin Cai

**Table 3.** Agenda of the 29th Northeast regional Stock Assessment Workshop (SAW-29) Stock Assessment Review Committee (SARC) meeting.

Aquarium Conference Room
NEFSC Woods Hole Laboratory
Woods Hole, Massachusetts
21 June (1:00 PM) - 25 June (6:00 PM) 1999

**AGENDA**

| TOPIC | WORKING GROUP & PRESENTER(S) | SARC LEADER | RAPPORTEUR(S) |
|---|---|---|---|
| **MONDAY, 21 June** (1:00 PM - 6:00 PM)... | | | |
| Opening | | | |
| Welcome | **Terry Smith, SAW Chairman** | | |
| Introduction | **Victor Restrepo, SARC Chairman** | | **P. Smith** |
| Agenda | | | |
| Conduct of meeting | | | |
| Witch Flounder (A) | Northern Demersal W.G.<br>**S. Wigley** | **L. O'Brien** | **R. Mayo** |
| SOCIAL at the Sissenwines' (7:00 PM) | | | |
| **TUESDAY, 22 June** (8:30 AM - 6:00 PM)... | | | |
| Scallops (B) | Invertebrate W.G.<br>**H. Lai** | **M. Bravington** | **R. Mayo** |
| **WEDNESDAY, 23 June** (8:30 AM - 5:00 PM)... | | | |
| Loligo Squid (C) | Invertebrate W.G.<br>**S. Cadrin/E. Hatfield** | **W. Macy** | **G. Shepherd** |
| Illex Squid (D) | Invertebrate W.G.<br>**L. Hendrickson/P. Rago** | **J. Brodziak** | **E. Holmes** |
| **THURSDAY, 24 June** (8:30 AM - 6:00 PM)... | | | |
| Review Advisory Reports and Sections for the SARC Report | | | |
| **FRIDAY, 25 June** (8:30 AM - 6:00 PM)... | | | |
| SARC comments, research recommendations, and 2nd drafts of Advisory Reports | | | |
| Other business | | | **P. Smith** |

Dr. Smith briefly reviewed the responsibilities of SARC members, the SARC leaders, rapporteurs, and presenters and Dr. Restrepo invited the meeting participants to introduce themselves.

## The Process

The SAW Steering Committee, which guides the SAW process, is composed of the executives of the five partner organizations responsible for fisheries management in the Northeast Region (NMFS/Northeast Fisheries Science Center, New England Fishery Management Council, Mid-Atlantic Fishery Management Council, and the Atlantic States Marine Fisheries Commission). Working groups assemble the data for assessments, decide on methodology, and prepare documents for SARC review. The SARC members have a dual role; panelists are both reviewers of assessments and drafters of management advice. More specifically, although the SARC's primary role is peer review of the assessments tabled at the meeting, the Committee also prepares a report with advice for fishery managers contained in the *29th SAW Public Review Workshop Report, NEFSC Ref. Doc. 99-13.*

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

**Table 4.** SAW-29 Working Group meetings and participants.

| Working Group and Participants | Meeting Date | Stock/Species |
|---|---|---|
| <u>Northern Demersal Working Group</u> | 26-28 May, 1999 | Witch Flounder |
| J. Brodziak, NEFSC | | |
| R. Brown, NEFSC | | |
| S. Cadrin, NEFSC | | |
| S. Correia,, MA DMF | | |
| R. Mayo, NEFSC (Chair) | | |
| L. O'Brien, NEFSC | | |
| P. Rago, NEFSC | | |
| K. Sosebee, NEFSC | | |
| S. Wigley, NEFSC | | |
| <u>Invertebrate Working Group</u> | 19 February, 1999 | Inshore Longfin Squid (*Loligo pealeii*) |
| L. Axelson, MAFMC | 31 March, 1999 | |
| G. Begg, NEFSC | 6 May, 1999 | |
| J. Brodziak, NEFSC | 17-19 May, 1999 | |
| S. Cadrin, NEFSC | | |
| G. Goodwin, Sea Freeze Ltd. | 29 October, 1998 | Northern Shortfin Squid (*Illex illecebrosus*) |
| E. Hatfield, NEFSC | 14 December, 1998 | |
| D. Hart, NEFSC | 17-21 May, 1999 | |
| L. Hendrickson, NEFSC | | |
| L. Jacobson, NEFSC (Chair) | 19-21 May, 1999 | Sea Scallop |
| J. Link, NEFSC | | |
| M. Maxwell, MBL | | |
| S. Murawski, NEFSC | | |
| W. Overholtz, NEFSC | | |
| E. Powell, Rutgers Unv. | | |
| P. Rago, NEFSC | | |
| J. Rule, MAFMC | | |
| R. Seagraves, MAFMC | | |
| L. Shulman, NEFSC | | |
| M. Terceiro, NEFSC | | |
| J. Weinberg, NEFSC | | |
| W. Macy, URI | | |
| R. Mayo, NEFSC | | |

## Agenda and Reports

The SAW-29 SARC agenda (Table 3) included presentations on assessments for witch flounder, sea scallops, loligo Squid, and illex Squid.

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 two sessions of the SAW-29 Public Review Workshop that were held during regularly scheduled NEFMC and MAFMC meetings (10 August, 1999). The documents will be published in the NEFSC Reference Document series as the *29th SARC Consensus Summary of Assessments* and the 29th *SAW Public Review Workshop* Report (the latter document includes the Advisory Report), after the Public Review Workshop sessions.

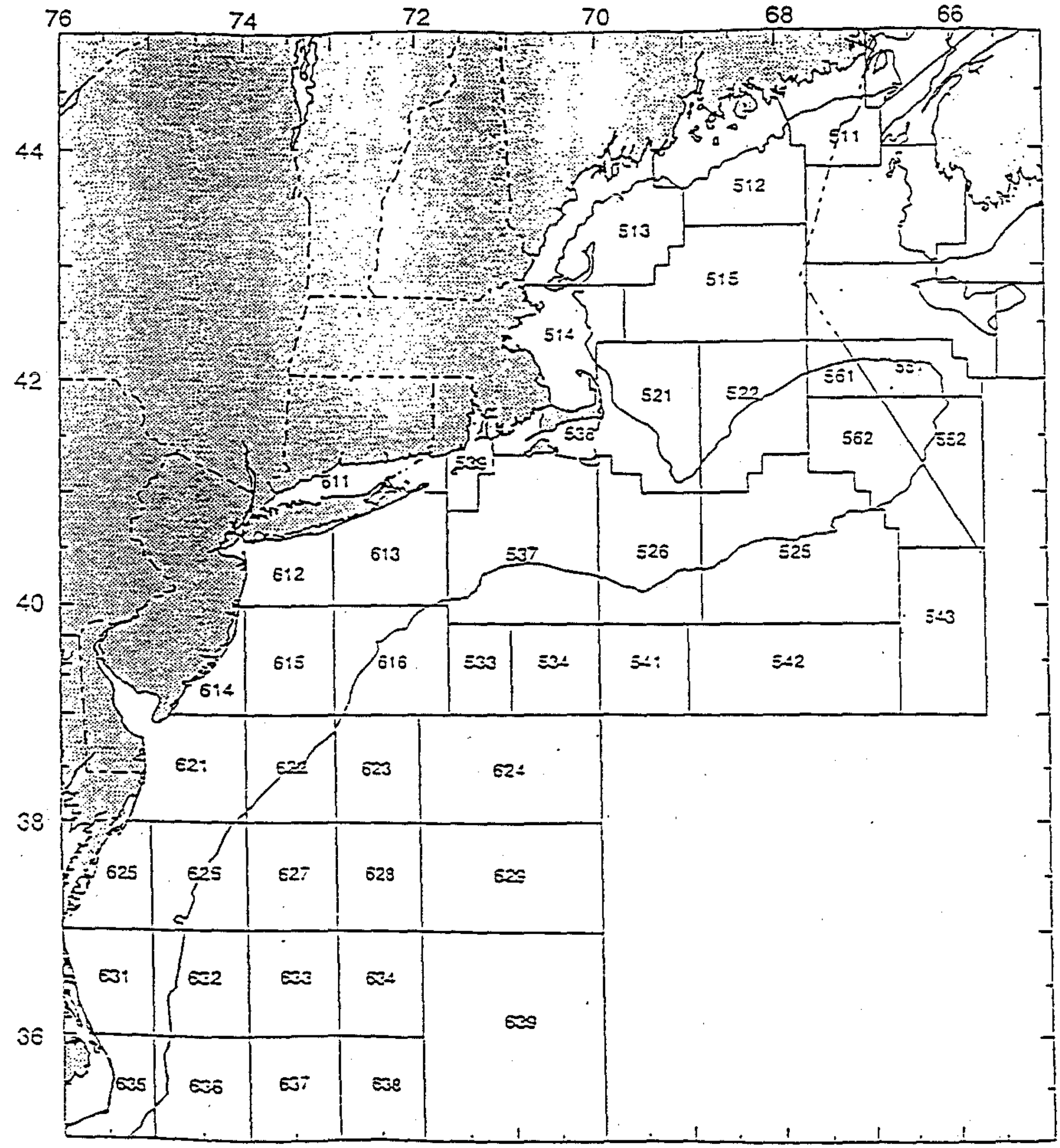


**Figure 1.** Statistical areas used for catch monitoring in offshore fisheries in the Northeast United States.

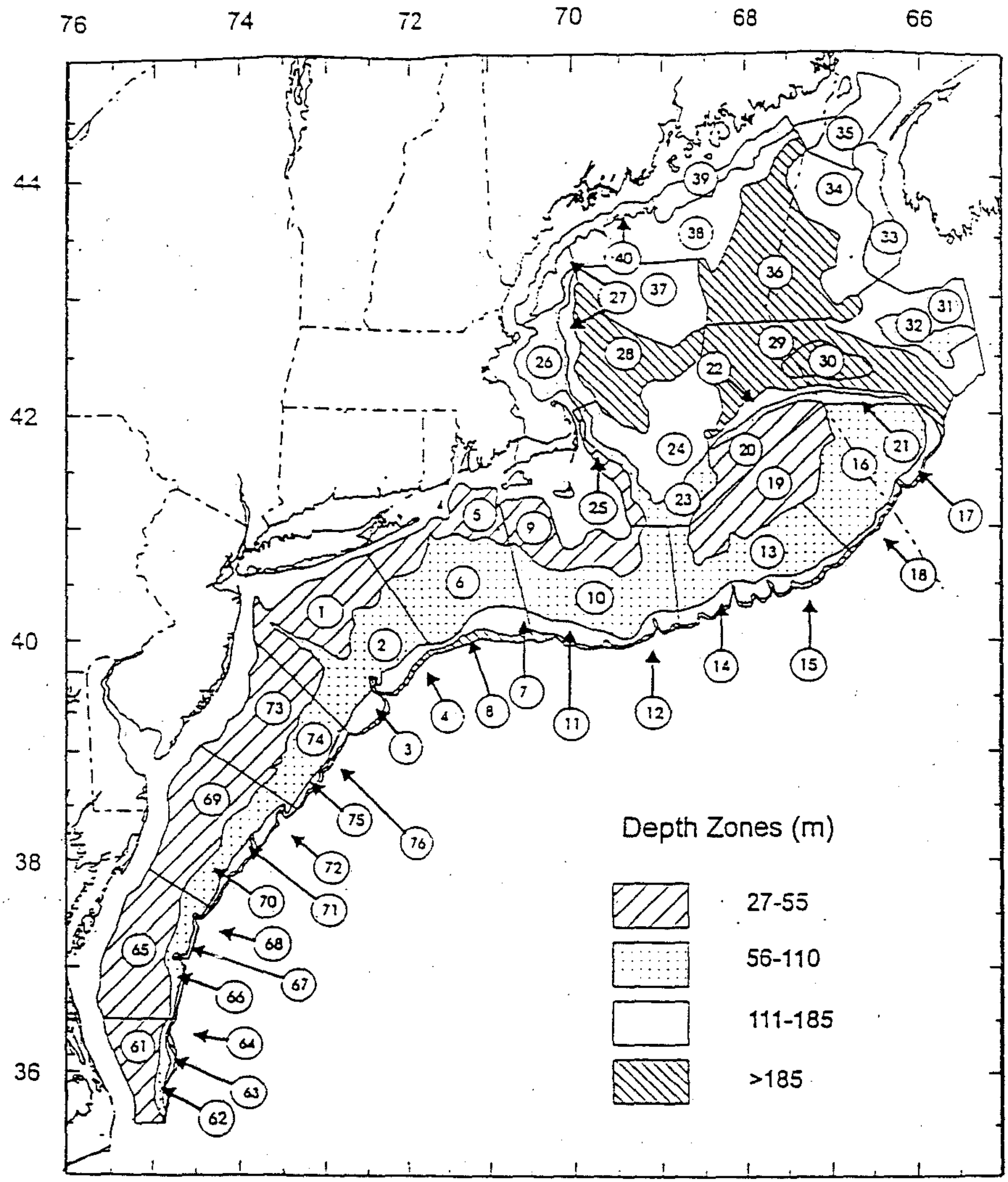


**Figure 2.** Offshore sampling strata used in NEFSC bottom trawl surveys.

## A. WITCH FLOUNDER (*Glyptocephalus cynoglosus, L.*)

### TERMS OF REFERENCE

a. Update the status of the Gulf of Maine - Georges Bank witch flounder stock through 1998 and characterize the variability of estimates of stock size and fishing mortality rates.

b. Provide projected estimates of catch for 1999 and spawning stock biomass for 2000-2001 at various levels of F.

c. Comment on and revise, if necessary, the overfishing definition reference points for witch flounder recommended by the Overfishing Definition Review Panel.

### INTRODUCTION

The witch flounder (*Glyptocephalus cynoglossus, L.*) or grey sole is a deep water boreal flatfish occurring on both sides of the North Atlantic. In the Northwest Atlantic, witch flounder are distributed from Labrador to Georges Bank and in continental slope waters southward to Cape Hatteras, North Carolina. In U.S. waters, the species is commercially abundant in the Gulf of Maine-Georges Bank region [defined as Northeast Fisheries Science Center (NEFSC) Statistical Reporting Areas (SA) 511-515, 521-522, 525-526, and 561-562; Figure 1], and, in the absence of any stock structure information, is assumed to comprise a single stock unit. Prized as a table fish, witch flounder receives a high ex-vessel price relative to other flounders and represents an important by-catch component in the New England mixed species groundfish fishery.

Annual landings during the period 1910-82 averaged 3,000 metric tons (mt), and ranging from 1,000 to 6,000 mt (Lange and Lux, 1978; Burnett and Clark 1983). More recently, landings declined from a peak of 6,660 mt in 1984 to a low of 1,490 mt in 1990. Landings for 1998 were 1.849 mt (Figure A1).

Previous witch flounder stock assessments were conducted by Burnett and Clark (1983) and Wigley and Mayo (1994). This report provides an update on the status of witch flounder in Subareas 5 and 6, presents an analytical assessment for the stock for the 1982-1998 period, and provides estimates of discards from the shrimp fishery and large-mesh otter trawl fishery based upon analyses of sea sampling, commercial and research vessel survey data through 1998.

Witch flounder is managed under the Multispecies Fisheries Management plan since 1987. Significant changes in these regulations include: 1) increases in minimum size in 1983 and 1987; 2) increases in mesh size in 1982, 1983, 1994; and 3) effort reductions in 1996. Management regulations for the northern shrimp fishery also impact witch flounder; significant changes in the shrimp fishery include a monthly 10% by-catch limit which restricted the possession of groundfish to 10% by weight of shrimp in the mid-1980's to early 1990s; and the implementation of the Nordmore grate to exclude groundfish in 1992. In 1998 the Sustainable Fisheries Act revised the overfishing definition for witch flounder. The Amendment 9 control rule was developed to define overfishing thresholds and targets (Applegate et al. 1998) for witch flounder.

## THE FISHERY

Recreational Catches

There is no recreational fishery for witch flounder.

Commercial Landings

USA commercial landings in 1998 totaled 1,849 mt, a 4% increase over 1997 (Table A1); and 24% higher than in 1990, the lowest value since 1964 (Figure A1). Canadian landings from the stock have been negligible (<10 mt in 1997; Table A1). Landings from the Grand Banks (NAFO Divisions 3LNO) during 1985 to 1990 are not included in this assessment. Canadian landings from the western Scotian Shelf (NAFO Division 4X) are not considered due to the fact that, until recently, witch flounder were reported as 'other flounders' by Canada, and cannot be separated from other flounder species.

The western Gulf of Maine (SA 513 and 514) and the central basin (SA 515) provide nearly half of the USA witch flounder landings; landings from Georges Bank are confined to the deeper waters north of the South Channel (SA 521, 522; Table A2). Otter trawl catches account for about 97% of witch flounder landings, with sink gillnets comprising the remainder. Catches are generally highest during March-July when witch flounder form dense pre-spawning aggregations (Burnett et al. 1992). The majority of witch flounder are landed in Maine ports, primarily Portland, with lesser amounts landed in New Bedford, and Gloucester, MA.

Although culling and grading practices vary by port, witch flounder have historically been landed as either 'small' or 'large'; however, three market categories ('peewee', 'medium', and 'jumbo') were added in some ports beginning in 1982 (Table A3, Figure A2). Since the early 1990s, the proportions of witch flounder landings from the peewee and small market categories have steadily increased. In 1998, witch flounder less than 45 cm ('peewee' and 'small' market categories) constituted 85% of total landings (Table A3). The current regulated minimum landing size for witch flounder is 36 cm (14 inches).

Sampling Intensity

Length frequency and age sampling data for witch flounder landings from the Gulf of Maine-Georges Bank region are summarized by quarter and market category (because some ports do not cull into 'peewee' or 'jumbo' categories, NEFSC sampling protocols incorporate these categories into the 'small' and 'large' categories, respectively). Until 1982, sampling was minimal and sporadic. During 1982-1988, an average of 48 length frequency samples was obtained annually over all market categories, representing 1 sample per 102 mt landed. In 1990, sampling requirements were adjusted to 1 sample per 50 mt to obtain more samples from the 'large' market category. However, samples for the 'large' market category have been difficult to obtain due to the sharp decrease in the landings of larger fish in recent years. Sampling intensity during 1990-1998 averaged 35 samples annually, representing 1 sample per 56 mt landed; nonetheless, even with this increased sampling intensity, inadequate numbers of samples were obtained for some market categories and quarter combinations.

In 1998, of the 23 samples collected, 14 were small samples (61%) 6 were medium (26%) and 3 were large (13%). Compared with the 1998 market category landings distribution by weight (small 85%; medium: 10%; large: 5%), sampling in 1998 reasonably approximated the market category distribution of landings on an annual basis. However, pooling of length frequency samples across quarters were required when only one or no samples existed. A summary of pooling procedures by year, market category and quarter is presented in Table A4.

Commercial Landings at Age

Commercial age data for the years 1982 to 1998 were available for this assessment. Quarterly age-length keys (ALKs) were applied to corresponding commercial landings length frequency data by market category. Resulting estimates of annual age compositions (age 0 to 14+) are presented in Table A5. No discernible changes in growth are evident during the 1982-1998 period; although landings mean weights and mean lengths at ages 6 to 8 declined in 1996-1998, this may be an artifact of poor sampling in recent years.

Discards

The Domestic Sea Sampling Program (DSSP), which began in 1989, has generated various levels of coverage for different fisheries. Prior to the DSSP, NEFSC conducted sea sampling on an ad-hoc basis. The northern shrimp fishery, the small-mesh otter trawl fishery, and the large-mesh otter trawl fishery are three fisheries in which discarding of witch flounder occurs. A summary of available sea sample data collected, by gear type, in the DSSP is presented in Table A6. In this assessment, discard estimates have been estimated for the shrimp fishery and the large-mesh otter trawl fishery.

*Northern shrimp fishery*

Since the 'shrimp season' spans a calendar year, in this report, the year in which most of the fishing occurred will be used to identify the entire season. For example, 1990 will refer to the shrimp season from December 1, 1989 to May 31, 1990. The estimation procedures used in the 1994 assessment (Wigley and Mayo 1994) and reviewed by the SAW 18 (NEFSC 1994), were extended through 1998 using the same methodology. The ratio of witch flounder discarded (kg) to days fished was calculated using DSSP data for individual shrimp seasons, 1989-1997, by fishing zone. Since depth is an important factor influencing discards (Wigley MS 1994), discard ratios were calculated for each of three fishing zones (zone 1 = 0=3 miles from shore, zone 2 = 3 - 12 miles, and zone 3 = greater than 12 miles) in each season. For the most part, fishing zones are analogous to depth zones. Statistical testing of zonal discard rates (Table A7) indicated differences between fishing zones in most years. The zone-specific discard rates were weighted by the days fished in each zone to calculate a weighted mean discard rate for each season (Table A8). To estimate witch flounder discard rates prior to the DSSP program, (i.e., 1982-1988), a simple linear regression was employed using 1989-1992 weighted mean discard rates and annual indices of witch flounder abundance. The NEFSC autumn bottom trawl survey index of age 3 fish was found to be the best predictor of annual discard rates ($r^2 = 0.97$, $p = 0.0127$; Figure A3; Wigley MS 1994).

With no 1998 DSSP sampling in the northern shrimp fishery, an alternative method of survey filtering was explored to estimate witch flounder discard rates; however, due to insufficient length frequency data at small sizes, this method did not prove fruitful. A simple linear regression using 1993-1997 annual shrimp season discard rates and annual survey indices of autumn age 3 fish was employed ($r^2 = 0.87$, $p = 0.0206$). This five-point regression may not be as robust as the $r^2$ suggests, as 4 of the points were somewhat clustered (Figure A3).

To obtain total weight of witch flounder discarded during a shrimp season, season discard rates (kg per day fished) were multiplied by the total number of days fished by the commercial fleet in each season (Table A8). Estimated discard weight was then translated into discarded numbers at age by applying witch flounder sea-sampled discard length-frequencies expanded up to the total discard weight and then applying NEFSC spring bottom trawl survey age-length keys. Detailed information on this method is given in Wigley (MS 1994). For 1995-1998, days fished were estimated from the Vessel Trip Reports (VTR) using a stratification level of year, ton class, port group, month, and fishing zone. To derive the number of trips by fishing zone, the proportion of VTR trips by fishing zone was applied to the number of trips in the weighout database. Days fished per trip in each fishing zone were derived from the VTR data. Days fished per trip were then multiplied by the estimated number of trips for each fishing zone to derive estimated days fished by fishing zone, and then summed over year and fishing zone. The number of shrimp trips estimated in this analysis compares favorably with number of trips reported in the shrimp assessment which were derived via a different method (Armstrong, et al. 1998).

Without 1998 DSSP sampling, length-frequency data were unavailable to partition the 1998 estimated discard weight into numbers at length; therefore, as a surrogate, the 1997 DSSP length-frequency was used. The 1998 NEFSC spring survey age/length key was applied to apportion numbers at age for each shrimp season.

Discard estimates of numbers at age and weight were derived on a shrimp season basis due to the limited number of length frequency samples in December. To adjust the shrimp fishery discard-at-age matrix from a shrimp season basis to calendar year, the ratio of December days fished to the entire shrimp season days fished was used to apportion of the weight and numbers discarded into December and January-May categories. The December discard-at-age matrix was shifted back one age, and then re-combined with the January-May matrix of the corresponding calendar year. The December discard weight was combined with January-May of the same calendar year. Mean lengths and mean weights at age in the re-combined catch at age were weighted by the numbers at age from each category.

Witch flounder discards in the northern shrimp fishery ranged from a low 6 mt in 1982 to a high of 34 mt in 1988 and 1995 (Table A9). Similarly, number of witch flounder discarded ranged from 62,000 fish discarded in 1982 to 1.8 million fish in 1994 (Table A9). Estimates of age compositions of discarded witch flounder in the shrimp fishery are presented in Table A10. Discarded witch flounder from the shrimp fishery range from age 0 to 6, with ages 2 and 3 most commonly discarded (Table A10). Over the time series, an estimated 7.3 million witch flounder have been discarded in this fishery.

*Large-mesh otter trawl fishery*

The DSSP has not generated sufficient data for directly estimating the age composition of discards in the large-mesh otter trawl fishery due to low sample sizes over the time series (Table A6). The estimation of discards in the large-mesh otter trawl fishery is based upon a method developed by Mayo et al. (1992) which utilizes survey and commercial catch at length data, commercial gear retention ogives, and information on culling practices. Research vessel length frequency data were filtered through commercial gear retention ogives corresponding to the predominant mesh size employed in the large-mesh fishery (130, 140, and 152 mm) and then through a culling practice ogive. Due to the sparse gear retention studies for witch flounder, mesh selection ogives were taken from Walsh et al. (1992) for American plaice. Given the high value and low abundance of this species, the culling practice of commercial fishermen was assumed to be knife edge at the minimum landing size. A semi-annual ratio estimator of survey filtered 'kept' index to semi-annual numbers landed was used to expand the estimated 'discard' survey index to obtain numbers of fish discarded at length. The method used in this analysis differs from the method described by Mayo et al (1992) which employs an expansion factor derived from a linear regression from the ratios of kept to landed at length. A spreadsheet illustrating the method used is presented in Table A11 for 1993 using the spring survey and commercial landings from quarters 1 and 2. Semi-annual numbers of discard fish at length were apportioned to age using the corresponding season NEFSC age/length key. Estimated numbers of discarded witch flounder in the large-mesh otter trawl fishery are presented by season in Table A12. Results indicate that in recent years, numbers discarded at sea comprised as much as 64% of the witch flounder landed. The general pattern of discarding appears to be consistent with that expected given strong recruitment during 1979-1981, 1985, and 1989-1993.

For years in which sufficient DSSP data were available, i.e. 1989, 1993, 1995, 1996, 1997, survey filtered length-frequencies were compared with DSSP length-frequencies by half-year. Length-frequencies from the kept and discarded catch were found to be generally consistent between the survey filtered data and the DSSP data.

Estimates of age compositions of discarded witch flounder in the large-mesh otter trawl fishery are presented in Table A13. Witch flounder discard-at-age from the large-mesh fishery range in age from 0 to 6, with majority at ages 3 to 5. Over the time series, an estimated 17.8 million witch flounder have been discarded in this fishery.

The Vessel Trip Report data were explored for information on discarding of witch flounder. Reporting of discard information in the logbooks are known to be incomplete. To eliminate problems associated with incomplete reporting, a subset of the VTR data was used. The VTR subset included only logbooks which reported discards of any species (Delong et al. 1997), assuming that operators who report discards of any species, would reliably report witch flounder discards. This subset was used to estimate discard ratios (discard weight/kept weight) by quarter and gear type from 1994 to 1998. Limitations of this analysis are: 1) the dealer data used to expand discard rates to total discard weight does not contain information on mesh size, precluding partitioning of otter trawl fisheries into small and large mesh trips; and 2) no area information on dealer data to isolate trips from the Gulf of Maine-Georges Bank region. From this exploratory analysis, results suggest that discarding of witch flounder in the otter trawl fishery ranges from approximately 5 to 10 % of the landed weight of witch flounder. Caution should be noted in using these estimates as not all fishermen report discarding practices. The estimate of discards to landings, by weight, derived from the survey filtering method ranged from 10 to 21% during the 1994 to 1998 period.

Mean weights at age of fish discarded in the shrimp fishery were lower than those discarded or landed in the large-mesh otter trawl fishery, reflecting seasonal differences between these fisheries. Mean weights and lengths at age of discarded fish in the large-mesh fishery were lower than those of landed fish.

Total Catch at Age

Total catch at age compositions (including commercial landings, discards from the northern shrimp fishery and the large-mesh otter trawl fishery) are presented in Table A14 and Figure A4. The age composition data reveal strong 1979-1981 year classes (Table A14). The 1985 year class also appears to have been strong;

however, this cohort was heavily discarded in both the shrimp and large-mesh otter trawl fisheries (Tables A10 and A13). High levels of discarding were also evident for the 1988 and 1989. and 1991-1995 year classes (Figure A4).

Since witch flounder landings are highest during March-July, the average weights-at-age approximate mid-year weights. Mean weights at age for January 1 (necessary for computing stock biomass in the VPA) were calculated using procedures developed by Rivard (1980) and are given in Table A15.

## STOCK ABUNDANCE AND BIOMASS INDICES

### Commercial LPUE

Commercial catch rates (landings per unit effort, LPUE, expressed as landings in mt per day fished) were derived for vessel tonnage classes 2-4 [Class 2 consists of vessels 5 to 50 gross registered tons (GRT); Class 3, 51 to 150 GRT; and Class 4, 151 to 500 GRT]. These vessel classes account for greater than 95% of annual witch flounder otter trawl landings. LPUE indices for the Georges Bank-Gulf of Maine region were computed for: 1) all trips landing witch flounder, and 2) trips in which 40% or more of the total landings comprised witch flounder (Table 25). These '40% trips' may represent effort that is 'directed' towards witch flounder, a species historically taken as by-catch.

For all trips landing witch flounder, increases in LPUE occurred in 1977-1978 for tonnage classes 2 and 3 and in 1982 for tonnage class 4, and remained high during the early 1980s; however, LPUE indices declined steadily for all tonnage classes from 1986 to 1990. Although a slight increase occurred in the early 1990s, recent LPUE indices are still among the lowest values observed in the time series (Figure A5a). Indices for 40% trips peaked in the early 1980's and have declined dramatically since then (Figure A5a). Effort (days fished) associated with all trips and 40% trips increased during the late 1970s and early 1980s, peaked during 1985-1988, decreased until 1990, and have since slightly increased (Figure A5b). While there is some evidence of increased directed effort in the early and mid 1980s [a period in which both witch flounder and American plaice were abundant and a small directed fishery emerged (Burnett and Clark 1983)], it is likely that LPUE indices derived for all trips landing witch flounder provide the best measure of relative abundance. In 1994 the NEFSC commercial data collection system changed from a voluntary to a mandatory system in which fishermen self-report fishing effort. Investigation is still on-going to determine if the time series of LPUE data can be extended (considered one series) or whether the post 1993 LPUE derived under the mandatory system constitutes a separate time series. Effort (days fished) for 1994 to 1998 may be underestimated in this report since effort is based upon preliminary VTR data, which does not represent 100% of the trips.

### Research Vessel Survey Indices

The NEFSC has conducted annual research vessel stratified random bottom trawl surveys during autumn since 1963 and during spring since 1968. Details on survey sampling design and the use of survey data in stock assessments are given in Azarovitz (1981) and Clark (1981), respectively. The Commonwealth of Massachusetts Division of Marine Fisheries (DMF) began an inshore trawl survey in 1978 which complements the NEFSC survey in coastal Massachusetts waters in that depths less than 27 meters (the lower depth limit sampled by the NEFSC offshore survey) are sampled (for details of this survey, see Howe et al. 1981). Additionally, the Northern Shrimp Technical

Committee of the Atlantic States Marine Fisheries Commission (ASFMC) has conducted an annual northern shrimp survey during August in the Gulf of Maine since 1983, with catch data for witch flounder available from 1984 on (for details of the shrimp survey, see Northern Shrimp Technical Committee MS 1984). All three surveys provide useful information relative to trends in abundance, distribution, and recruitment of witch flounder in the Gulf of Maine-Georges Bank region. Strata utilized in the derivation of indices of relative abundance and biomass for witch flounder are as follows: NEFSC, offshore strata 22-30, 36-40 (Figure 2); Massachusetts DMF, regions 4 and 5); and northern shrimp, strata 1, 3, 6, and 8 [See Wigley et al. 1999 for survey strata charts].

Witch flounder are generally distributed throughout the Gulf of Maine, along the Northern Edge and southern flank of Georges Bank, and southward along the continental shelf as far south as Cape Hatteras, NC (Figures A6a and A6b). Juvenile witch flounder (< 25 cm) are distributed along the western Gulf of Maine, with a few in the canyon areas in the Mid-Atlantic region (Figure A7a and A7b). Concentrations of witch flounder along the western portion of the Gulf of Maine are observed the ASMFC shrimp survey, however this survey has limited spatial coverage.

Research vessel survey indices of abundance, biomass, and mean length for NEFSC surveys, Mass. DMF surveys, and ASMFC shrimp surveys are presented in Table A16 and Figures A8 - A12, respectively. Length frequency data from these surveys are presented in Wigley et al 1999. A summary of available age data from NEFSC surveys is given in Table A17; survey age samples collected during 1976 to 1979 have not been aged. Too few age samples are collected during DMF surveys to reliably characterize the age composition of witch flounder in the inshore areas, and no age samples are collected on ASMFC surveys. Age-specific relative abundance indices from NEFSC spring and autumn surveys 1982-1993 are presented in Table A18.

While NEFSC spring survey indices tend to be more variable due to the pre-spawning aggregations of witch flounder, spring and autumn indices generally display similar trends. Abundance and biomass remained fairly stable from 1963 until the late 1970s (Table A18, Figures A8a and A8b ); autumn indices declined during the early and mid 1980s, reaching record low levels in 1987. Abundance sharply increased in 1993, due to a strong 1993 year class (Table A18, Figures A8b) and has generally remained high. At the same time, mean length declined, and has not re-bounded (Figure A9). The NEFSC spring and autumn survey indices of witch flounder greater than 40 cm have declined over the time series and are currently at low levels (Figure A10).

Length frequency data from the ASMFC shrimp survey suggest that incoming year classes can be identified prior to their appearance in the NEFSC surveys. Thus, the ASMFC survey appears to be more useful in providing a pre-recruit index than in characterizing the population as a whole. The ASMFC survey data indicate improved recruitment during the mid-1990's Figure A11; see Wigley et al 1999 for length frequency modes at 12 cm, corresponding to age 1 fish, during 1990-1993, ). Significant numbers of small fish were also observed in the NEFSC autumn survey during the same year. The Massachusetts DMF survey indices do not reflect this recent improved recruitment (Figures A12a and A12b). However, the DMF surveys do not consistently catch significant numbers of witch flounder less than 20 cm.

Mean lengths at age from NEFSC spring and autumn surveys are presented in Table A19 and for ages 4 to 8 in Figures A13a and A13b. Mean lengths at age for ages 5 to 7 appear to have increased approximately 3-5 cm from 1980 to the late 1980's, and then declined (Figures A13a and A13b); however, Von Bertalanffy growth analyses detected no significant changes in resulting growth parameters over the time period.

Reduced abundance levels in recent years have resulted in fewer age samples and highly variable estimates of numbers at age. Additionally, age compositions have become more truncated resulting in a diminished ability to track of individual cohorts.

NEFSC spring and autumn survey mean weights at age are given in Table A20. Survey mean weights are variable, however, similar declines in mean weights for ages 6-8 were observed during 1996-1998 in both the commercial landings and spring and autumn surveys.

## MATURITY

Witch flounder maturity observations have been collected on the NEFSC research bottom trawl surveys since 1977. The NEFSC spring surveys were used for maturity analyses as these surveys occur closest to and prior to spawning (Halliday 1987). Probit analyses (SAS 1985) of maturity at age data revealed that there have been five maturity stanzas over the assessment period (Table A21). The proportion at which 50% of the fish are mature at age ($A_{50}$) was significantly different for the time periods 1980-1982, 1983-1984, 1985-1990, 1991-1993 and 1994-1998. Due to small sample sizes, it was necessary to pool individual years, however, individual years were examined, and then pooled into time blocks. Trends in female $A_{50}$ and $L_{50}$ were similar, progressively decreasing from 1980-82 to 1985-90, then increasing to 1983-84 levels, then declining in 1994-98 to 1985-90 levels. It appears that the strong 1985 year class may have had an effect on maturation patterns. For maturity-at-length analyses, data from 1977-1980 were applied to the 1963-1976 period.

Stratified mean weight and number per tow of mature (spawning stock) witch flounder were calculated for spring NEFSC research vessel surveys (Table A22). The spawning stock biomass indices closely track total biomass index except in most recent years, indicating a larger proportion of immature fish in the population.

## MORTALITY

Natural Mortality

Burnett (MS 1987) estimated instantaneous natural mortality (M) to be 0.16 from a regression of survey-derived instantaneous total mortality (Z) estimates on commercial fishing effort. Halliday (1973) used a value of M = 0.15 for females and M = 0.2 for males in an assessment of Scotian Shelf witch flounder. In the present study, virtual population analyses, yield per recruit and spawning stock biomass per recruit analyses were performed assuming M = 0.15.

Total Mortality

Estimates of instantaneous total mortality (Z) were computed from NEFSC spring and autumn research vessel bottom trawl survey catch per tow at age data by combining cohorts over the following time periods: 1982-1985, 1986-1989,1990-1993, and 1994-1997. Given the variability in age at full recruitment to the sampling gear observed during the survey time series (Table A23), estimates were derived for each time period and each season by taking the natural logarithm of the ratio of pooled age 7+ to pooled 8+. For example, the estimate of Z for 1982-1985 was computed as:

**Spring**:
ln (sum age 7+ for 1982-1985 / sum age 8+ 1983-1986)

**Autumn**:
ln (sum age 6+ for 1981-1984 / sum age 7+ 1982-1985).

To evaluate Z over identical year classes within each of the survey series, different age groups were used in the spring and autumn.

Total mortality estimates from the two survey series exhibited similar trends, although autumn estimates were generally lower than those in the spring (Table A23). With no objective basis to select one survey series over another, total mortality was calculated by taking the geometric mean of the spring and autumn estimates during each time period. Total mortality increased from 0.41 during 1982-1985 to 0.74 during 1986-1989, declined to 0.44 during 1990-1993, and increased to 0.54 during 1994-1997 (Table A23). Additionally, annual estimates of total mortality were calculated, and smoothed with a three year moving average (Figure A14).

## ESTIMATION OF FISHING MORTALITY RATES AND STOCK SIZE

Virtual Population Analysis and Calibration

The ADAPT calibration method (Parrack 1986, Gavaris 1988, Conser and Powers 1990) was applied to estimate abundance at age in 1999 using catch-at-age estimates (i.e., landings plus discards from the shrimp and large-mesh otter trawl fishery; Table A14). Estimates of stock sizes, their associated statistics, and F in the terminal year are summarized in Table A24.

An initial formulation (RUN 45) based upon the 1994 VPA (Wigley and Mayo 1994) was performed to estimate 1982-1999 stock sizes for ages 4,7,8,9 (Table A24) using a catch-at-age matrix with a 10+ age group, NEFSC spring and autumn abundance indices for ages 3 to 9, and age-specific commercial LPUE indices for ages 7 to 9 as tuning indices. All indices were given equal weighting. Autumn survey indices were lagged forward one year and one age to calibrate with beginning year population sizes of the subsequent year. Spring indices calibrated beginning year abundance and LPUE indices calibrated mid-year stock sizes. A flat-top partial recruitment (PR) pattern was assumed, with full fishing mortality on ages 7 and older. Instantaneous rate of natural mortality (M) was assumed to be 0.15. The results of the initial run indicated that coefficients of variation (CV) for estimated ages ranged between 32% and 46% and the CVs for survey catchability coefficients (q) were consistent, ranging from 22% to 25%.

Alternative formulations included: 1) shortening the LPUE time series [RUN 46]; 2) excluding discards from the catch-at-age [RUN 51]; 3) excluding the LPUE indices [RUN 52]; and 4) varying the ages to be estimated and reducing the plus group from 10+ to 11+ [RUN 50]. Results from these alternative formulations showed a consistent pattern of increasing F during 1992 to 1996, and a dramatic drop in F in the terminal year. Residuals showed a persistent pattern of high negative values apparently caused by weakly detected year classes in the NEFSC surveys and improved recruitment since 1989.

Based on these alternative formulations, a final formulation was developed whereby age 3 was not estimated (due to high CV on age 3 in run 50; Table A24), and LPUE indices were excluded due to uncertainties in the later years. This formulation retained the desirability of an 11+ catch-at-age matrix which increased the numbers of fully-recruited ages for which F was estimated and should perform better for projecting rebuilding scenarios. Thus, the final ADAPT formulation (Run 54) provided stock sizes estimates for ages 4 to 10 in 1999 and corresponding F estimates for ages 1 to 10 in 1998.

Assuming full recruitment at age 7, the F on ages 10 and 11+in the terminal year was estimated as the average of F on ages 7 through 9. The F on ages 10 and 11+ in all years prior to the terminal year was derived from weighted estimates of Z for ages 7 through 9. Spawning stock biomass (SSB) was calculated at time of spawning (March) by applying maturity ogives given in Table A21 and mean weight at age calculated by the Rivard method (Table A15). The final calibration assumed a PR on age 3 in 1998 derived from the 1995-1997 F pattern taken from the penultimate calibration run (due to mesh regulation changes in May 1994).

The VPA calibration indicated that 1999 age 3 stock size was 131 million fish, approximately 4-fold higher than any previously estimate of age 3 estimate. Given the extremely high estimate of age 3 stock size in 1999, three additional VPA formulations were conducted for sensitivity of the age 3 stock size; these formulations included: 1) estimating age 3 stock size (Run 55) ; 2) eliminating shrimp discards from the catch-at-age (Run 56); and 3) estimating age 3 stock size and eliminating shrimp discards from the catch-at-age (Run 57; Table A24). However, the negative residual pattern associated with the stock size estimates of age 3 and 4 persisted, and given the retrospective pattern associated with age 3 recruitment (discussed below) it was determined that the best estimates of age 3 and 4 stock sizes in 1999 would come from the survey indices of recruitment. Stock sizes in 1999 for age 3 and 4 were estimated directly from the survey data using regressions of VPA stock sizes on the corresponding survey indices (Table A25; RTC3 program of ICES). The 1999 age 3 stock size was estimated to be 38.706 million fish (1996 year class) and age 4 stock size in 1999 was estimated to be 19.457 million fish (1995 year class). To estimate age 3 fish in 1998 (the 1995 year class), the 1995 year class at age 4 was back-calculated (accounting for natural mortality) to be 22.686 million fish (Table A26).

VPA Estimates of Fishing Mortality, Spawning Stock Biomass and Recruitment

A full listing of the final ADAPT VPA calibration output and diagnostics is presented in Appendix A, and results including estimates of F, stock size and spawning stock biomass at age, are given in Table A26. The mean residual for the VPA calibration was 0.811. The CVs on age 4 - 10 stock size estimates ranged from 0.35 to 0.52, while the CVs on the estimates of survey catchabilities were between 0.22 and 0.25. Normalized indices and standardized residuals are presented in Figures A15 and A16, respectively.

The VPA indicates that average fishing mortality on fully recruited ages (7+) increased from 0.21 in 1982 to 0.59 in 1985, declined to 0.24 in 1990, increased to 0.86 in 1996 then dropped to 0.37 in 1998, a 45% decrease from 1997 (Table A26, Figure A17). This trend in F is generally confirmed by the trend of pooled survey Z (Table A23, Figure A14).

Spawning stock biomass declined from 18,000 mt in 1982 to about 4,000 mt in 1993. Following the recruitment and maturation of the strong 1991-1993 year classes, SSB increased sharply to 8,600 mt in 1998 (Table A26, Figure A18). Mean biomass (age 3+) declined steadily from 28,000 mt in 1982 to a low of 7,700 mt in 1994 and has subsequently increased to 18,934 mt in 1998.

Since 1982 recruitment at age 3 has ranged from approximately 3 million fish (1984 year class) to 38 million fish (1996 year class), with most estimates between 15 and 30 million fish (Table A26, Figure A18). Over the 1982-1998 period, geometric mean recruitment of age 3 fish (the 1979-1996 year classes) equaled 12 million fish, indicating that the 1989, 1991-1993 year classes were above average, with the 1995 and 1996 year classes among the highest in the VPA time series (Table A26).

The relationship between spawning stock biomass and recruitment (age 3) is presented in Figure A19. Survival ratios, estimated as the ratio of age 3 recruits over the SSB which produced those recruits, shows increasing survival in the 1990's (Figure A20). The age composition of the spawning stock biomass revealed that more than half the SSB in 1982 was composed of age 11+ fish, but by 1998, more than half of the SSB consisted of age 5 - 7 fish, many of which were first-time spawners (Figure A21).

Precision of F and SSB

The uncertainty associated with the estimates of stock size and fishing mortality from the final VPA was evaluated using a bootstrap procedure (Efron 1982). One thousand bootstrap iterations were performed to derive standard errors, coefficients of variation (CVs) and bias estimates for the stock size estimates at the start of 1999, the catchability estimates (q) of the abundance indices used in calibrating the VPA, and the 1998 fully recruited fishing mortality rate (age 7+). Frequency distributions of the 1998 mean fishing mortality and spawning stock biomass bootstrap estimates were generated, and cumulative probability curves produced (Figures A22 and A23).

The bootstrap results indicate that age-specific stock sizes in 1999 were moderately well estimated with CVs ranging from 0.33 to 0.56. CVs on the catchability estimates associated with the tuning indices of abundance ranged from 0.19 to 0.24. Age-specific Fs in 1998 were reasonably well estimated with CVs ranging from 0.25 to 0.61, as was the mean fully recruited F (CV = 0.25).

The mean bootstrap estimate of the fully recruited F in 1998 (0.39) was nearly identical to the VPA point estimate (0.37). Based on the cumulative probability curve (Figure A22), there is an 80% probability that the 1998 F lies between 0.28 and 0.51.

The bootstrap mean of spawning stock biomass in 1998 (9,100 tons) was rather precise (CV = 0.17) and slightly higher (5%) than the VPA point estimate (8,600 tons). Based on the cumulative probability curve (Figure A23), there is an 80% probability that the 1998 SSB was between 7,400 mt and 11,000 mt.

To gain a historical perspective of spawning stock biomass, the survey time series of stratified mean weight of mature fish from the NEFSC spring survey was re-scaled to the VPA SSB via a linear regression ($r^2 = 0.82$). The re-scaled survey SSB reveals that SSB has generally declined since the mid-1970's, and although SSB has increased in recent years, current levels of SSB remain at low levels (Figure A24).

Retrospective Analyses

A retrospective analysis was conducted on final formulation (Run 54) from 1998 to 1991 by sequentially removing the terminal year of the data to evaluate internal consistency of the current ADAPT formulation with respect to terminal estimates of F, SSB, and recruits at age 3 for the 7 years prior to the current assessment. Results indicate that average fishing mortality was over estimated during 1991-1995; however, F appears to be underestimated in 1996 and 1997 (Figure A25a). In general, estimates of SSB were over estimated in 1994 through 1997, yet underestimated in 1991-1993 (Figure A25b). The retrospective analysis indicated a pattern of relatively consistent estimates of the number of age 3 recruits, with the notable exception of the 1992 and 1993 year classes, which were considerably over estimated (Figure A25c)

Stock Synthesis Model

The size-based version of the Stock Synthesis model (Methot 1989, 1990, 1998) was applied to estimate witch flounder population biomass and fishing mortality during 1982-1998. This age-structured analysis was conducted to explore whether biomass levels and trends from two different assessment models would be similar given identical input data. Several Synthesis model configurations that used different submodels and observation components were explored. In the final model, a single fishery and two research surveys (NEFSC spring and autumn bottom trawl) were included. Population numbers at age were modeled for ages 1 through 25+. Population age observations were predicted for a total of 11 age bins. The age bins were age-1, age-2, ..., age-11+. Population length observations were predicted for a total of 31 length bins consisting of 5-6 cm, ..., 65-66 cm. Selectivity-at-length curves were estimated for the fishery and both surveys. Retention of catch at length in the fishery was estimated for two time periods (1982-1987 & 1988-1998) based on a change in minimum landed fish size in 1988. Overall, the final model had a total of 10 likelihood components with equal emphasis levels. The likelihood components were: (1) fishery age composition, (2) fishery size composition, (3) distribution of fishery catch into retained and discarded categories, (4) spring survey abundance index, (5) spring survey age composition, (6) spring survey size composition, (7) autumn survey abundance index, (8) autumn survey age composition, (9) autumn survey size composition, (10) annual recruitment deviations from a mean stock-recruitment curve. Maximum likelihood estimates of a total of 38 parameters were determined when the total log-likelihood changed by less than 0.001 in successive iterations.

Results of the exploratory Synthesis analysis were generally similar to VPA results. Model fits to the spring and autumn survey weight-per-tow indices tracked observed values, although there was a notably large negative residual for the 1982 autumn survey data point. Residuals from model fits to fishery discard and landings length compositions, as well as the proportion of catch discarded by weight, exhibited some moderate residual patterns. However, residuals from model fits to survey age and length composition data appeared to be randomly distributed. Key model outputs were similar to VPA outputs (Figure A 26 ). Estimates of population biomass, fully-recruited fishing mortality, and age-1 stock size had similar levels and trends throughout the assessment time horizon, although estimates of the 1995-1996 year classes were relatively lower with the Synthesis model. Overall, this analysis suggested that assessment results for witch flounder were relatively insensitive to the choice of an age-structured model.

## BIOLOGICAL REFERENCE POINTS

Yield and Spawning Stock Biomass Per Recruit

Yield-per-recruit (Y/R), total stock biomass per recruit, and spawning stock biomass per recruit (SSB/R) analyses were performed using the Thompson and Bell (1934) method. Mean weights at age used in the Y/R analyses were computed as an arithmetic average of catch mean weights at age (Table A14) over the 1982-1998 period. Mean weights at age for use in the SSB/R analyses were computed as the arithmetic average of stock mean weights at age calculated by the Rivard method (Table A15) over the period 1982-1998. The maturation ogives used are presented in Table A21. Given the changes in regulated mesh size in 1994, the exploitation pattern used in the yield and SSB per recruit analyses and short-term projections was computed from the 1995-1997 VPA results (Table A26). Geometric mean F at age was computed for the 1995-1997 period and divided by the geometric mean of the fully recruited annual Fs to derive the partial recruitment vector. The final exploitation pattern was smoothed, applying full exploitation on ages 7 and older, viz.

| Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6 | Age 7+ |
|---|---|---|---|---|---|---|
| 0.001 | 0.005 | 0.013 | 0.073 | 0.233 | 0.473 | 1.000 |

The input data and results for the Y/R and SSB/R analyses are given in Table A27 and Figure A27. The biological reference points were $F_{0.1} = 0.16$, $F_{max} = .35$, and $F_{20\%} = .37$. An additional yield per recruit analysis was conducted using catch mean weights at age dis-aggregated by landings, large-mesh otter trawl discards, and shrimp fishery discards. The proportion of F for each component was also applied. Based on the landings per recruit, the biological reference points were slight lower ($F_{0.1} = 0.15$ and $F_{max} = .30$; Table A28).

MSY Based Reference Points

A non-equilibrium surplus production analysis (ASPIC; Prager, 1994,1995) was performed on total catch and survey indices of stock biomass from 1963 to 1998. The model was calibrated with NEFSC spring and autumn biomass indices, where spring indices were lagged back one year to calibrate biomass at the end of the previous year. Exploratory formulations included unconstrained survey catchabilities (q), and constrained q's, spring series only, autumn series only. Spring and autumn biomass indices were well correlated (r=0.65) and fit the model reasonably well ($r^2$= 0.62 and 0.40, respectively. When q was unconstrained, the intrinsic rate of increase (r) was unreasonably high for this slow growing, long-lived species.

Summary of reference point estimates from alternative ASPIC analyses:

| q constraint | Surveys | MSY | Bmsy | Fmsy |
|---|---|---|---|---|
| No | Spring & Autumn | 4.303 | 8.87 | 0.49 |
| Yes | Spring & Autumn | 3.049 | 20.19 | 0.15 |
| Yes | Spring | 3.096 | 18.24 | 0.17 |
| Yes | Autumn | 3.096 | 19.94 | 0.16 |

In the final formulation, survey q's were fixed according to ADAPT VPA estimates of age 3+ biomass. The dynamic range of the model was good (the B-ratio coverage was 1.7 and the B-ratio nearness = 1.0). Results of the final formulation estimated MSY to be 2,684 mt, $B_{msy}$ to be 25,000 mt, and the corresponding $F_{msy}$ = 0.106 (Table A29)

The Amendment 9 control rule states that when the stock biomass exceeds $B_{msy}$, the overfishing threshold is $F_{msy}$, and target F is lower 10th percentile of $F_{msy}$ (Applegate et al. 1998). When stock biomass is less than $B_{msy}$, the overfishing threshold is based on maximum F that would allow rebuilding to $B_{msy}$ in five years as derived by projections describe by Cadrin (1999). When biomass is less than the biomass threshold, F = 0. The biomass threshold is defined by the minimum stock size that is projected to rebuild to $B_{msy}$ in 10 years at F=0, as derived by Cadrin (1999).

The Amendment 9 control rule was updated with the revised estimates of $F_{msy}$ (0.106), $B_{msy}$ (25,000 mt) and the tenth percentile of $F_{msy}$ (0.090; Figure A28). Based on the ADAPT estimates of age 3+ mean biomass in 1998 (18,934 mt) and F on biomass (0.13), overfishing was occurring in 1998 (Figure A28). Assuming 1999 catches will equal 1998 catches, the 1999 F is estimated to be 0.20, and the target fishing mortality prescribed by the control rule for the 1999 stock size is 0.096 on biomass, which is approximately equivalent to 0.19 on fully recruited ages assuming the current age structure of the population (assuming an equilibrium age structure, the F on 3+ biomass would be 0.12).

## PROJECTIONS FOR 2000 AND 2001

Short-term three year stochastic projections were performed to estimate landings, SSB and total biomass (3+) during 2000-2001 under two F scenarios using bootstrapped VPA calibrated stock sizes in 1999 (age 3 and 4 stock sizes were estimated using RCT3 where the mean and standard error were used to generate 1,000 estimates of age 3 and 4 stock sizes from a log-normal distribution, and ages 5-11+ were taken from the VPA results). Assuming status quo landings in 1999, the fully-recruited F was projected to be 0.20. The partial recruitment, maturity ogive, and mean weights at age were the same as described in the yield and SSB per recruit section (Table A30). Recruitment (age 3) in 2000-2001 was derived by re-sampling from the empirical observations during 1982-1997 (1979-1994 year classes). Fishing mortality was apportioned among landings and discards based on the observed proportion landed at age during 1995-1997. The proportion of F and M which occurs before spawning equals 0.1667 (March 1): M assumed to be 0.15. Spawning stock biomass and total biomass (3+) in 1998 were estimated to be 8,652 and 18,934 mt, respectively. The F scenarios are: status quo $F_{99}$ = 0.20 and $F_{control\ rule}$ = 0.19.

At fishing mortality of 0.20, landings are projected to increase to 3,033 mt in 2000, and 3,769 mt in 2001. SSB is projected to increase to 18,924 mt in 2000, and increase further to 23,440 mt in 2001. Total biomass (3+) will increase to 29,695 mt in 2000, and 31,955 mt in 2001, above $B_{msy}$ of 25,000 mt (Table A30, Figure A29). Fishing at $F_{control\ rule}$ (0.19), landings in 2000 are projected to be 2,894 mt and will increase to 3,623 mt in 2001. SSB at $F_{control\ rule}$ will increase to 18,951 mt in 2000 and 23,619 mt in 2001 and total biomass (3+) is projected to be 29,779 mt in 2000 and 32,213 mt in 2001 (Table A30).

## CONCLUSIONS

Based on the ADAPT VPA estimates of age 3+ mean biomass in 1998 (18,934 mt) and the 1998

F on 3+ biomass (0.13), overfishing was occurring in 1998. However, overfishing is not expected to occur in 1999 based on catch statistics to-date where estimated 3+ biomass in 1999 is projected to be 26,048 mt and F on 3+ biomass is estimated to be 0.20. Recent year classes appear to be above average. Fishing mortality should not be allowed to increase as fishing above F=0.19 (fishing mortality target) will dissipate the potential benefits that the recent recruitment levels should produce. Spawning stock biomass is still at a low level relative to the long-term survey biomass indices. It is clear that, despite the variability in the survey indices, the age range of the stock has been greatly reduced since 1985-1986 and that the catch at ages 2-4 is due almost entirely from fish discarded in the shrimp and large-mesh otter trawl fisheries.

## WORKING GROUP DISCUSSION

The Northern Demersal Working Group discussed the spatial distribution of the stock and the use of landings and survey indices in the assessment. The Working Group noted that the Canadian landings from 4X and 5Z were not included in the landings-at-age. This results in an underestimation of total catch and affects estimates of abundance. However, the amount of Canadian landings from 5Z are small and uncertain due to the large amounts of unspecified flounders landed in that area. The Working Group also noted that landings from subarea 6 are included in the total landings used in the catch-at-age, but the survey indices used to calibrate the VPA only include the area from Georges Bank north. This creates a potential inconsistency. However, the core abundance of the stock is well-surveyed within the strata set used and the landings outside the core area are small. Adding the survey strata from subarea 6 into the survey index would probably only add noise to the index as the abundance in that area is very low compared to the core area. The Working Group did recommend that the trends in abundance outside the strata set should be examined in the future.

The Working Group discussed whether the Massachusetts observer data for the shrimp fishery should be used in the discard estimation. These data are from a small group of boats from Gloucester whose fishing patterns are different from the rest of the shrimp fleet. Therefore, until an appropriate weighting scheme is developed, the Working Group determined that exclusion of this fleet sector from the analysis was appropriate.

The accuracy of days fished by the shrimp fleet by fishing zone (a proxy for depth) was discussed in relation to estimation of discards. The total number of days fished in the shrimp fishery from the weighout/logbook method is consistent with the estimates derived by the Northern Shrimp Technical Committee which are based on a different data collection system. The Working Group concluded that the discard/day fished was sufficiently different by fishing zone to warrant separating them in the analysis whether or not the days fished by zone are precisely determined.

Possible reasons for the high 1995 shrimp fishery discard estimate were discussed. The Working Group was concerned that the estimate was high for reasons other than good recruitment of witch flounder such as inadequate fishery coverage or sampling variation. However, given that total discard weights are low and the survey corroborated the presence of some large year classes, the Working Group determined that the estimates were valid but may present a source of uncertainty.

The Working Group discussed the possible effects of pooling commercial length and age samples by season and market category on the accuracy of the landings-at-age. The size frequency differences between large and jumbo and those between small and peewee were examined and found to be negligible, allowing for pooling of these market categories when insufficient numbers of samples were collected. Seasonal pooling was necessary, particularly in the most recent years, when the amount of sampling by quarter and market category was insufficient to characterize the fishery. This could lead to uncertainties in the catch-at-age.

The Working Group discussed possible reasons for a declining trend from the late 1980s to early 1990s in the mean weight-at-age from the landings. The poor sampling in recent years could be a cause of this decline. However, the same trend was noted in the survey mean weights. Several reasons for this change were discussed (including changes in growth, emigration, or the fishery selectively harvesting fast-growing fish at those ages) but no conclusion was reached.

Biological reasons for apparent changes in median age at maturity (A50) were discussed and were generally explained by changes in abundance and/or strong year classes. As abundance declined in the 1980s, A50 also declined. As the strong 1985 year class became mature, maturity was delayed and there was an increase in the A50. The decline in A50 in 1994-1998 was more difficult to explain. The Working Group concluded that truncation of the size structure over time was probably a more significant factor in reducing reproductive potential of the spawning stock biomass regardless of the actual ogive used to derive SSB. With fewer older fish in the population, much of the SSB is comprised of first-time spawners which are have a lower fecundity to weight ratio and potentially lower egg viability.

The Working Group discussed the dome-shaped PR observed in almost all years of the VPA. Several reasons were discussed including change in natural mortality with age, emigration of older fish outside the survey area, and poor sampling or catchability of older ages.

The appropriateness of using an unstandardized LPUE index as a tuning index in the VPA was discussed. The uncertainty of the index from 1994-1998 due to a change in the reporting systems led to exclusion of those years. Since the inclusion of the remaining years of the LPUE series did not change the results significantly and did not add much to the stability of the calibration as has been the case in other assessments, the Working Group decided to exclude it as a tuning index but recommended exploring the use of a GLM to standardize the LPUE to characterize fishery trends. This resulted in a more parsimonious calibration by eliminating five estimated parameters.

The appropriate use of survey mean weights at age versus Rivard weights at age (mid-year weights adjusted to beginning of year) for SSB calculations was discussed. The Working Group decided that the survey mean weights needed considerable post-processing before being used. Discussion focused on different methods of smoothing the noise and filling in holes in the weight-at-age matrix including smoothing over a cohort or over a year. Alternate calculations using survey mean weights at age were also discussed such as January 1 or mid-year biomass calculations. Weights at age could be adjusted to January 1 or any time of year in the fitting process by including a time adjustment factor in a growth equation. For SSB calculations, should only the weights of mature individuals be used to estimate weights at age? The Working Group decided to continue using Rivard weights and recommend that the Methods Working Group investigate the matter in a thorough manner.

The Working Group was presented with three analytical models: VPA, Stock Synthesis, and

ASPIC. ASPIC showed very little recent increase in biomass because the model structure cannot anticipate the strong recruitment observed in the last few years. Stock Synthesis and VPA give similar results although Stock Synthesis estimates of recent recruitment were relatively lower because the model constrains recruitment.

The Working Group examined various VPA formulations and accepted the results from a final calibration that estimated ages 4-10, and was tuned using NEFSC spring and autumn survey ages 3-11+. Estimating age 3 was problematic because of low numbers in the catch-at-age and high variability in the survey. Estimating age 10, however, allows three ages to be used to determine fully-recruited F and was also beneficial for projecting when rebuilding of the age structure occurs.

## SARC DISCUSSION

Data Issues

Discard estimates derived for the shrimp fishery since 1989 (except for 1998) were based on observed sea sample tows while estimates for the period prior to 1989 were based on proxy methods using a combination of survey abundance index of age 3 witch flounder and effort in the shrimp fishery. The low estimates of discards during the 1980s relative to the period since 1989 was discussed, and it was suggested that differences may be due to the change in estimation methodology. The lower discard estimates obtained using the proxy method reflects decreased effort in the shrimp fishery in the late 1980s, combined with a series of poor year classes of witch flounder during the early 1980s. Either or both of these factors would result in lower discard estimates when the survey proxy method is applied.

Several minor points were clarified. The spring 1999 survey indices were included in the VPA calibration. No vessel or door conversion factors were applied as the analyses indicated no significant differences for witch flounder. The mean weights at age used in the projections represented long-term averages rather than recent averages as there were no long-term trends in mean weight at age noted. The decline in mean weight at ages 6-8 in 1996 and 1997 may be a year class effect.

Assessment Issues

The residual pattern emanating from the ADAPT/VPA calibration and the ASPIC model results were discussed at length. In the VPA, there are years of large residuals which appear periodically. More importantly, there is a consistent set of large negative residuals in the terminal year (1999) across all ages used in the calibration block, particularly in the spring 1999 survey. The SARC noted that this pattern in residuals versus random variation adds uncertainty to the outcome of the VPA, but this is not captured by standard bootstrapping techniques as employed in this assessment. In addition, the SARC noted that the bootstrap procedure incorporated in the standard ADAPT software captures variability in estimates of N, but not q. The two sets of parameters are estimated simultaneously and the final N estimates are associated with a set of final q estimates. The variability associated with N estimates is retained but the variability associated with the estimates of q is not. This may lead to an underestimate of the amount of uncertainty in the overall assessment.

As well, there appears to be a cyclical pattern in the annual residuals from the ASPIC model fit, but this was attributed to the model's inability to account for age structure in the population or to track changes in incoming recruitment on an annual basis. This pattern appears in all model runs including those based on a single survey (spring or autumn) alone. The ASPIC model was conditioned on the VPA in that q in ASPIC was fixed so that the biomass estimated from ASPIC was in accordance with the estimates of 3+ biomass estimated by the VPA over the time series.

The SARC also noted a strong retrospective pattern associated with estimates of F and recruitment in the VPA.

The reproductive capacity of the stock, as indicated by the estimates of SSB, may not be as high in recent years in light of the steady reduction of older ages and the resulting shift in the age structure towards younger fish. The SARC suggested that other measures of reproductive capacity, including population fecundity might be investigated to better understand this phenomenon.

The VPA calibration was discussed at length; in addition to the preferred formulation, several trial formulations were described. The primary issues centered around the strength of the 1995 and 1996 year classes as estimated by the VPA for 1999. The age 3 and 4 stock sizes estimated by the VPA were extremely high (3-4 times) compared to any other values in the time series. The SARC questioned whether the stock sizes for these year classes were estimated as parameters in the ADAPT model or conditioned in the partial recruitment. It was noted that, in the preferred formulation, the 1995 year class (age 4) stock size was a direct estimate, whereas the 1996 year class (age 3) was conditioned on the partial recruitment.

The SARC suggested that an examination of recruitment indices from the survey alone may reveal information on year class strength independent of the VPA, particularly in light of the large negative residuals associated with the stock size estimates of ages 3 and 4. It was noted that the survey indices for the 1995 and 1996 year classes, while high, were not substantially greater than those for other relatively strong year classes (1-2 times), whereas the estimates of year class strength of the 1995 and 1996 year classes derived from the VPA were 4-8 times higher than other strong year classes at comparable ages. After considerable discussion, the SARC suggested that these stock sizes be estimated directly from the survey data using regressions of VPA stock sizes on corresponding survey indices. It was noted that estimation of year class strength from the VPA-survey regressions does not capture the variance in the catch at age. However, based on the retrospective pattern observed in the VPA, ADAPT is more likely to overestimate recruitment in the terminal year, whereas direct estimates of recruitment from the VPA-survey regressions are not subject to this retrospective pattern.

Several alternative formulations of the VPA were requested by the SARC to ascertain the potential impact of the catch at age, particularly discards, on the estimation of the strength of the 1995 and 1996 year classes in 1999. It was noted that the age 3 stock size estimate is not independent of the catch at age, even though the catch is small. There was a high catch at age 2 in 1998 (1996 year class) attributed to discarding in the shrimp fishery. The 1998 discard estimates were not derived from sea sample data as there was no coverage in 1998. Instead, the survey proxy method applied to the pre-1989 period was applied in 1998, but with a separate regression since the Nordmore grate was in use after 1992. The regression was highly dependent on a single point which influenced the 1998 estimate. The SARC concluded that the effect of discard estimates on VPA performance is a source of uncertainty. The survey index and shrimp fishery effort used to predict the 1998 discards also contains uncertainty, but these sources are not captured in the overall statistics on uncertainty estimated by the bootstrap procedure. As in other VPAs, the catch at age is considered to be estimated without error.

The effect of the size of recruiting year classes on the catch and stock projections was discussed at length. It was noted that recruitment in 2000 and 2001 was determined by resampling the age 3 stock size estimates derived from the VPA through 1999, thereby including the high 1995 and 1996 year classes in the distribution of observed recruitment. More importantly, these year classes were also included as 1999 survivors used to initiate the projections. Based on these observations, the SARC considered the 2000 and 2001 projections as initially presented to be optimistic, and recommended that stock size estimates of the 1995 and 1996 year classes in 1999 be derived directly from the RCT3 VPA-survey regressions.

The SARC considered the various re-runs of the VPA and concluded that none had improved upon the Working Group's preferred formulation as originally presented, but no formulation provided satisfactory estimates of the size of the 1995 and 1996 year classes in 1999. Therefore, the SARC accepted the stock size estimates derived from the VPA-survey log-log regressions and requested that the two point estimates be cast in a stochastic framework, taking account of the standard error of the regressions.

Projections were then based on the VPA bootstrapped 1999 stock sizes at ages 5-11+ and the estimated stock sizes at ages 3 and 4 in 1999 as derived from the survey regressions.

## SOURCES OF UNCERTAINTY

1. The bootstrap procedure as applied does not capture the full extent of variability and uncertainty in the VPA results, particularly that which comes from the residual pattern and the retrospective pattern, and, therefore, the percentile distributions of the projected stock parameters understate the extent of the uncertainty in the forecasts.

2. Confounding of survey based estimates of discards and use of same surveys as tuning indices for VPA calibration.

3. Low frequency of samples across market category and season resulting in variable mean weights at age and estimates of numbers at age.

4. Low catchability of standard survey gear leading to highly variable survey indices.

5. Lack of data to support direct estimates of discards at age requiring use of various surrogate survey-based methods.

6. The simple biomass dynamics model used to derive MSY-reference points does not account for age structure of the stock or current recruitment.

7. Estimates of current recruitment are highly variable due to the dependence on catch at younger ages which consists almost entirely of discards and highly variable and imprecise survey indices for recruiting ages.

## RESEARCH RECOMMENDATIONS

1. Measures of reproductive capacity, including population fecundity should be investigated to better understand the impact of the truncated age structure on recruitment.

2. Current survey indices measure abundance in core area only; examine usefulness of other strata sets outside the core area (i.e. southern

New England and the Mid-Atlantic (strata 1-21,61-76) and in Canadian waters (31-35)) and report indices as appropriate.

3. Explore use of GLM to standardize LPUE from the otter trawl fishery.

4. Use Hoenig and Morgan's method of weighting maturity observations by number observed in the survey catch at length. Explore deriving maturity estimates as a function of length and age with interaction terms. Explore other statistical methods to determine if differences in maturity are significant.

5. Explore ageing of witch flounder in NEFSC survey prior to 1980.

6. Explore the possibility of collection of age structures from the ASMFC shrimp survey.

7. Explore the use of other age-disaggregated surveys (i.e. Massachusetts spring and autumn, and ASMFC shrimp) as tuning indices (i.e. cohort slicing to determine recruitment from shrimp survey, using NEFSC age-length keys to age Massachusetts surveys).

Recommendation to the Methods Working Group

1. Explore methods to smooth survey mean weights at age and to fill in missing values in the weights at age.

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Table A1. Witch flounder landings, discards and catch (metric tons, live) from Subareas 5 and 6, by country, 1960-1998 [1960-1963 reported to ICNAF/NAFO (Burnett and Clark, 1983)].

| | Landings | | | | | Total USA Catch |
|---|---|---|---|---|---|---|
| Year | Canada | USA [2] | Other[1] | Total | Discards | (used in VPA) |
| 1960 | - | 1255 | - | 1255 | | |
| 1961 | 2 | 1022 | - | 1024 | | |
| 1962 | 1 | 976 | - | 977 | | |
| 1963 | 27 | 1226 | 121 | 1374 | | |
| 1964 | 37 | 1381 | - | 1418 | | |
| 1965 | 22 | 2140 | 502 | 2664 | | |
| 1966 | 68 | 2935 | 311 | 3314 | | |
| 1967 | 63 | 3370 | 249 | 3682 | | |
| 1968 | 56 | 2807 | 191 | 3054 | | |
| 1969 | - | 2542 | 1310 | 3852 | | |
| 1970 | 19 | 3112 | 130 | 3261 | | |
| 1971 | 35 | 3220 | 2860 | 6115 | | |
| 1972 | 13 | 2934 | 2568 | 5515 | | |
| 1973 | 10 | 2523 | 629 | 3162 | | |
| 1974 | 9 | 1839 | 292 | 2140 | | |
| 1975 | 13 | 2127 | 217 | 2357 | | |
| 1976 | 5 | 1871 | 6 | 1882 | | |
| 1977 | 11 | 2469 | 13 | 2493 | | |
| 1978 | 18 | 3501 | 6 | 3525 | | |
| 1979 | 17 | 2878 | - | 2895 | | |
| 1980 | 18 | 3128 | 1 | 3147 | | |
| 1981 | 7 | 3422 | - | 3449 | | |
| 1982 | 9 | 4906 | - | 4915 | 48 | 4953 |
| 1983 | 45 | 6000 | - | 6045 | 162 | 6162 |
| 1984 | 15 | 6660 | - | 6675 | 100 | 6760 |
| 1985 | 46 | 6130 | - | 6431 | 61 | 6191 |
| 1986 | 67 | 4610 | - | 5216 | 25 | 4635 |
| 1987 | 23 | 3450 | - | 3819 | 47 | 3497 |
| 1988 | 45 | 3262 | - | 3665 | 60 | 3322 |
| 1989 | 13 | 2074 | - | 2384 | 133 | 2207 |
| 1990 | 12 | 1478 | - | 1492 | 184 | 1662 |
| 1991 | 7 | 1798 | - | 1805 | 95 | 1893 |
| 1992 | 7 | 2246 | - | 2253 | 171 | 2417 |
| 1993 | 10 | 2605 | - | 2615 | 376 | 2981 |
| 1994 | 34 | 2670 | - | 2704 | 422 | 3092 |
| 1995 | 11 | 2212 | - | 2223 | 265 | 2477 |
| 1996 | 10 | 2088 | - | 2098 | 454 | 2542 |
| 1997 | 7 | 1775 | - | 1782 | 393 | 2168 |
| 1998 | * | 1849 | - | 1849 | 334 | 2184 |

[1]Includes West Germany, East Germany, Poland, Spain, Japan, & the former USSR.
[2]Excluding Landings from Grand Banks (subarea 3).
* 1998 Canadian Landings not available.

Table A2. Summary of USA commercial witch flounder landings (mt) by Statistical Area, 1973 - 1998.

| | Statistical Areas | | | | | | | | | | | | | | | 561 | 562 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | 300 | 400 | 464 | 465 | 466 | 500 | 510 | 511 | 512 | 513 | 514 | 515 | 520 | 521 | 522 | 523* | 524* | 525 | 526 | 530 | 537 | 538 | 539 | 540 | 600 | TOTAL |
| 1973 | - | 27 | - | 21 | - | - | - | 102 | 236 | 470 | 349 | 39 | - | 266 | 412 | 20 | 74 | 192 | 271 | - | 26 | 0 | 4 | - | 14 | 2523 |
| 1974 | - | 49 | - | 2 | 4 | - | - | 19 | 76 | 319 | 213 | 23 | - | 334 | 294 | 17 | 104 | 145 | 192 | - | 41 | 2 | 2 | - | 3 | 1839 |
| 1975 | - | 15 | - | 18 | 1 | - | - | 18 | 150 | 360 | 289 | 92 | - | 371 | 238 | 10 | 159 | 281 | 105 | - | 13 | 0 | 3 | - | 4 | 2127 |
| 1976 | - | 22 | - | 6 | 2 | - | - | 25 | 140 | 470 | 365 | 37 | - | 278 | 209 | 24 | 81 | 144 | 50 | - | 12 | 2 | 1 | - | 3 | 1871 |
| 1977 | - | 5 | - | 5 | 2 | - | - | 15 | 192 | 756 | 682 | 101 | - | 257 | 250 | 19 | 62 | 71 | 30 | - | 13 | 2 | 5 | - | 2 | 2469 |
| 1978 | - | 11 | - | 5 | - | - | - | 8 | 333 | 1370 | 642 | 164 | - | 366 | 306 | 85 | 86 | 38 | 45 | - | 20 | 8 | 4 | - | 10 | 3501 |
| 1979 | - | 5 | - | 1 | - | - | - | 67 | 270 | 1025 | 416 | 120 | - | 367 | 393 | 97 | 35 | 15 | 28 | - | 21 | 1 | 3 | - | 14 | 2878 |
| 1980 | - | 4 | - | 7 | - | - | - | 44 | 278 | 1320 | 386 | 258 | - | 317 | 231 | 67 | 26 | 38 | 111 | - | 19 | 1 | 6 | - | 15 | 3128 |
| 1981 | - | 7 | - | 34 | - | - | - | 66 | 317 | 1410 | 419 | 322 | - | 390 | 183 | 68 | 62 | 48 | 40 | - | 39 | 0 | 9 | - | 28 | 3442 |
| 1982 | - | 22 | - | 34 | - | - | 1 | 154 | 759 | 1432 | 427 | 760 | - | 558 | 289 | 120 | 52 | 69 | 96 | - | 51 | 6 | 12 | - | 64 | 4906 |
| 1983 | - | 31 | - | 145 | - | - | - | 252 | 1233 | 1460 | 479 | 1045 | - | 555 | 322 | 121 | 46 | 63 | 104 | - | 88 | 2 | 14 | - | 40 | 6000 |
| 1984 | - | 15 | - | 147 | - | - | - | 158 | 750 | 1564 | 788 | 1322 | - | 800 | 430 | 155 | 67 | 118 | 181 | - | 99 | 1 | 8 | - | 57 | 6660 |
| 1985 | 255 | 5 | - | 68 | - | - | - | 234 | 752 | 1474 | 658 | 1263 | - | 735 | 468 | 128 | 62 | 99 | 106 | - | 34 | 1 | 2 | - | 41 | 6385 |
| 1986 | 539 | 12 | - | 66 | 1 | - | - | 204 | 765 | 1213 | 468 | 787 | - | 481 | 298 | 100 | 20 | 33 | 77 | - | 31 | 2 | 2 | - | 50 | 5149 |
| 1987 | 346 | 3 | - | 15 | - | - | - | 103 | 441 | 1039 | 364 | 720 | - | 344 | 214 | 55 | 20 | 25 | 47 | - | 16 | 0 | 1 | - | 43 | 3796 |
| 1988 | 358 | - | - | 11 | - | - | - | 94 | 288 | 958 | 352 | 617 | - | 450 | 207 | 53 | 35 | 96 | 47 | - | 13 | 1 | 1 | - | 39 | 3620 |
| 1989 | 297 | 1 | - | 2 | - | - | - | 32 | 175 | 517 | 224 | 381 | - | 304 | 135 | 39 | 28 | 52 | 129 | - | 21 | 2 | 1 | - | 31 | 2371 |
| 1990 | 2 | 5 | - | 2 | - | - | - | 24 | 135 | 429 | 183 | 188 | - | 164 | 82 | 35 | 36 | 55 | 77 | - | 38 | 0 | 2 | - | 23 | 1480 |
| 1991 | - | 2 | - | 1 | - | - | - | 19 | 168 | 470 | 198 | 281 | - | 146 | 138 | 43 | 54 | 36 | 87 | - | 85 | 1 | 2 | - | 67 | 1798 |
| 1992 | - | 1 | - | - | - | - | - | 13 | 235 | 520 | 227 | 332 | - | 152 | 188 | 46 | 39 | 63 | 219 | - | 143 | 0 | 4 | - | 64 | 2246 |
| 1993 | - | 12 | - | - | - | - | - | 14 | 175 | 580 | 419 | 422 | - | 180 | 270 | 82 | 65 | 94 | 134 | - | 98 | 0 | 2 | - | 58 | 2605 |
| 1994* | - | - | 3 | - | - | 11 | 7 | 45 | 349 | 414 | 414 | 360 | 4 | 382 | 326 | 70 | 40 | 57 | 43 | 4 | 73 | 11 | 4 | 5 | 47 | 2670 |
| 1995* | - | - | 10 | 10 | - | 14 | 4 | 25 | 150 | 311 | 337 | 455 | 6 | 382 | 331 | 42 | 15 | 33 | 13 | 4 | 25 | 4 | 1 | 2 | 36 | 2212 |
| 1996* | - | - | 3 | 3 | - | 16 | 25 | 35 | 132 | 378 | 289 | 436 | 25 | 287 | 294 | 44 | 9 | 45 | 6 | 1 | 27 | 9 | 2 | 3 | 20 | 2088 |
| 1997* | - | - | - | 1 | - | 20 | 12 | 12 | 165 | 292 | 224 | 388 | 11 | 196 | 286 | 48 | 8 | 57 | 13 | - | 21 | 6 | 1 | - | 14 | 1775 |
| 1998* | - | - | - | 1 | - | 22 | 2 | 13 | 153 | 268 | 205 | 404 | 4 | 280 | 299 | 65 | 24 | 47 | 10 | 1 | 20 | 12 | 5 | 2 | 10 | 1849 |

Note: USA portions of SA 523 and 524 were renamed 561 and 562, respectively, in 1985.
* 1994-1998 spatial distribution based upon Vessel Trip Report data, considered provisional.

Table A3. Percentage of USA commercial witch flounder landings by market category, 1973 - 1998.

| Year | Peewee | Small | Medium | Large | Jumbo | Uncl. | Total |
|---|---|---|---|---|---|---|---|
| 1973 | 0.0 | 13.5 | 0.0 | 45.9 | 0.0 | 40.7 | 100.0 |
| 1974 | 0.0 | 26.2 | 0.0 | 73.8 | 0.0 | 0.0 | 100.0 |
| 1975 | 0.0 | 26.3 | 0.0 | 73.7 | 0.0 | 0.0 | 100.0 |
| 1976 | 0.0 | 21.5 | 0.0 | 78.4 | 0.0 | 0.1 | 100.0 |
| 1977 | 0.0 | 22.9 | 0.0 | 77.1 | 0.0 | 0.0 | 100.0 |
| 1978 | 0.0 | 30.2 | 0.0 | 69.8 | 0.0 | 0.0 | 100.0 |
| 1979 | 0.0 | 30.8 | 0.0 | 69.2 | 0.0 | 0.0 | 100.0 |
| 1980 | 0.0 | 23.4 | 0.0 | 76.0 | 0.0 | 0.6 | 100.0 |
| 1981 | 0.0 | 30.1 | 0.0 | 68.3 | 0.0 | 1.6 | 100.0 |
| 1982 | 0.3 | 26.3 | 5.4 | 64.0 | 0.0 | 4.0 | 100.0 |
| 1983 | 1.4 | 25.0 | 14.7 | 58.4 | 0.0 | 0.4 | 100.0 |
| 1984 | 3.4 | 25.2 | 19.1 | 51.7 | 0.0 | 0.6 | 100.0 |
| 1985 | 7.7 | 27.8 | 23.2 | 40.5 | 0.1 | 0.7 | 100.0 |
| 1986 | 5.1 | 33.7 | 25.3 | 34.6 | 0.0 | 1.2 | 100.0 |
| 1987 | 3.6 | 37.2 | 26.0 | 31.0 | 0.5 | 1.7 | 100.0 |
| 1988 | 2.8 | 34.3 | 29.0 | 30.7 | 0.6 | 2.7 | 100.0 |
| 1989 | 3.3 | 29.8 | 31.2 | 31.5 | 1.1 | 3.0 | 100.0 |
| 1990 | 5.5 | 26.2 | 30.6 | 32.6 | 0.7 | 4.4 | 100.0 |
| 1991 | 6.6 | 33.1 | 25.5 | 31.0 | 1.3 | 2.4 | 100.0 |
| 1992 | 13.2 | 39.0 | 20.3 | 25.0 | 0.1 | 2.4 | 100.0 |
| 1993 | 17.7 | 39.3 | 18.5 | 21.6 | 0.0 | 2.9 | 100.0 |
| 1994 | 19.3 | 43.7 | 16.0 | 16.8 | 0.0 | 4.1 | 100.0 |
| 1995 | 26.0 | 46.6 | 11.9 | 13.0 | 0.0 | 2.5 | 100.0 |
| 1996 | 27.4 | 53.1 | 9.9 | 8.0 | 0.0 | 1.7 | 100.0 |
| 1997 | 18.2 | 63.7 | 10.5 | 6.1 | 0.0 | 1.4 | 100.0 |
| 1998 | 13.2 | 72.1 | 9.4 | 4.6 | 0.0 | 0.7 | 100.0 |

Table A4. Data pool procedures used to apply age and length frequency samples to landings by market category and quarter to estimate landings (numbers) at age of witch flounder, 1982-1998.

| Year | Mkt. Cat. | Quarter 1 | Quarter 2 | Quarter 3 | Quarter 4 |
|---|---|---|---|---|---|
| 1982 | Small | <=Pooled => | | X | X |
| | Med. | X | X | X | X |
| | Large | X | X | X | X |
| 1983 | Small | X | X | X | X |
| | Med. | <=Pooled => | | X | X |
| | Large | X | X | <=Pooled => | |
| 1984 | Small | X | X | X | X |
| | Med. | <=Pooled => | | <=Pooled => | |
| | Large | X | X | <=Pooled => | |
| 1985 | Small | X | X | X | X |
| | Med. | X | X | X | X |
| | Large | X | X | X | X |
| 1986 | Small | X | X | X | X |
| | Med. | X | X | X | X |
| | Large | X | X | X | X |
| 1987 | Small | <=Pooled => | | X | X |
| | Med. | <=Pooled => | | X | X |
| | Large | X | X | X | X |
| 1988 | Small | X | X | X | X |
| | Med. | X | X | X | X |
| | Large | X | X | X | X |
| 1989 | Small | <= Pooled => | | <=Pooled => | |
| | Med. | X | X | X | X |
| | Large | <=== Pooled ===> | | | |
| 1990 | Small | <= Pooled => | | X | X |
| | Med. | X | X | X | X |
| | Large | <=Pooled => | | <=Pooled => | |
| 1991 | Small | X | X | X | X |
| | Med. | X | X | X | X |
| | Large | <=Pooled => | | X | X |
| 1992 | Small | X | X | X | X |
| | Med. | <===Pooled ===> | | | |
| | Large | X | X | <=Pooled => | |
| 1993 | Small | X | X | <=Pooled => | |
| | Med. | <===Pooled ===> | | | |
| | Large | <===Pooled ===> | | | |
| 1994 | Small | <=Pooled => | | X | X |
| | Med. | <=Pooled => | | X | X |
| | Large | <=Pooled => | | <=Pooled => | |
| 1995 | Small | X | <== Pooled ==> | | |
| | Med. | X | <==Pooled ==> | | |
| | Large | X | <==Pooled ==> | | |
| 1996 | Small | X | X | X | X |
| | Med. | <=Pooled => | | X | X |
| | Large | <=Pooled => | | X | X |
| 1997 | Small | X | X | X | X |
| | Med. | X | X | <=Pooled => | |
| | Large | X | X | <=Pooled => | |
| 1998 | Small | X | X | <=Pooled => | |
| | Med. | <=Pooled => | | <=Pooled => | |
| | Large | <===Pooled ===> | | | |

Table A5. USA commercial landings at age in numbers, weight (thousands of fish; mt) and mean weight (kg) and mean length 9cm) at age of witch flounder, 1982-1998.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USA Commercial Landings in Numbers (1000's) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 0.00 | 117.90 | 826.60 | 1119.9 | 1454.3 | 665.20 | 656.00 | 399.50 | 239.40 | 201.00 | 356.30 | 183.70 | 837.40 | 7057.2 | 1578.4 |
| 1983 | 0.00 | 0.00 | 0.00 | 219.80 | 768.60 | 1033.7 | 1567.3 | 1590.2 | 977.80 | 737.70 | 510.40 | 366.00 | 287.30 | 289.10 | 733.10 | 9081.0 | 1675.5 |
| 1984 | 0.00 | 0.00 | 0.00 | 90.60 | 1012.4 | 1808.7 | 1734.3 | 1486.5 | 1497.5 | 696.70 | 375.10 | 279.50 | 356.40 | 261.30 | 821.60 | 10420. | 1718.8 |
| 1985 | 0.00 | 0.00 | 0.00 | 0.00 | 985.10 | 2026.8 | 1933.8 | 1524.9 | 1247.9 | 606.00 | 400.40 | 261.20 | 221.50 | 170.70 | 705.80 | 10084. | 1359.2 |
| 1986 | 0.00 | 0.00 | 0.00 | 6.30 | 298.50 | 1441.6 | 2772.6 | 1566.9 | 834.90 | 412.70 | 222.80 | 188.20 | 157.00 | 137.00 | 276.00 | 8314.5 | 758.20 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 81.50 | 321.60 | 1276.0 | 1574.7 | 870.90 | 480.60 | 252.40 | 132.40 | 90.80 | 62.10 | 204.10 | 5347.1 | 489.40 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 50.80 | 176.00 | 654.70 | 1382.7 | 1154.1 | 401.50 | 266.70 | 124.10 | 94.00 | 71.90 | 307.50 | 4684.0 | 597.50 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 7.30 | 49.80 | 315.20 | 761.60 | 884.70 | 350.70 | 123.80 | 73.40 | 61.30 | 56.80 | 157.50 | 2842.1 | 349.00 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 183.20 | 579.40 | 257.90 | 276.30 | 475.30 | 336.90 | 82.10 | 43.50 | 38.80 | 19.30 | 77.50 | 2370.2 | 179.10 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 181.70 | 741.70 | 525.70 | 238.60 | 247.50 | 295.60 | 317.30 | 52.40 | 44.50 | 22.80 | 141.10 | 2808.9 | 260.80 |
| 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 513.70 | 846.60 | 943.50 | 723.10 | 203.40 | 179.40 | 121.10 | 219.50 | 46.70 | 26.70 | 87.30 | 3911.0 | 380.20 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 422.80 | 1024.5 | 919.10 | 598.10 | 586.50 | 219.10 | 279.00 | 114.00 | 32.60 | 103.80 | 140.70 | 4440.2 | 391.10 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 201.68 | 1432.1 | 1288.6 | 828.40 | 197.06 | 540.16 | 113.70 | 71.49 | 40.32 | 132.53 | 80.56 | 4926.6 | 324.90 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 23.72 | 764.04 | 1599.6 | 849.85 | 267.81 | 97.35 | 269.86 | 55.03 | 43.94 | 8.15 | 49.94 | 4029.2 | 157.06 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 45.82 | 468.05 | 1264.7 | 1431.5 | 263.42 | 215.63 | 57.09 | 78.87 | 3.57 | 13.02 | 18.23 | 3859.9 | 113.69 |
| 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 212.65 | 529.11 | 1051.8 | 1016.3 | 592.64 | 83.33 | 49.90 | 17.92 | 36.65 | 2.21 | 13.46 | 3605.9 | 70.24 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 18.10 | 488.22 | 1214.1 | 1583.8 | 370.71 | 141.42 | 15.54 | 37.18 | 5.55 | 19.90 | 7.71 | 3902.3 | 70.34 |
| USA Commercial Landings in Weight (mt) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 0.00 | 25.47 | 227.32 | 386.37 | 616.62 | 365.86 | 476.91 | 353.96 | 235.33 | 230.35 | 447.16 | 240.65 | 1300.4 | 4906.4 | 2218.6 |
| 1983 | 0.00 | 0.00 | 0.00 | 42.86 | 197.53 | 332.85 | 642.59 | 823.72 | 599.39 | 586.47 | 498.66 | 408.46 | 347.06 | 381.90 | 1137.0 | 5998.5 | 2274.4 |
| 1984 | 0.00 | 0.00 | 0.00 | 19.21 | 271.32 | 625.81 | 731.87 | 801.22 | 994.34 | 569.20 | 345.84 | 280.62 | 431.96 | 348.05 | 1241.4 | 6660.8 | 2302.0 |
| 1985 | 0.00 | 0.00 | 0.00 | 0.00 | 249.23 | 630.33 | 829.60 | 861.57 | 862.30 | 510.25 | 385.99 | 276.09 | 264.25 | 223.79 | 1037.5 | 6130.9 | 1801.6 |
| 1986 | 0.00 | 0.00 | 0.00 | 0.53 | 67.76 | 441.13 | 1131.2 | 835.16 | 564.39 | 352.03 | 217.23 | 213.04 | 188.24 | 180.43 | 419.80 | 4610.9 | 1001.5 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 22.17 | 109.99 | 553.78 | 883.41 | 597.44 | 397.94 | 247.35 | 141.27 | 110.96 | 86.07 | 299.41 | 3449.7 | 637.71 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 15.75 | 64.59 | 284.79 | 743.89 | 770.94 | 328.83 | 261.37 | 133.28 | 111.86 | 92.75 | 454.18 | 3262.2 | 792.07 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 1.90 | 17.13 | 133.96 | 437.16 | 603.37 | 286.87 | 119.84 | 82.80 | 77.12 | 74.69 | 239.24 | 2074.0 | 473.85 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 56.43 | 187.15 | 112.96 | 161.91 | 327.01 | 286.03 | 86.12 | 52.77 | 48.97 | 29.36 | 129.35 | 1478.0 | 260.43 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 51.97 | 275.17 | 232.89 | 137.91 | 173.74 | 247.12 | 309.05 | 57.59 | 60.92 | 35.04 | 216.73 | 1798.1 | 370.28 |
| 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 168.49 | 324.25 | 433.07 | 443.98 | 150.31 | 147.47 | 106.81 | 228.06 | 62.44 | 38.96 | 143.17 | 2247.0 | 472.63 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 123.46 | 372.92 | 397.05 | 319.98 | 390.61 | 193.25 | 285.42 | 127.45 | 39.09 | 142.00 | 213.72 | 2604.9 | 522.26 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 62.12 | 511.26 | 554.12 | 442.37 | 136.17 | 449.41 | 103.35 | 77.42 | 47.26 | 159.57 | 126.96 | 2670.0 | 411.21 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 6.74 | 280.40 | 716.62 | 476.77 | 184.79 | 88.69 | 262.84 | 60.59 | 52.86 | 11.50 | 70.22 | 2212.0 | 195.16 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 11.91 | 166.16 | 550.16 | 793.06 | 186.50 | 184.58 | 55.61 | 87.86 | 5.00 | 18.75 | 28.40 | 2087.9 | 140.01 |
| 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 67.62 | 188.89 | 428.08 | 503.07 | 372.18 | 72.58 | 51.75 | 20.93 | 43.83 | 3.73 | 22.33 | 1775.0 | 90.82 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 4.25 | 161.60 | 463.81 | 779.26 | 216.87 | 123.18 | 15.20 | 41.46 | 6.28 | 25.09 | 12.00 | 1849.0 | 84.84 |

Table A5. Continued.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **USA Commercial Landings Mean Weight (kg) at Age** | | | | | | | | | | | | | | | | | |
| 1982 | 0.000 | 0.000 | 0.000 | 0.216 | 0.275 | 0.345 | 0.424 | 0.550 | 0.727 | 0.886 | 0.983 | 1.146 | 1.255 | 1.310 | 1.553 | 0.695 | 1.406 |
| 1983 | 0.000 | 0.000 | 0.000 | 0.195 | 0.257 | 0.322 | 0.410 | 0.518 | 0.613 | 0.795 | 0.977 | 1.116 | 1.208 | 1.321 | 1.551 | 0.661 | 1.357 |
| 1984 | 0.000 | 0.000 | 0.000 | 0.212 | 0.268 | 0.346 | 0.422 | 0.539 | 0.664 | 0.817 | 0.922 | 1.004 | 1.212 | 1.332 | 1.511 | 0.639 | 1.339 |
| 1985 | 0.000 | 0.000 | 0.000 | 0.000 | 0.253 | 0.311 | 0.429 | 0.565 | 0.691 | 0.842 | 0.964 | 1.057 | 1.193 | 1.311 | 1.470 | 0.608 | 1.326 |
| 1986 | 0.000 | 0.000 | 0.000 | 0.084 | 0.227 | 0.306 | 0.408 | 0.533 | 0.676 | 0.853 | 0.975 | 1.132 | 1.199 | 1.317 | 1.521 | 0.555 | 1.321 |
| 1987 | 0.000 | 0.000 | 0.000 | 0.000 | 0.272 | 0.342 | 0.434 | 0.561 | 0.686 | 0.828 | 0.980 | 1.067 | 1.222 | 1.386 | 1.467 | 0.645 | 1.303 |
| 1988 | 0.000 | 0.000 | 0.000 | 0.000 | 0.310 | 0.367 | 0.435 | 0.538 | 0.668 | 0.819 | 0.980 | 1.074 | 1.190 | 1.290 | 1.477 | 0.696 | 1.326 |
| 1989 | 0.000 | 0.000 | 0.000 | 0.000 | 0.260 | 0.344 | 0.425 | 0.574 | 0.682 | 0.818 | 0.968 | 1.128 | 1.258 | 1.315 | 1.519 | 0.730 | 1.358 |
| 1990 | 0.000 | 0.000 | 0.000 | 0.000 | 0.308 | 0.323 | 0.438 | 0.586 | 0.688 | 0.849 | 1.049 | 1.213 | 1.262 | 1.521 | 1.669 | 0.624 | 1.454 |
| 1991 | 0.000 | 0.000 | 0.000 | 0.000 | 0.286 | 0.371 | 0.443 | 0.578 | 0.702 | 0.836 | 0.974 | 1.099 | 1.369 | 1.537 | 1.536 | 0.640 | 1.420 |
| 1992 | 0.000 | 0.000 | 0.000 | 0.000 | 0.328 | 0.383 | 0.459 | 0.614 | 0.739 | 0.822 | 0.882 | 1.039 | 1.337 | 1.459 | 1.640 | 0.575 | 1.243 |
| 1993 | 0.000 | 0.000 | 0.000 | 0.000 | 0.292 | 0.364 | 0.432 | 0.535 | 0.666 | 0.882 | 1.023 | 1.118 | 1.199 | 1.368 | 1.519 | 0.587 | 1.335 |
| 1994 | 0.000 | 0.000 | 0.000 | 0.000 | 0.308 | 0.357 | 0.430 | 0.534 | 0.691 | 0.832 | 0.909 | 1.083 | 1.172 | 1.204 | 1.576 | 0.542 | 1.266 |
| 1995 | 0.000 | 0.000 | 0.000 | 0.000 | 0.284 | 0.367 | 0.448 | 0.561 | 0.690 | 0.911 | 0.974 | 1.101 | 1.203 | 1.411 | 1.406 | 0.549 | 1.243 |
| 1996 | 0.000 | 0.000 | 0.000 | 0.000 | 0.260 | 0.355 | 0.435 | 0.554 | 0.708 | 0.856 | 0.974 | 1.114 | 1.401 | 1.440 | 1.558 | 0.541 | 1.232 |
| 1997 | 0.000 | 0.000 | 0.000 | 0.000 | 0.318 | 0.357 | 0.407 | 0.495 | 0.628 | 0.871 | 1.037 | 1.168 | 1.196 | 1.687 | 1.659 | 0.492 | 1.293 |
| 1998 | 0.000 | 0.000 | 0.000 | 0.000 | 0.235 | 0.331 | 0.382 | 0.492 | 0.585 | 0.871 | 0.978 | 1.115 | 1.132 | 1.261 | 1.557 | 0.474 | 1.206 |
| **USA Commercial Landings Mean Length (cm) at Age** | | | | | | | | | | | | | | | | | |
| 1982 | 0.0 | 0.0 | 0.0 | 32.3 | 35.0 | 37.5 | 39.8 | 42.9 | 46.5 | 49.3 | 50.9 | 53.2 | 54.6 | 55.2 | 58.0 | 44.3 | 56.3 |
| 1983 | 0.0 | 0.0 | 0.0 | 31.7 | 34.3 | 36.8 | 39.4 | 42.2 | 44.2 | 47.7 | 50.7 | 52.8 | 54.0 | 56.6 | 55.8 | 35.9 | 55.0 |
| 1984 | 0.0 | 0.0 | 0.0 | 32.6 | 34.9 | 37.6 | 39.8 | 42.7 | 45.3 | 48.2 | 49.9 | 51.2 | 54.1 | 55.6 | 57.6 | 43.6 | 55.5 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.0 | 34.2 | 36.3 | 40.0 | 43.3 | 45.9 | 48.6 | 50.6 | 51.9 | 53.8 | 55.3 | 57.1 | 42.9 | 55.3 |
| 1986 | 0.0 | 0.0 | 0.0 | 25.0 | 33.2 | 36.2 | 39.4 | 42.5 | 45.6 | 48.8 | 50.7 | 53.0 | 53.9 | 55.4 | 57.7 | 42.0 | 55.3 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.0 | 35.0 | 37.4 | 40.1 | 43.2 | 45.8 | 48.4 | 50.8 | 52.1 | 54.2 | 56.2 | 57.1 | 44.3 | 55.1 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.0 | 36.4 | 38.2 | 40.1 | 42.7 | 45.4 | 48.2 | 50.8 | 52.1 | 53.7 | 55.0 | 57.1 | 45.3 | 55.3 |
| 1989 | 0.0 | 0.0 | 0.0 | 0.0 | 34.6 | 37.5 | 39.8 | 43.5 | 45.6 | 48.1 | 50.6 | 52.9 | 54.6 | 55.3 | 57.6 | 46.0 | 55.7 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.0 | 36.2 | 36.8 | 40.2 | 43.7 | 45.8 | 48.7 | 51.8 | 54.1 | 54.6 | 57.8 | 59.2 | 43.5 | 56.8 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.0 | 35.4 | 38.3 | 40.3 | 43.3 | 46.1 | 48.5 | 50.6 | 52.5 | 56.0 | 57.8 | 57.8 | 43.8 | 56.5 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.0 | 37.0 | 38.6 | 40.7 | 44.3 | 46.8 | 48.3 | 49.2 | 51.7 | 55.5 | 57.0 | 58.9 | 42.7 | 54.2 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.0 | 35.8 | 38.1 | 40.0 | 42.6 | 45.3 | 49.3 | 51.5 | 52.8 | 53.9 | 55.9 | 57.7 | 42.8 | 55.5 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.0 | 36.0 | 37.6 | 39.7 | 42.3 | 45.6 | 48.0 | 49.1 | 51.8 | 53.0 | 53.4 | 57.8 | 41.7 | 54.1 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.0 | 35.3 | 37.9 | 40.2 | 42.8 | 45.4 | 49.3 | 50.1 | 52.0 | 53.4 | 56.0 | 55.8 | 42.0 | 53.8 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.0 | 34.4 | 37.5 | 39.8 | 42.7 | 45.8 | 48.4 | 50.1 | 52.2 | 55.8 | 56.2 | 57.6 | 42.0 | 53.6 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.0 | 36.4 | 37.6 | 39.1 | 41.3 | 44.2 | 48.5 | 51.1 | 52.9 | 53.3 | 59.0 | 58.7 | 40.8 | 54.4 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.0 | 33.4 | 36.8 | 38.4 | 41.2 | 43.3 | 48.7 | 50.5 | 52.3 | 52.7 | 54.1 | 57.6 | 40.5 | 53.4 |

Table A6. Summary of the Domestic Sea Sampling Program trips which caught witch founder in the Gulf of Maine - Georges Bank region and the availability of Length samples (number measured fish) of kept (K) and discarded (D) witch flounder, by year, gear, and quarter (Q), 1989-1998.

| | | Shrimp Trawl | | | | | Sink Gillnet | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | Q1 | Q2 | Q3 | Q4 | | Q1 | Q2 | Q3 | Q4 | Total |
| 1989 | Trips | 6 | 12 | . | 4 | 22 | . | . | 8 | 7 | 15 |
| | Lengths (K) | 8 | . | . | . | 8 | . | . | 83 | 3 | 86 |
| | Lengths (D) | 362 | 491 | . | . | 853 | . | . | . | . | . |
| 1990 | Trips | 13 | 4 | . | 4 | 21 | . | 27 | 6 | 5 | 38 |
| | Lengths (K) | . | . | . | . | . | . | 102 | 95 | . | 197 |
| | Lengths (D) | 37 | 134 | . | . | 171 | . | 20 | . | . | 20 |
| 1991 | Trips | 21 | 9 | . | 5 | 35 | . | 68 | 134 | 32 | 234 |
| | Lengths (K) | . | . | . | . | . | . | 463 | 714 | . | 1177 |
| | Lengths (D) | 326 | 971 | . | 286 | 1583 | . | 2 | . | . | 2 |
| 1992 | Trips | 49 | 4 | . | 6 | 59 | 7 | 94 | 60 | 31 | 192 |
| | Lengths (K) | . | . | . | . | . | . | 122 | 56 | 15 | 193 |
| | Lengths (D) | 310 | 55 | . | 231 | 596 | . | 6 | . | . | 6 |
| 1993 | Trips | 37 | 1 | . | 3 | 41 | 5 | 65 | 28 | 36 | 134 |
| | Lengths (K) | 1 | . | . | . | 1 | 1 | 8 | 4 | 18 | 31 |
| | Lengths (D) | 998 | 23 | . | 85 | 1106 | . | 4 | . | 4 | 8 |
| 1994 | Trips | 50 | 2 | . | 5 | 57 | 3 | 5 | 7 | 3 | 18 |
| | Lengths (K) | . | . | . | . | . | 2 | 40 | 28 | 6 | 76 |
| | Lengths (D) | 1060 | 5 | . | 1139 | 2204 | . | . | 17 | 1 | 18 |
| 1995 | Trips | 45 | 6 | . | 8 | 59 | . | 7 | 15 | 3 | 25 |
| | Lengths (K) | . | . | . | . | . | . | 170 | 309 | 2 | 481 |
| | Lengths (D) | 1540 | 513 | . | 399 | 2452 | . | . | 9 | . | 9 |
| 1996 | Trips | 11 | 8 | . | 5 | 24 | 3 | 12 | 6 | 1 | 22 |
| | Lengths (K) | . | . | . | . | . | 5 | 149 | 16 | . | 170 |
| | Lengths (D) | 191 | 733 | . | 172 | 1096 | 1 | 3 | 1 | . | 5 |
| 1997 | Trips | 10 | . | . | . | 10 | 1 | 8 | 5 | 1 | 15 |
| | Lengths (K) | . | . | . | . | . | . | 170 | 3 | . | 173 |
| | Lengths (D) | 268 | . | . | . | 268 | . | . | . | . | . |
| 1998 | Trips | . | . | . | . | . | . | 11 | 4 | 1 | 16 |
| | Lengths (K) | . | . | . | . | . | . | . | 11 | 4 | 5 |
| | Lengths (D) | . | . | . | . | . | . | . | . | . | . |

Table A6. Continued.

| Year | | Large-Mesh Otter Trawl | | | | | Small-Mesh Otter Trawl | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q1 | Q2 | Q3 | Q4 | | Q1 | Q2 | Q3 | Q4 | Total |
| 1989 | Trips | 3 | 18 | 25 | 6 | 52 | 1 | 2 | 12 | 2 | 17 |
| | Lengths (K) | 387 | 218 | 153 | 139 | 897 | . | | | | |
| | Lengths (D) | 6 | 62 | 319 | 92 | 479 | . | 53 | | | 53 |
| 1990 | Trips | 3 | 8 | 9 | 8 | 28 | . | 1 | 2 | 3 | 6 |
| | Lengths (K) | 184 | 12 | 39 | | 235 | . | | | | |
| | Lengths (D) | 20 | | 10 | | 30 | . | | 29 | | 29 |
| 1991 | Trips | 8 | 10 | 18 | 17 | 53 | 1 | 3 | 1 | 4 | 9 |
| | Lengths (K) | 21 | | 56 | 116 | 193 | . | | | | |
| | Lengths (D) | 15 | | 97 | 51 | 163 | . | | | | |
| 1992 | Trips | 23 | 10 | 4 | 5 | 42 | 4 | 1 | 3 | 3 | 11 |
| | Lengths (K) | 62 | 42 | | | 104 | . | | | | |
| | Lengths (D) | 31 | | | | 31 | 33 | | | | 33 |
| 1993 | Trips | 6 | 8 | 7 | 4 | 25 | 1 | | | | 1 |
| | Lengths (K) | 96 | 220 | 104 | 447 | 867 | . | | | | |
| | Lengths (D) | 166 | 262 | 161 | 68 | 657 | 1 | | | | 1 |
| 1994 | Trips | 10 | 6 | 3 | 2 | 21 | . | 3 | | 2 | 5 |
| | Lengths (K) | 529 | | | 172 | 701 | . | | | 45 | 45 |
| | Lengths (D) | 39 | 25 | 102 | 23 | 189 | . | | | 4 | 4 |
| 1995 | Trips | 24 | 11 | 5 | 6 | 46 | 4 | | 16 | 13 | 33 |
| | Lengths (K) | 2267 | 1229 | 210 | 573 | 4279 | 131 | | 308 | | 439 |
| | Lengths (D) | 1101 | 632 | 275 | 298 | 2306 | 694 | | 342 | 451 | 1487 |
| 1996 | Trips | 7 | 11 | | 1 | 19 | 2 | 2 | 26 | 18 | 48 |
| | Lengths (K) | 1211 | 286 | | | 1497 | . | | | 18 | 18 |
| | Lengths (D) | 194 | 90 | | 75 | 359 | . | 173 | 946 | 2739 | 3858 |
| 1997 | Trips | 9 | 1 | 4 | 3 | 17 | 4 | | | | 4 |
| | Lengths (K) | 666 | | 44 | | 710 | 6 | | | | 6 |
| | Lengths (D) | 537 | 56 | 62 | 15 | 670 | 107 | | | | 107 |
| 1998 | Trips | 4 | 4 | 2 | | 10 | . | | | | |
| | Lengths (K) | 186 | | | | 186 | . | | | | |
| | Lengths (D) | 71 | 129 | 3 | . | 203 | . | . | . | . | . |

Table A7. Results 9p-values) of Kruskal-Wallis non-parametric one-way analysis of variance tests of fishing zone discard rates (kg-days fished) from sea sampled trips conducted by the NEFSC Domestic Sea Sampling Program, 1989-1997.

| Year | Zone 1 vs Zone 2 | Zone 2 vs Zone 3 | Zone 1 vs Zone 3 |
|---|---|---|---|
| 1989 | 0.2923 | 0.0014 | 0.0099 |
| 1990 | 0.0558 | 0.1387 | 0.0170 |
| 1991 | 0.0623 | 0.0010 | 0.0001 |
| 1992 | 0.5002 | 0.7441 | 0.6044 |
| 1993 | 0.0075 | 0.0413 | 0.0005 |
| 1994 | 0.8274 | 0.0134 | 0.0020 |
| 1995 | 0.0061 | 0.0263 | 0.0001 |
| 1996 | 0.0495 | 0.0005 | 0.0003 |
| 1997 | 0.1002 | 0.4659 | 0.1573 |

Table A8. Estimated discard rates (kg/day fished) by fishing zone[1] obtained from a ratio estimator (kg of witch flounder discarded to days fished) using Domestic Sea Sampling Program data collected from the northern shrimp fishery, number of days fished by the shrimp fishery, mean discard rates (kg/df) and estimated discard weight (kg) of witch flounder in the northern shrimp fishery, during the 1989-1997 shrimp season.

| | | Sea Sample Data | | | | | |
|---|---|---|---|---|---|---|---|
| Shrimp Season | Fishing Zone | Trips | Discard Rate (kg/df) | Commercial days fished | Mean discard rate | Estimated discard weight (kg) | Estimated discard weight (mt) |
| 1989 | 1 | 5 | 0.0000 | 398.2 | | | |
| | 2 | 15 | 2.2032 | 1680.2 | | | |
| | 3 | 16 | 17.7543 | 761.1 | | | |
| | | | | 2839.5 | 6.0626 | 17,215 | 17.2 |
| 1990 | 1 | 4 | 0.0000 | 416.9 | | | |
| | 2 | 23 | 7.0751 | 1610.9 | | | |
| | 3 | 20 | 14.1459 | 1176.8 | | | |
| | | | | 3204.6 | 8.7512 | 28,044 | 28.0 |
| 1991 | 1 | 13 | 0.9770 | 528.0 | | | |
| | 2 | 25 | 4.4822 | 1154.8 | | | |
| | 3 | 24 | 29.9863 | 904.9 | | | |
| | | | | 2587.7 | 12.6856 | 32,827 | 32.8 |
| 1992 | 1 | 30 | 2.7834 | 187.3 | | | |
| | 2 | 60 | 8.9270 | 1764.1 | | | |
| | 3 | 20 | 7.6787 | 361.9 | | | |
| | | | | 2313.3 | 8.2343 | 19,048 | 19.0 |
| 1993 | 1 | 38 | 1.3559 | 526.9 | | | |
| | 2 | 53 | 3.7619 | 1094.2 | | | |
| | 3 | 13 | 12.9178 | 281.1 | | | |
| | | | | 1902.2 | 4.4485 | 8,462 | 8.5 |
| 1994* | 1 | 37 | 3.3021 | 498.7 | | | |
| | 2 | 56 | 5.8385 | 1334 | | | |
| | 3 | 5 | 11.1394 | 149.6 | | | |
| | | | | 1982.3 | 5.6004 | 11,102 | 11.1 |
| 1995* | 1 | 24 | 2.0007 | 2036.2 | | | |
| | 2 | 46 | 27.5162 | 1109 | | | |
| | 3 | 18 | 11.7543 | 230.5 | | | |
| | | | | 3375.7 | 11.0492 | 37,299 | 37.3 |
| 1996* | 1 | 8 | 0.3532 | 2079.4 | | | |
| | 2 | 31 | 7.6343 | 958.2 | | | |
| | 3 | 11 | 28.919 | 205.3 | | | |
| | | | | 3242.9 | 4.3130 | 13,987 | 14.0 |
| 1997* | 1 | 6 | 0.4065 | 1996.1 | | | |
| | 2 | 19 | 2.9403 | 1191.8 | | | |
| | 3 | 3 | 16.3461 | 473.2 | | | |
| | | | | 3661.1 | 3.2915 | 12,051 | 12.1 |

[1] Fishing zones: 1 = 0-3 miles; 2 = 3 - 12 miles, and 3 = greater than 12 miles from shore.
* Commercial days fished have been estimated from Vessel Trip Report data.

Table A9. Days fished for January-May and December, weight discarded (mt), and numbers ('000s) of witch flounder discarded in the Gulf of Maine northern shrimp fishery for the calendar year, 1982-1998. Calendar year discard weight and numbers at age were derived by partitioning the shrimp discard weight and numbers at age by the proportion of days fished for December and January-May categories.

| | Calendar Year | | | |
|---|---|---|---|---|
| | Days fished[i] | | Estimated Discard Weight (mt) | Estimated Discard Numbers of fish('000s) |
| | January - | December | | |
| 1982 | 970.1 | 35.6 | 5.93 | 62.14 |
| 1983 | 1121.3 | 141.7 | 12.56 | 131.67 |
| 1984 | 1612.3 | 237.6 | 10.97 | 110.94 |
| 1985 | 1843.8 | 272.8 | 12.12 | 91.32 |
| 1986 | 2122.3 | 428.9 | 13.11 | 98.80 |
| 1987 | 3279.3 | 380.4 | 21.75 | 235.99 |
| 1988 | 2434.8 | 426.9 | 33.95 | 723.95 |
| 1989 | 2412.6 | 491.9 | 18.93 | 219.81 |
| 1990 | 2712.7 | 377.6 | 28.54 | 468.56 |
| 1991 | 2210.1 | 172.3 | 29.44 | 443.85 |
| 1992 | 2141.0 | 113.2 | 18.14 | 384.45 |
| 1993 | 1789.0 | 161.7 | 8.77 | 356.77 |
| 1994 | 1820.6 | 530.8 | 16.11 | 1891.71 |
| 1995 | 2844.9 | 547.6 | 33.81 | 1176.37 |
| 1996 | 2695.3 | 645.2 | 13.75 | 250.46 |
| 1997 | 3016.0 | 361.4 | 13.31 | 304.52 |
| 1998 | 1833.9 | 48.7 | 17.12 | 389.10 |

[i] 1994-1998 days fished estimated from NMFS weighout and Vessel Trip Reports.

Table A10. Shrimp fishery discards at age in numbers, weight (thousands of fish; mt) and mean weight (kg) and mean length (cm) at age of witch flounder, 1982-1998.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shrimp Fishery Discards in Numbers (1000's) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 1.59 | 25.24 | 21.12 | 11.27 | 2.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 62.14 | 0.00 |
| 1983 | 0.00 | 0.00 | 3.62 | 53.11 | 44.65 | 23.81 | 6.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 131.67 | 0.00 |
| 1984 | 0.00 | 0.33 | 0.77 | 46.84 | 38.55 | 19.41 | 5.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 110.94 | 0.00 |
| 1985 | 0.00 | 0.34 | 3.37 | 11.72 | 47.06 | 26.39 | 2.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 91.32 | 0.00 |
| 1986 | 0.00 | 0.53 | 3.86 | 15.07 | 49.83 | 27.04 | 2.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 98.80 | 0.00 |
| 1987 | 2.08 | 18.92 | 79.51 | 15.62 | 74.59 | 41.46 | 3.81 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 235.99 | 0.00 |
| 1988 | 0.42 | 14.62 | 130.29 | 495.50 | 42.57 | 37.70 | 2.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 723.95 | 0.00 |
| 1989 | 0.74 | 10.47 | 47.52 | 69.23 | 76.39 | 15.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 219.81 | 0.00 |
| 1990 | 1.19 | 5.18 | 92.78 | 239.97 | 97.13 | 32.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 468.56 | 0.00 |
| 1991 | 2.96 | 17.79 | 15.98 | 287.35 | 102.86 | 11.59 | 5.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 443.85 | 0.00 |
| 1992 | 2.71 | 43.41 | 136.92 | 118.76 | 82.06 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 384.45 | 0.00 |
| 1993 | 112.06 | 78.84 | 107.58 | 38.69 | 14.13 | 5.02 | 0.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 356.77 | 0.00 |
| 1994 | 8.06 | 1368.4 | 495.50 | 19.62 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1891.7 | 0.00 |
| 1995 | 2.68 | 49.95 | 630.10 | 480.83 | 12.25 | 0.20 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1176.3 | 0.00 |
| 1996 | 5.21 | 32.68 | 50.83 | 99.45 | 59.21 | 2.09 | 0.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 250.46 | 0.00 |
| 1997 | 8.68 | 74.91 | 102.92 | 86.49 | 23.71 | 7.30 | 0.52 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 304.52 | 0.00 |
| 1998 | 0.00 | 44.07 | 256.67 | 59.77 | 21.04 | 6.56 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 389.10 | 0.00 |
| Shrimp Fishery Discards in Weight (mt) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 0.06 | 1.09 | 2.13 | 1.86 | 0.74 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.93 | 0.00 |
| 1983 | 0.00 | 0.00 | 0.15 | 2.31 | 4.50 | 3.94 | 1.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.56 | 0.00 |
| 1984 | 0.00 | 0.01 | 0.03 | 2.33 | 4.06 | 3.20 | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.97 | 0.00 |
| 1985 | 0.00 | 0.01 | 0.08 | 0.94 | 5.80 | 4.73 | 0.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.12 | 0.00 |
| 1986 | 0.00 | 0.01 | 0.10 | 1.34 | 6.24 | 4.86 | 0.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.11 | 0.00 |
| 1987 | 0.01 | 0.29 | 2.63 | 1.11 | 9.37 | 7.45 | 0.88 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 21.75 | 0.00 |
| 1988 | 0.00 | 0.09 | 2.22 | 17.87 | 5.14 | 7.77 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 33.95 | 0.00 |
| 1989 | 0.01 | 0.12 | 1.58 | 4.04 | 9.34 | 3.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.93 | 0.00 |
| 1990 | 0.01 | 0.05 | 2.72 | 10.31 | 10.44 | 5.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 28.54 | 0.00 |
| 1991 | 0.01 | 0.25 | 0.47 | 12.97 | 12.04 | 2.56 | 1.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 29.44 | 0.00 |
| 1992 | 0.01 | 0.28 | 2.84 | 5.07 | 9.79 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.14 | 0.00 |
| 1993 | 0.32 | 0.67 | 2.41 | 2.19 | 1.93 | 1.19 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.77 | 0.00 |
| 1994 | 0.04 | 6.16 | 9.24 | 0.62 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.11 | 0.00 |
| 1995 | 0.01 | 0.37 | 14.52 | 17.74 | 1.02 | 0.06 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 33.81 | 0.00 |
| 1996 | 0.02 | 0.62 | 1.57 | 5.54 | 5.32 | 0.38 | 0.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.74 | 0.00 |
| 1997 | 0.03 | 1.76 | 3.43 | 4.17 | 2.72 | 1.05 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.31 | 0.00 |
| 1998 | 0.00 | 0.18 | 8.47 | 4.30 | 2.80 | 1.04 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.12 | 0.00 |

Table A10. Continued.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **Shrimp Fishery Discards Mean Weight (kg) at Age** | | | | | | | | | | |
| 1982 | - | - | 0.040 | 0.043 | 0.101 | 0.165 | 0.256 | - | - | - | - | - | - | - | - | 0.095 | |
| 1983 | - | - | 0.040 | 0.044 | 0.101 | 0.166 | 0.256 | - | - | - | - | | - | - | - | 0.095 | - |
| 1984 | - | 0.017 | 0.044 | 0.050 | 0.105 | 0.165 | 0.256 | - | - | - | - | | - | - | - | 0.099 | |
| 1985 | - | 0.017 | 0.023 | 0.081 | 0.123 | 0.179 | 0.231 | - | - | - | - | - | - | - | - | 0.133 | |
| 1986 | - | 0.017 | 0.026 | 0.089 | 0.125 | 0.180 | 0.231 | - | - | - | - | - | -- | -- | - | 0.133 | - |
| 1987 | 0.006 | 0.015 | 0.033 | 0.071 | 0.126 | 0.180 | 0.231 | - | - | - | - | - | -- | -- | - | 0.092 | - |
| 1988 | 0.004 | 0.006 | 0.017 | 0.036 | 0.121 | 0.206 | 0.282 | - | - | - | - | - | -- | -- | - | 0.047 | - |
| 1989 | 0.010 | 0.012 | 0.033 | 0.058 | 0.122 | 0.249 | - | - | - | - | - | - | -- | -- | - | 0.086 | - |
| 1990 | 0.004 | 0.010 | 0.029 | 0.043 | 0.107 | 0.155 | - | - | - | - | - | - | -- | -- | - | 0.061 | - |
| 1991 | 0.004 | 0.014 | 0.030 | 0.045 | 0.117 | 0.221 | 0.218 | - | - | - | - | - | -- | -- | - | 0.066 | - |
| 1992 | 0.003 | 0.007 | 0.021 | 0.043 | 0.119 | 0.225 | - | - | - | - | - | - | -- | -- | - | 0.047 | - |
| 1993 | 0.003 | 0.009 | 0.022 | 0.057 | 0.136 | 0.237 | 0.317 | - | - | - | - | - | -- | -- | - | 0.025 | - |
| 1994 | 0.005 | 0.004 | 0.019 | 0.032 | - | 0.282 | - | - | - | - | - | - | -- | -- | - | 0.009 | - |
| 1995 | 0.005 | 0.007 | 0.023 | 0.037 | 0.083 | 0.289 | 0.282 | - | - | - | - | - | -- | -- | - | 0.029 | - |
| 1996 | 0.004 | 0.019 | 0.031 | 0.056 | 0.090 | 0.184 | 0.289 | - | - | - | - | - | -- | -- | - | 0.055 | - |
| 1997 | 0.004 | 0.023 | 0.033 | 0.048 | 0.115 | 0.144 | 0.256 | - | - | - | - | - | -- | -- | - | 0.044 | - |
| 1998 | - | 0.004 | 0.033 | 0.072 | 0.133 | 0.158 | 0.220 | - | - | - | - | - | - | -- | - | 0.044 | - |
| | | | | | | | | | | | | | | - | - | | - |
| | | | | | | | **Shrimp Fishery Discards Mean Length (cm) at Age** | | | | | | | | | | |
| 1982 | - | - | 20.3 | 20.6 | 26.5 | 30.7 | 34.9 | - | - | - | - | - | - | - | - | 25.1 | - |
| 1983 | - | - | 20.3 | 20.6 | 26.5 | 30.7 | 34.9 | - | - | - | - | - | - | - | - | 25.1 | - |
| 1984 | - | 15.7 | 20.7 | 21.2 | 26.7 | 30.7 | 34.9 | - | - | - | - | - | - | - | - | 25.4 | - |
| 1985 | - | 15.7 | 16.9 | 24.2 | 28.1 | 31.4 | 33.9 | - | - | - | - | - | - | - | - | 28.3 | - |
| 1986 | - | 15.7 | 17.3 | 24.9 | 28.2 | 31.4 | 33.9 | - | - | - | - | - | - | - | - | 28.2 | - |
| 1987 | 10.6 | 15.3 | 19.0 | 23.4 | 28.2 | 31.4 | 33.9 | - | - | - | - | - | - | - | - | 24.3 | - |
| 1988 | 10.2 | 10.9 | 15.6 | 19.4 | 27.9 | 32.8 | 36.0 | - | - | - | - | - | - | - | - | 19.8 | - |
| 1989 | 13.6 | 13.9 | 18.9 | 22.2 | 28.1 | 34.6 | - | - | - | - | - | - | - | - | - | 24.0 | - |
| 1990 | 10.5 | 13.6 | 17.9 | 20.4 | 27.0 | 30.2 | - | - | - | - | - | - | - | - | - | 21.9 | - |
| 1991 | 9.7 | 14.2 | 17.7 | 20.9 | 27.6 | 33.6 | 33.4 | - | - | - | - | - | - | - | - | 22.5 | - |
| 1992 | 9.3 | 10.8 | 16.6 | 20.5 | 27.9 | 33.7 | - | - | - | - | - | - | - | - | - | 19.5 | - |
| 1993 | 9.2 | 12.0 | 16.9 | 22.1 | 28.9 | 34.2 | 37.3 | - | - | - | - | - | - | - | - | 14.7 | - |
| 1994 | 10.7 | 9.8 | 15.9 | 18.5 | - | 36.0 | - | - | - | - | - | - | - | - | - | 11.5 | - |
| 1995 | 10.9 | 11.6 | 17.0 | 19.6 | 24.9 | 36.2 | 36.0 | - | - | - | - | - | - | - | - | 18.0 | - |
| 1996 | 10.0 | 15.3 | 18.4 | 22.1 | 25.6 | 31.7 | 36.2 | - | - | - | - | - | - | - | - | 21.2 | - |
| 1997 | 10.2 | 16.1 | 18.9 | 21.2 | 27.6 | 29.5 | 35.0 | - | - | - | - | - | - | - | - | 19.6 | - |
| 1998 | - | 10.2 | 19.0 | 23.9 | 28.9 | 30.3 | 33.4 | - | - | - | - | - | - | - | - | 19.6 | |

Table A11. Spreadsheet calculations for estimating semi-annual discarded witch flounder in the large-mesh otter trawl fishery. This spreadsheet illustrates 1993, quarters 1 and 2 with the NEFSC spring survey. The **bold numbers** indicate columns and the mathematical operation performed.

| 1993 Landings from Q1+Q2 and 1993 spring survey | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3=1*2** | **4** | **5=3*4** | **6=3-5** | **7** | **8=6*factor** |
| | | 140 mm | | | | | 100's | units |
| Length (cm) | Survey No/tow | Prop. Retained | Survey Retained | Prop Kept | Survey Kept | Survey Discarded | Numbers Landed | Numbers Discarded |
| 1 | 0.000 | 0.00005 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 0 |
| 3 | 0.000 | 0.00008 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 0 |
| 5 | 0.034 | 0.00015 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 34 |
| 7 | 0.064 | 0.00028 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 120 |
| 9 | 0.051 | 0.00051 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 174 |
| 11 | 0.000 | 0.00092 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 0 |
| 13 | 0.000 | 0.00168 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 0 |
| 15 | 0.011 | 0.00305 | 0.0000 | 0.00 | 0.0000 | 0.0000 | 0 | 224 |
| 17 | 0.067 | 0.00554 | 0.0004 | 0.00 | 0.0000 | 0.0004 | 0 | 2483 |
| 19 | 0.042 | 0.01005 | 0.0004 | 0.00 | 0.0000 | 0.0004 | 0 | 2823 |
| 21 | 0.028 | 0.01816 | 0.0005 | 0.00 | 0.0000 | 0.0005 | 0 | 3401 |
| 23 | 0.042 | 0.03261 | 0.0014 | 0.00 | 0.0000 | 0.0014 | 0 | 9161 |
| 25 | 0.061 | 0.05787 | 0.0035 | 0.00 | 0.0000 | 0.0035 | 0 | 23612 |
| 27 | 0.165 | 0.10065 | 0.0166 | 0.00 | 0.0000 | 0.0166 | 0 | 111083 |
| 29 | 0.079 | 0.16938 | 0.0134 | 0.00 | 0.0000 | 0.0134 | 0 | 89503 |
| 31 | 0.205 | 0.27091 | 0.0555 | 0.01 | 0.0006 | 0.0550 | 0 | 367759 |
| 33 | 0.165 | 0.40372 | 0.0666 | 0.10 | 0.0067 | 0.0600 | 231 | 401011 |
| 35 | 0.152 | 0.55231 | 0.0840 | 0.99 | 0.0831 | 0.0008 | 2519 | 5615 |
| 37 | 0.076 | 0.69211 | 0.0526 | 1.00 | 0.0526 | 0.0000 | 4892 | 0 |
| 39 | 0.042 | 0.80377 | 0.0338 | 1.00 | 0.0338 | 0.0000 | 3984 | 0 |
| 41 | 0.050 | 0.88184 | 0.0441 | 1.00 | 0.0441 | 0.0000 | 3143 | 0 |
| 43 | 0.000 | 0.93150 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 1699 | 0 |
| 45 | 0.000 | 0.96121 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 1658 | 0 |
| 47 | 0.000 | 0.97833 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 1293 | 0 |
| 49 | 0.054 | 0.98799 | 0.0534 | 1.00 | 0.0534 | 0.0000 | 1268 | 0 |
| 51 | 0.046 | 0.99337 | 0.0457 | 1.00 | 0.0457 | 0.0000 | 1225 | 0 |
| 53 | 0.000 | 0.99635 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 812 | 0 |
| 55 | 0.018 | 0.99799 | 0.0180 | 1.00 | 0.0180 | 0.0000 | 486 | 0 |
| 57 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 354 | 0 |
| 59 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 198 | 0 |
| 61 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 72 | 0 |
| 63 | 0.019 | 1.0000 | 0.0190 | 1.00 | 0.0190 | 0.0000 | 27 | 0 |
| 65 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 4 | 0 |
| 67 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 0 | 0 |
| 69 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 0 | 0 |
| 71 | 0.000 | 1.0000 | 0.0000 | 1.00 | 0.0000 | 0.0000 | 0 | 0 |
| TOTAL | 1.471 | | 0.5088 | | 0.3568 | 0.1520 | 2,386,500 | 1,017,005 |
| | | | | | | | **Factor = 6,688,621** | |

1: From SURVAN, stratified mean number per tow at length.

2: From LOGEST Program using 140 mm mesh in 1993 from adjusted 130-d mm from Walsh et al. (1992) for Am plaice

4: knife-edge at 36 cm

7: From Length BIOSTAT

Table A12. Estimated number (000's) of witch flounder discarded in the large-mesh otter trawl fishery in the Gulf of Maine-Georges Bank region derived from a ratio estimator of NEFSC index of 'kept' number per tow (spring and autumn) to semi-annual (quarters 1 &2 , and 3 & 4) numbers of fish landed (in thousands of fish), 1982-1998, and percentage (%) of discarded fish to landed fish.

| | SPRING | | | | AUTUMN | | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey | | Landings Q1&Q2 | | Survey | | Landings Q3&Q4 | | | | |
| Year | Kept Index | Discard Index | Numbers Landed | Numbers Discarded | Kept Index | Discard Index | Numbers Landed | Numbers Discarded | Numbers Landed | Numbers Discarded | % |
| 1982 | 2.137 | 0.178 | 3,481 | 290 | 0.832 | 0.017 | 3,305 | 69 | 6,786 | 359 | 5.3 |
| 1983 | 2.928 | 0.341 | 5,246 | 612 | 2.115 | 0.285 | 3,351 | 451 | 8,597 | 1,062 | 12.4 |
| 1984 | 1.852 | 0.103 | 5,703 | 317 | 2.618 | 0.176 | 4,207 | 282 | 9,909 | 599 | 6.1 |
| 1985 | 3.378 | 0.149 | 5,349 | 236 | 2.054 | 0.039 | 4,486 | 85 | 9,835 | 321 | 3.3 |
| 1986 | 1.691 | 0.013 | 4,946 | 37 | 1.248 | 0.018 | 2,806 | 41 | 7,751 | 79 | 1.0 |
| 1987 | 0.785 | 0.035 | 2,874 | 129 | 0.393 | 0.001 | 2,354 | 8 | 5,227 | 136 | 2.6 |
| 1988 | 1.144 | 0.019 | 3,225 | 53 | 0.551 | 0.060 | 1,364 | 150 | 4,589 | 203 | 4.4 |
| 1989 | 0.727 | 0.182 | 1,837 | 461 | 0.281 | 0.083 | 924 | 273 | 2,760 | 734 | 26.6 |
| 1990 | 0.204 | 0.081 | 1,364 | 545 | 0.308 | 0.144 | 889 | 415 | 2,252 | 960 | 43.0 |
| 1991 | 0.615 | 0.050 | 1,178 | 97 | 0.533 | 0.137 | 1,396 | 359 | 2,574 | 455 | 17.7 |
| 1992 | 0.541 | 0.071 | 2,100 | 277 | 0.194 | 0.096 | 1,441 | 711 | 3,541 | 988 | 27.9 |
| 1993 | 0.357 | 0.152 | 2,387 | 1,017 | 0.435 | 0.284 | 1,769 | 1,154 | 4,155 | 2,171 | 52.3 |
| 1994 | 0.591 | 0.401 | 2,571 | 1,744 | 0.582 | 0.111 | 2,152 | 412 | 4,723 | 2,156 | 45.6 |
| 1995 | 0.646 | 0.129 | 2,250 | 449 | 0.641 | 0.326 | 1,674 | 853 | 3,924 | 1,303 | 33.2 |
| 1996 | 0.357 | 0.179 | 1,884 | 946 | 1.095 | 0.849 | 1,915 | 1,486 | 3,799 | 2,432 | 64.0 |
| 1997 | 0.522 | 0.440 | 1,906 | 1,604 | 1.272 | 0.364 | 1,632 | 467 | 3,539 | 2,071 | 58.5 |
| 1998 | 1.132 | 0.505 | 2,371 | 1,057 | 0.509 | 0.227 | 1,490 | 665 | 3,861 | 1,723 | 44.6 |

Table A13. Large-mesh otter trawl discards at age in numbers (thousands of fish), weight (mt) and mean weight (kg) and mean length (cm) at age of witch flounder, 1982-1998.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Large-mesh otter trawl discards in Numbers (1000's) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.03 | 0.06 | 0.13 | 47.35 | 216.75 | 76.50 | 18.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 359.01 | 0.00 |
| 1983 | 0.00 | 0.02 | 0.66 | 64.20 | 532.92 | 463.25 | 1.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1062.39 | 0.00 |
| 1984 | 0.00 | 0.00 | 0.11 | 9.17 | 415.36 | 174.59 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 599.49 | 0.00 |
| 1985 | 0.00 | 0.00 | 0.10 | 111.86 | 143.96 | 65.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 320.94 | 0.00 |
| 1986 | 0.00 | 0.00 | 0.00 | 1.58 | 28.74 | 48.15 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 78.75 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.42 | 6.63 | 25.17 | 104.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 136.47 | 0.00 |
| 1988 | 0.00 | 0.04 | 0.00 | 104.77 | 46.54 | 50.60 | 0.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 202.67 | 0.00 |
| 1989 | 0.11 | 0.22 | 2.80 | 377.82 | 352.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 733.52 | 0.00 |
| 1990 | 0.27 | 1.11 | 2.52 | 103.96 | 355.44 | 496.52 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 959.82 | 0.00 |
| 1991 | 0.10 | 0.11 | 7.28 | 154.42 | 123.36 | 119.27 | 50.68 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 455.22 | 0.00 |
| 1992 | 0.13 | 0.94 | 22.51 | 280.70 | 664.19 | 19.17 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 988.11 | 0.00 |
| 1993 | 1.70 | 6.96 | 22.01 | 378.54 | 1371.0 | 391.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2171.25 | 0.00 |
| 1994 | 0.00 | 0.02 | 0.94 | 22.35 | 800.5 | 1330.4 | 1.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2155.99 | 0.00 |
| 1995 | 0.00 | 0.01 | 5.21 | 160.47 | 581.53 | 432.87 | 122.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1302.62 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.23 | 19.93 | 847.12 | 1508.1 | 56.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2432.13 | 0.00 |
| 1997 | 0.00 | 0.01 | 1.18 | 18.38 | 786.45 | 930.79 | 334.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2071.03 | 0.00 |
| 1998 | 0.00 | 0.01 | 3.33 | 87.69 | 571.15 | 791.18 | 269.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1722.55 | 0.00 |
| Large-mesh otter trawl discards in Weight (mt) at Age | | | | | | | | | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 0.00 | 2.37 | 27.74 | 9.26 | 3.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 42.44 | 0.00 |
| 1983 | 0.00 | 0.00 | 0.02 | 5.20 | 70.35 | 73.19 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 149.04 | 0.00 |
| 1984 | 0.00 | 0.00 | 0.00 | 0.66 | 59.81 | 28.28 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 88.81 | 0.00 |
| 1985 | 0.00 | 0.00 | 0.00 | 14.88 | 23.47 | 10.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 48.75 | 0.00 |
| 1986 | 0.00 | 0.00 | 0.00 | 0.17 | 3.59 | 8.19 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.01 | 0.70 | 3.07 | 21.84 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25.68 | 0.00 |
| 1988 | 0.00 | 0.00 | 0.00 | 9.01 | 7.49 | 9.87 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 26.55 | 0.00 |
| 1989 | 0.00 | 0.00 | 0.12 | 50.63 | 63.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 113.86 | 0.00 |
| 1990 | 0.00 | 0.02 | 0.07 | 10.92 | 51.89 | 92.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 155.75 | 0.00 |
| 1991 | 0.00 | 0.00 | 0.35 | 14.36 | 17.27 | 22.78 | 10.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 65.41 | 0.00 |
| 1992 | 0.00 | 0.01 | 1.28 | 36.21 | 111.58 | 4.10 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 153.31 | 0.00 |
| 1993 | 0.00 | 0.10 | 1.10 | 48.83 | 239.92 | 77.82 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 367.77 | 0.00 |
| 1994 | 0.00 | 0.00 | 0.04 | 2.30 | 140.09 | 263.43 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 406.30 | 0.00 |
| 1995 | 0.00 | 0.00 | 0.36 | 19.26 | 97.70 | 88.31 | 25.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 231.23 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.01 | 1.79 | 130.46 | 295.59 | 12.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 439.88 | 0.00 |
| 1997 | 0.00 | 0.00 | 0.08 | 2.02 | 129.76 | 177.78 | 70.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 379.83 | 0.00 |
| 1998 | 0.00 | 0.00 | 0.18 | 8.86 | 97.10 | 156.65 | 54.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 316.89 | 0.00 |

Table A13. Continued.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Large-mesh otter trawl Discards Mean Weight (kg) at Age | | | | | | | | | | | | |
| 1982 | 0.000 | 0.002 | 0.014 | 0.050 | 0.128 | 0.121 | 0.169 | - | - | - | - | - | - | - | - | 0.118 | - |
| 1983 | - | 0.009 | 0.029 | 0.081 | 0.132 | 0.158 | 0.209 | - | - | - | - | - | - | - | - | 0.140 | - |
| 1984 | - | - | 0.014 | 0.072 | 0.144 | 0.162 | 0.209 | - | - | - | - | - | - | - | - | 0.148 | - |
| 1985 | - | - | 0.031 | 0.133 | 0.163 | 0.160 | - | - | - | - | - | - | - | - | - | 0.152 | - |
| 1986 | 0.000 | - | - | 0.105 | 0.125 | 0.170 | 0.209 | - | - | - | - | - | - | - | - | 0.152 | - |
| 1987 | - | - | 0.014 | 0.105 | 0.122 | 0.210 | 0.256 | - | - | - | - | - | - | - | - | 0.188 | - |
| 1988 | - | 0.002 | - | 0.086 | 0.161 | 0.195 | 0.256 | - | - | - | - | - | - | - | - | 0.131 | - |
| 1989 | 0.001 | 0.013 | 0.044 | 0.134 | 0.179 | - | - | - | - | - | - | - | - | - | - | 0.155 | - |
| 1990 | 0.001 | 0.018 | 0.028 | 0.105 | 0.146 | 0.187 | - | - | - | - | - | - | - | - | - | 0.162 | - |
| 1991 | 0.001 | 0.010 | 0.048 | 0.093 | 0.140 | 0.191 | 0.210 | - | - | - | - | - | - | - | - | 0.144 | - |
| 1992 | 0.001 | 0.015 | 0.057 | 0.129 | 0.168 | 0.214 | 0.256 | - | - | - | - | - | - | - | - | 0.155 | - |
| 1993 | 0.001 | 0.014 | 0.050 | 0.129 | 0.175 | 0.199 | - | - | - | - | - | - | - | - | - | 0.169 | - |
| 1994 | - | 0.026 | 0.044 | 0.103 | 0.175 | 0.198 | 0.256 | - | - | - | - | - | - | - | - | 0.188 | - |
| 1995 | - | 0.020 | 0.070 | 0.120 | 0.168 | 0.204 | 0.209 | - | - | - | - | - | - | - | - | 0.178 | - |
| 1996 | - | 0.014 | 0.050 | 0.090 | 0.154 | 0.196 | 0.212 | - | - | - | - | - | - | - | - | 0.181 | - |
| 1997 | - | 0.020 | 0.065 | 0.110 | 0.165 | 0.191 | 0.210 | - | - | - | - | - | - | - | - | 0.183 | - |
| 1998 | - | 0.021 | 0.054 | 0.101 | 0.170 | 0.198 | 0.201 | - | - | - | - | - | - | - | - | 0.184 | - |
| | | | | | Large-mesh otter trawl Discards Mean Length (cm) at Age | | | | | | | | | | | | |
| 1982 | 5.0 | 7.8 | 15.0 | 21.4 | 28.3 | 28.1 | 31.0 | - | - | - | - | | - | - | - | 27.5 | - |
| 1983 | - | 13.0 | 18.5 | 24.7 | 28.6 | 30.4 | 33.0 | - | - | - | - | | - | - | - | 29.2 | - |
| 1984 | - | - | 15.0 | 23.6 | 29.5 | 30.6 | 33.0 | - | - | - | - | | - | - | - | 29.7 | - |
| 1985 | - | - | 19.0 | 28.8 | 30.7 | 30.5 | - | - | - | - | - | | - | - | - | 30.0 | - |
| 1986 | 5.0 | - | - | 27.0 | 28.3 | 31.1 | 33.0 | - | - | - | - | | - | - | - | 30.0 | - |
| 1987 | - | - | 15.0 | 27.0 | 28.1 | 33.0 | 35.0 | - | - | - | - | | - | - | - | 31.8 | - |
| 1988 | - | 9.0 | - | 25.4 | 30.4 | 32.3 | 35.0 | - | - | - | - | | - | - | - | 28.3 | - |
| 1989 | 5.9 | 14.4 | 20.7 | 28.8 | 31.5 | - | - | - | - | - | - | | - | - | - | 30.1 | - |
| 1990 | 6.1 | 16.0 | 18.1 | 26.8 | 29.6 | 31.8 | - | - | - | - | - | | - | - | - | 30.4 | - |
| 1991 | 5.5 | 12.7 | 21.3 | 25.8 | 29.2 | 32.1 | 33.0 | - | - | - | - | | - | - | - | 29.1 | - |
| 1992 | 5.7 | 15.0 | 22.5 | 28.4 | 30.8 | 33.2 | 35.0 | - | - | - | - | | - | - | - | 30.0 | - |
| 1993 | 5.5 | 14.5 | 21.5 | 28.5 | 31.2 | 32.5 | - | - | - | - | - | | - | - | - | 30.8 | - |
| 1994 | - | 17.9 | 20.7 | 26.5 | 31.2 | 32.4 | 35.0 | - | - | - | - | | - | - | - | 31.9 | - |
| 1995 | - | 16.7 | 23.8 | 27.9 | 30.8 | 32.8 | 33.0 | - | - | - | - | | - | - | - | 31.3 | - |
| 1996 | - | 15.0 | 21.5 | 25.7 | 30.1 | 32.3 | 33.1 | - | - | - | - | | - | - | - | 31.5 | - |
| 1997 | - | 16.6 | 23.3 | 27.2 | 30.7 | 32.1 | 33.0 | - | - | - | - | | - | - | - | 31.7 | - |
| 1998 | - | 16.9 | 22.2 | 26.6 | 31.0 | 32.4 | 32.6 | | | | | | - | - | - | 31.7 | - |

Table A14. Total USA commercial catch in numbers, weight (thousand of fish; mt) and mean weight 9kg) and mean length 9cm) at age of witch flounder, 1982-1998.

| | Age | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
| | | | | | | | | USA Commercial Catch in Numbers (1000's) at Age | | | | | | | | | |
| 1982 | 0.03 | 0.06 | 1.72 | 190.49 | 1064.4 | 1207.6 | 1475.4 | 665.20 | 656.00 | 399.50 | 239.40 | 201.00 | 356.30 | 183.70 | 837.40 | 7478.3 | 1578.4 |
| 1983 | 0.00 | 0.02 | 4.28 | 337.11 | 1346.1 | 1520.7 | 1575.1 | 1590.2 | 977.80 | 737.70 | 510.40 | 366.00 | 287.30 | 289.10 | 733.10 | 10275. | 1675.5 |
| 1984 | 0.00 | 0.33 | 0.88 | 146.61 | 1466.3 | 2002.7 | 1739.5 | 1486.5 | 1497.5 | 696.70 | 375.10 | 279.50 | 356.40 | 261.30 | 821.60 | 11131. | 1718.8 |
| 1985 | 0.00 | 0.34 | 3.47 | 123.58 | 1176.1 | 2118.2 | 1936.2 | 1524.9 | 1247.9 | 606.00 | 400.40 | 261.20 | 221.50 | 170.70 | 705.80 | 10496. | 1359.2 |
| 1986 | 0.00 | 0.53 | 3.86 | 22.95 | 377.07 | 1516.7 | 2775.3 | 1566.9 | 834.90 | 412.70 | 222.80 | 188.20 | 157.00 | 137.00 | 276.00 | 8492.0 | 758.20 |
| 1987 | 2.08 | 18.92 | 79.93 | 22.25 | 181.26 | 467.06 | 1280.0 | 1574.7 | 870.90 | 480.60 | 252.40 | 132.40 | 90.80 | 62.10 | 204.10 | 5719.5 | 489.40 |
| 1988 | 0.42 | 14.66 | 130.29 | 600.27 | 139.91 | 264.30 | 658.27 | 1382.7 | 1154.1 | 401.50 | 266.70 | 124.10 | 94.00 | 71.90 | 307.50 | 5610.6 | 597.50 |
| 1989 | 0.85 | 10.69 | 50.32 | 447.05 | 436.26 | 65.27 | 315.20 | 761.60 | 884.70 | 350.70 | 123.80 | 73.40 | 61.30 | 56.80 | 157.50 | 3795.4 | 349.00 |
| 1990 | 1.46 | 6.29 | 95.30 | 343.93 | 635.77 | 1108.2 | 257.90 | 276.30 | 475.30 | 336.90 | 82.10 | 43.50 | 38.80 | 19.30 | 77.50 | 3798.5 | 179.10 |
| 1991 | 3.06 | 17.90 | 23.26 | 441.77 | 407.92 | 872.56 | 581.70 | 238.60 | 247.50 | 295.60 | 317.30 | 52.40 | 44.50 | 22.80 | 141.10 | 3707.9 | 260.80 |
| 1992 | 2.84 | 44.35 | 159.43 | 399.46 | 1259.9 | 866.37 | 943.97 | 723.10 | 203.40 | 179.40 | 121.10 | 219.50 | 46.70 | 26.70 | 87.30 | 5283.5 | 380.20 |
| 1993 | 113.76 | 85.80 | 129.59 | 417.23 | 1807.9 | 1420.5 | 919.56 | 598.10 | 586.50 | 219.10 | 279.00 | 114.00 | 32.60 | 103.80 | 140.70 | 6968.2 | 391.10 |
| 1994 | 8.06 | 1368.4 | 496.44 | 41.97 | 1002.1 | 2762.6 | 1290.4 | 828.40 | 197.06 | 540.16 | 113.70 | 71.49 | 40.32 | 132.53 | 80.56 | 8974.3 | 324.90 |
| 1995 | 2.68 | 49.96 | 635.31 | 641.30 | 617.50 | 1197.1 | 1722.4 | 849.85 | 267.81 | 97.35 | 269.86 | 55.03 | 43.94 | 8.15 | 49.94 | 6508.2 | 157.06 |
| 1996 | 5.21 | 32.68 | 51.06 | 119.38 | 952.15 | 1978.2 | 1322.4 | 1431.5 | 263.42 | 215.63 | 57.09 | 78.87 | 3.57 | 13.02 | 18.23 | 6542.5 | 113.69 |
| 1997 | 8.68 | 74.92 | 104.10 | 104.87 | 1022.8 | 1467.2 | 1386.5 | 1016.3 | 592.64 | 83.33 | 49.90 | 17.92 | 36.65 | 2.21 | 13.46 | 5981.5 | 70.24 |
| 1998 | 0.00 | 44.08 | 260.00 | 147.46 | 610.29 | 1285.9 | 1484.3 | 1583.8 | 370.71 | 141.42 | 15.54 | 37.18 | 5.55 | 19.90 | 7.71 | 6014.0 | 70.34 |
| | | | | | | | | USA Commercial Catch in Weight (mt) at Age | | | | | | | | | |
| 1982 | 0.00 | 0.00 | 0.07 | 28.93 | 257.18 | 397.49 | 620.44 | 365.86 | 476.91 | 353.96 | 235.33 | 230.35 | 447.16 | 240.65 | 1300.4 | 4953.0 | 2218.6 |
| 1983 | 0.00 | 0.00 | 0.16 | 50.38 | 272.37 | 409.99 | 644.53 | 823.72 | 599.39 | 586.47 | 498.66 | 408.46 | 347.06 | 381.90 | 1137.0 | 6163.8 | 2274.4 |
| 1984 | 0.00 | 0.01 | 0.04 | 22.19 | 335.19 | 657.29 | 733.21 | 801.22 | 994.34 | 569.20 | 345.84 | 280.62 | 431.96 | 348.05 | 1241.4 | 6758.4 | 2302.0 |
| 1985 | 0.00 | 0.01 | 0.08 | 15.82 | 278.49 | 645.47 | 830.16 | 861.57 | 862.30 | 510.25 | 385.99 | 276.09 | 264.25 | 223.79 | 1037.5 | 6192.0 | 1801.6 |
| 1986 | 0.00 | 0.01 | 0.10 | 2.03 | 77.59 | 454.17 | 1131.8 | 835.16 | 564.39 | 352.03 | 217.23 | 213.04 | 188.24 | 180.43 | 419.80 | 4639.6 | 1001.5 |
| 1987 | 0.01 | 0.29 | 2.63 | 1.81 | 34.61 | 139.28 | 554.73 | 883.41 | 597.44 | 397.94 | 247.35 | 141.27 | 110.96 | 86.07 | 299.41 | 3496.2 | 637.71 |
| 1988 | 0.00 | 0.09 | 2.22 | 26.88 | 28.38 | 82.23 | 285.78 | 743.89 | 770.94 | 328.83 | 261.37 | 133.28 | 111.86 | 92.75 | 454.18 | 3320.5 | 792.07 |
| 1989 | 0.01 | 0.13 | 1.70 | 54.67 | 74.34 | 20.98 | 133.96 | 437.16 | 603.37 | 286.87 | 119.84 | 82.80 | 77.12 | 74.69 | 239.24 | 2207.3 | 473.85 |
| 1990 | 0.01 | 0.07 | 2.79 | 21.22 | 118.76 | 285.01 | 112.96 | 161.91 | 327.01 | 286.03 | 86.12 | 52.77 | 48.97 | 29.36 | 129.35 | 1663.0 | 260.43 |
| 1991 | 0.01 | 0.25 | 0.82 | 27.33 | 81.28 | 300.51 | 244.69 | 137.91 | 173.74 | 247.12 | 309.05 | 57.59 | 60.92 | 35.04 | 216.73 | 1892.6 | 370.28 |
| 1992 | 0.01 | 0.30 | 4.13 | 41.28 | 289.86 | 328.48 | 433.19 | 443.98 | 150.31 | 147.47 | 106.81 | 228.06 | 62.44 | 38.96 | 143.17 | 2420.1 | 472.63 |
| 1993 | 0.33 | 0.77 | 3.52 | 51.02 | 365.31 | 451.93 | 397.20 | 319.98 | 390.61 | 193.25 | 285.42 | 127.45 | 39.09 | 142.00 | 213.72 | 2982.1 | 522.26 |
| 1994 | 0.04 | 6.16 | 9.28 | 2.92 | 202.20 | 774.70 | 554.57 | 442.37 | 136.17 | 449.41 | 103.35 | 77.42 | 47.26 | 159.57 | 126.96 | 3091.6 | 411.21 |
| 1995 | 0.01 | 0.37 | 14.88 | 36.99 | 105.45 | 368.77 | 742.33 | 476.77 | 184.79 | 88.69 | 262.84 | 60.59 | 52.86 | 11.50 | 70.22 | 2477.7 | 195.16 |
| 1996 | 0.02 | 0.62 | 1.58 | 7.34 | 147.69 | 462.14 | 562.47 | 793.06 | 186.50 | 184.58 | 55.61 | 87.86 | 5.00 | 18.75 | 28.40 | 2542.1 | 140.01 |
| 1997 | 0.03 | 1.76 | 3.50 | 6.19 | 200.10 | 367.72 | 498.40 | 503.07 | 372.18 | 72.58 | 51.75 | 20.93 | 43.83 | 3.73 | 22.33 | 2166.4 | 90.82 |
| 1998 | 0.00 | 0.18 | 8.65 | 13.16 | 104.15 | 319.29 | 518.14 | 779.26 | 216.87 | 123.18 | 15.20 | 41.46 | 6.28 | 25.09 | 12.00 | 2183.7 | 84.84 |

Table A14. Continued.

| Year | Age 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | USA Commercial Catch Mean Weight (kg) at Age | | | | | | | | | |
| 1982 | 0.000 | 0.002 | 0.038 | 0.152 | 0.242 | 0.329 | 0.421 | 0.550 | 0.727 | 0.886 | 0.983 | 1.146 | 1.255 | 1.310 | 1.553 | 0.662 | 1.406 |
| 1983 | - | 0.009 | 0.038 | 0.149 | 0.202 | 0.270 | 0.409 | 0.518 | 0.613 | 0.795 | 0.977 | 1.116 | 1.208 | 1.321 | 1.551 | 0.600 | 1.357 |
| 1984 | - | 0.017 | 0.040 | 0.151 | 0.229 | 0.328 | 0.421 | 0.539 | 0.664 | 0.817 | 0.922 | 1.004 | 1.212 | 1.332 | 1.511 | 0.607 | 1.339 |
| 1985 | - | 0.017 | 0.023 | 0.128 | 0.237 | 0.305 | 0.429 | 0.565 | 0.691 | 0.842 | 0.964 | 1.057 | 1.193 | 1.311 | 1.470 | 0.590 | 1.326 |
| 1986 | 0.000 | 0.017 | 0.026 | 0.089 | 0.206 | 0.299 | 0.408 | 0.533 | 0.676 | 0.853 | 0.975 | 1.132 | 1.199 | 1.317 | 1.521 | 0.546 | 1.321 |
| 1987 | 0.006 | 0.015 | 0.033 | 0.081 | 0.191 | 0.298 | 0.433 | 0.561 | 0.686 | 0.828 | 0.980 | 1.067 | 1.222 | 1.386 | 1.467 | 0.611 | 1.303 |
| 1988 | 0.004 | 0.006 | 0.017 | 0.045 | 0.203 | 0.311 | 0.434 | 0.538 | 0.668 | 0.819 | 0.980 | 1.074 | 1.190 | 1.290 | 1.477 | 0.592 | 1.326 |
| 1989 | 0.009 | 0.012 | 0.034 | 0.122 | 0.170 | 0.321 | 0.425 | 0.574 | 0.682 | 0.818 | 0.968 | 1.128 | 1.258 | 1.315 | 1.519 | 0.582 | 1.358 |
| 1990 | 0.004 | 0.012 | 0.029 | 0.062 | 0.187 | 0.257 | 0.438 | 0.586 | 0.688 | 0.849 | 1.049 | 1.213 | 1.262 | 1.521 | 1.669 | 0.438 | 1.454 |
| 1991 | 0.004 | 0.014 | 0.035 | 0.062 | 0.199 | 0.344 | 0.421 | 0.578 | 0.702 | 0.836 | 0.974 | 1.099 | 1.369 | 1.537 | 1.536 | 0.510 | 1.420 |
| 1992 | 0.003 | 0.007 | 0.026 | 0.103 | 0.230 | 0.379 | 0.459 | 0.614 | 0.739 | 0.822 | 0.882 | 1.039 | 1.337 | 1.459 | 1.640 | 0.458 | 1.243 |
| 1993 | 0.003 | 0.009 | 0.027 | 0.122 | 0.202 | 0.318 | 0.432 | 0.535 | 0.666 | 0.882 | 1.023 | 1.118 | 1.199 | 1.368 | 1.519 | 0.428 | 1.335 |
| 1994 | 0.005 | 0.004 | 0.019 | 0.070 | 0.202 | 0.280 | 0.430 | 0.534 | 0.691 | 0.832 | 0.909 | 1.083 | 1.172 | 1.204 | 1.576 | 0.345 | 1.266 |
| 1995 | 0.005 | 0.007 | 0.023 | 0.058 | 0.171 | 0.308 | 0.431 | 0.561 | 0.690 | 0.911 | 0.974 | 1.101 | 1.203 | 1.411 | 1.406 | 0.381 | 1.243 |
| 1996 | 0.004 | 0.019 | 0.031 | 0.061 | 0.155 | 0.234 | 0.425 | 0.554 | 0.708 | 0.856 | 0.974 | 1.114 | 1.401 | 1.440 | 1.558 | 0.389 | 1.232 |
| 1997 | 0.004 | 0.023 | 0.034 | 0.059 | 0.196 | 0.251 | 0.359 | 0.495 | 0.628 | 0.871 | 1.037 | 1.168 | 1.196 | 1.687 | 1.659 | 0.362 | 1.293 |
| 1998 | - | 0.004 | 0.033 | 0.089 | 0.171 | 0.248 | 0.349 | 0.492 | 0.585 | 0.871 | 0.978 | 1.115 | 1.132 | 1.261 | 1.557 | 0.363 | 1.206 |
| | | | | | | | | USA Commercial Catch Mean Length (cm) at Age | | | | | | | | | |
| 1982 | 5.0 | 7.8 | 19.9 | 28.1 | 33.5 | 36.8 | 39.7 | 42.9 | 46.5 | 49.3 | 50.9 | 53.2 | 54.6 | 55.2 | 58.0 | 43.3 | 56.3 |
| 1983 | - | 13.0 | 20.0 | 28.6 | 31.8 | 34.7 | 39.4 | 42.2 | 44.2 | 47.7 | 50.7 | 52.8 | 54.0 | 56.6 | 55.8 | 35.0 | 55.0 |
| 1984 | - | 15.7 | 20.0 | 28.4 | 33.1 | 36.9 | 39.7 | 42.7 | 45.3 | 48.2 | 49.9 | 51.2 | 54.1 | 55.6 | 57.6 | 42.7 | 55.5 |
| 1985 | - | 15.7 | 16.9 | 28.4 | 33.6 | 36.1 | 39.9 | 43.3 | 45.9 | 48.6 | 50.6 | 51.9 | 53.8 | 55.3 | 57.1 | 42.4 | 55.3 |
| 1986 | 5.0 | 15.7 | 17.3 | 25.1 | 32.2 | 36.0 | 39.3 | 42.5 | 45.6 | 48.8 | 50.7 | 53.0 | 53.9 | 55.4 | 57.7 | 41.8 | 55.3 |
| 1987 | 10.6 | 15.3 | 19.0 | 24.5 | 31.3 | 35.9 | 40.1 | 43.2 | 45.8 | 48.4 | 50.8 | 52.1 | 54.2 | 56.2 | 57.1 | 43.2 | 55.1 |
| 1988 | 10.2 | 10.9 | 15.6 | 20.4 | 31.8 | 36.3 | 40.1 | 42.7 | 45.4 | 48.2 | 50.8 | 52.1 | 53.7 | 55.0 | 57.1 | 41.4 | 55.3 |
| 1989 | 12.6 | 13.9 | 19.0 | 27.8 | 30.9 | 36.8 | 39.8 | 43.5 | 45.6 | 48.1 | 50.6 | 52.9 | 54.6 | 55.3 | 57.6 | 41.6 | 55.7 |
| 1990 | 9.7 | 14.0 | 18.0 | 22.3 | 31.1 | 34.3 | 40.2 | 43.7 | 45.8 | 48.7 | 51.8 | 54.1 | 54.6 | 57.8 | 59.2 | 37.5 | 56.8 |
| 1991 | 9.6 | 14.1 | 18.8 | 22.6 | 31.6 | 37.4 | 39.6 | 43.3 | 46.1 | 48.5 | 50.6 | 52.5 | 56.0 | 57.8 | 57.8 | 39.4 | 56.5 |
| 1992 | 9.1 | 10.9 | 17.4 | 26.1 | 33.1 | 38.5 | 40.7 | 44.3 | 46.8 | 48.3 | 49.2 | 51.7 | 55.5 | 57.0 | 58.9 | 38.6 | 54.2 |
| 1993 | 9.1 | 12.2 | 17.7 | 27.9 | 32.3 | 36.6 | 40.0 | 42.6 | 45.3 | 49.3 | 51.5 | 52.8 | 53.9 | 55.9 | 57.7 | 37.6 | 55.5 |
| 1994 | 10.7 | 9.8 | 15.9 | 22.8 | 32.2 | 35.1 | 39.7 | 42.3 | 45.6 | 48.0 | 49.1 | 51.8 | 53.0 | 53.4 | 57.8 | 33.0 | 54.1 |
| 1995 | 10.9 | 11.6 | 17.1 | 21.7 | 30.9 | 36.1 | 39.6 | 42.8 | 45.4 | 49.3 | 50.1 | 52.0 | 53.4 | 56.0 | 55.8 | 35.5 | 53.8 |
| 1996 | 10.0 | 15.3 | 18.5 | 22.7 | 30.0 | 33.5 | 39.5 | 42.7 | 45.8 | 48.4 | 50.1 | 52.2 | 55.8 | 56.2 | 57.6 | 37.3 | 53.6 |
| 1997 | 10.2 | 16.1 | 18.9 | 22.2 | 31.8 | 34.1 | 37.6 | 41.3 | 44.2 | 48.5 | 51.1 | 52.9 | 53.3 | 59.0 | 58.7 | 36.6 | 54.4 |
| 1998 | - | 10.2 | 19.0 | 25.5 | 31.0 | 34.1 | 37.3 | 41.2 | 43.3 | 48.7 | 50.5 | 52.3 | 52.7 | 54.1 | 57.6 | 36.6 | 53.4 |

Table A15. Mean weights at age (kg) at the beginning of the year (January 1) for witch flounder 1982-1998. Values derived from catch mean weight-at-age data (mid-year, Table A14) using procedures described by Rivard (1980).

| | Age | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | 11+ |
| 1982 | 0.000 | 0.019 | 0.132 | 0.229 | 0.295 | 0.380 | 0.521 | 0.695 | 0.844 | 0.923 | 1.116 | 1.223 | 1.282 | 1.553 | 1.406 |
| 1983 | 0.004 | 0.009 | 0.075 | 0.175 | 0.256 | 0.367 | 0.467 | 0.581 | 0.760 | 0.930 | 1.047 | 1.177 | 1.288 | 1.551 | 1.357 |
| 1984 | 0.015 | 0.019 | 0.076 | 0.185 | 0.257 | 0.337 | 0.470 | 0.586 | 0.708 | 0.856 | 0.990 | 1.163 | 1.268 | 1.511 | 1.339 |
| 1985 | 0.014 | 0.020 | 0.072 | 0.189 | 0.264 | 0.375 | 0.488 | 0.610 | 0.748 | 0.887 | 0.987 | 1.094 | 1.261 | 1.470 | 1.326 |
| 1986 | 0.012 | 0.021 | 0.045 | 0.162 | 0.266 | 0.353 | 0.478 | 0.618 | 0.768 | 0.906 | 1.045 | 1.126 | 1.253 | 1.521 | 1.321 |
| 1987 | 0.014 | 0.024 | 0.046 | 0.130 | 0.248 | 0.360 | 0.478 | 0.605 | 0.748 | 0.914 | 1.020 | 1.176 | 1.289 | 1.467 | 1.303 |
| 1988 | 0.003 | 0.016 | 0.039 | 0.128 | 0.244 | 0.360 | 0.483 | 0.612 | 0.750 | 0.901 | 1.026 | 1.127 | 1.256 | 1.477 | 1.326 |
| 1989 | 0.008 | 0.014 | 0.046 | 0.087 | 0.255 | 0.364 | 0.499 | 0.606 | 0.739 | 0.890 | 1.051 | 1.162 | 1.251 | 1.519 | 1.358 |
| 1990 | 0.007 | 0.019 | 0.046 | 0.151 | 0.209 | 0.375 | 0.499 | 0.628 | 0.761 | 0.926 | 1.084 | 1.193 | 1.383 | 1.669 | 1.454 |
| 1991 | 0.010 | 0.020 | 0.042 | 0.111 | 0.254 | 0.329 | 0.503 | 0.641 | 0.758 | 0.909 | 1.074 | 1.289 | 1.393 | 1.536 | 1.420 |
| 1992 | 0.004 | 0.019 | 0.060 | 0.119 | 0.275 | 0.397 | 0.508 | 0.654 | 0.760 | 0.859 | 1.006 | 1.212 | 1.413 | 1.640 | 1.243 |
| 1993 | 0.006 | 0.014 | 0.056 | 0.144 | 0.270 | 0.405 | 0.496 | 0.639 | 0.807 | 0.917 | 0.993 | 1.116 | 1.352 | 1.519 | 1.335 |
| 1994 | 0.002 | 0.013 | 0.043 | 0.157 | 0.238 | 0.370 | 0.480 | 0.608 | 0.744 | 0.895 | 1.053 | 1.145 | 1.201 | 1.576 | 1.266 |
| 1995 | 0.003 | 0.010 | 0.033 | 0.109 | 0.249 | 0.347 | 0.491 | 0.607 | 0.793 | 0.900 | 1.000 | 1.141 | 1.286 | 1.406 | 1.243 |
| 1996 | 0.014 | 0.015 | 0.037 | 0.095 | 0.200 | 0.362 | 0.489 | 0.630 | 0.769 | 0.942 | 1.042 | 1.242 | 1.316 | 1.558 | 1.232 |
| 1997 | 0.019 | 0.025 | 0.043 | 0.109 | 0.197 | 0.290 | 0.459 | 0.590 | 0.785 | 0.942 | 1.067 | 1.154 | 1.537 | 1.659 | 1.293 |
| 1998 | 0.001 | 0.028 | 0.055 | 0.100 | 0.220 | 0.296 | 0.420 | 0.538 | 0.740 | 0.923 | 1.075 | 1.150 | 1.228 | 1.557 | 1.206 |
| 1982-1998 | 0.009 | 0.018 | 0.056 | 0.140 | 0.247 | 0.357 | 0.484 | 0.615 | 0.764 | 0.907 | 1.040 | 1.170 | 1.309 | 1.541 | 1.319 |

Table A16. Stratified mean number, weight (kg) and length (cm) per tow of witch flounder in NEFSC offshore spring and autumn bottom trawl surveys in Gulf of Maine-Georges Bank region (strata 22-30, 36-40), 1963-1998, 1999 preliminary.

| | SPRING | | | AUTUMN | | |
|---|---|---|---|---|---|---|
| YEAR | Number per tow | Weight per tow | Length per tow | Number per tow | Weight per tow | Length per tow |
| 1963 | - | - | - | 5.52 | 3.46 | 39.7 |
| 1964 | - | - | - | 2.89 | 2.00 | 44.2 |
| 1965 | - | - | - | 3.94 | 2.27 | 40.6 |
| 1966 | - | - | - | 7.80 | 4.56 | 41.2 |
| 1967 | - | - | - | 3.01 | 2.02 | 43.6 |
| 1968 | 4.76 | 3.34 | 42.5 | 4.82 | 3.49 | 44.8 |
| 1969 | 3.74 | 2.53 | 45.3 | 5.81 | 4.40 | 43.9 |
| 1970 | 6.39 | 4.49 | 44.7 | 4.89 | 3.71 | 45.0 |
| 1971 | 2.74 | 2.06 | 46.5 | 4.32 | 2.95 | 42.1 |
| 1972 | 5.35 | 4.01 | 45.8 | 3.24 | 2.42 | 43.9 |
| 1973 | 8.20 | 6.21 | 44.8 | 3.18 | 2.05 | 43.6 |
| 1974 | 6.23 | 3.62 | 39.3 | 2.34 | 1.54 | 40.9 |
| 1975 | 3.72 | 2.75 | 43.9 | 1.66 | 1.03 | 39.8 |
| 1976 | 5.50 | 3.70 | 42.3 | 1.34 | 0.94 | 41.9 |
| 1977 | 4.20 | 1.96 | 37.2 | 5.06 | 3.38 | 42.0 |
| 1978 | 3.87 | 2.56 | 41.7 | 4.04 | 2.94 | 42.9 |
| 1979 | 3.01 | 1.77 | 38.3 | 1.94 | 1.62 | 45.2 |
| 1980 | 8.46 | 3.89 | 36.0 | 2.62 | 2.04 | 43.6 |
| 1981 | 8.40 | 4.18 | 38.1 | 3.66 | 2.19 | 40.4 |
| 1982 | 3.64 | 1.87 | 37.2 | 0.99 | 0.83 | 44.7 |
| 1983 | 6.41 | 2.74 | 36.3 | 4.72 | 2.12 | 36.7 |
| 1984 | 3.00 | 1.66 | 39.9 | 4.37 | 2.34 | 39.7 |
| 1985 | 5.18 | 2.75 | 40.3 | 2.76 | 1.59 | 42.0 |
| 1986 | 2.07 | 1.35 | 44.1 | 1.59 | 1.09 | 43.3 |
| 1987 | 1.01 | 0.65 | 43.4 | 0.48 | 0.37 | 44.0 |
| 1988 | 1.43 | 0.85 | 42.3 | 1.38 | 0.57 | 35.2 |
| 1989 | 1.95 | 0.74 | 35.8 | 0.89 | 0.38 | 31.3 |
| 1990 | 0.63 | 0.24 | 35.2 | 2.00 | 0.40 | 24.8 |
| 1991 | 1.68 | 0.57 | 31.5 | 2.08 | 0.54 | 29.3 |
| 1992 | 1.26 | 0.50 | 34.8 | 0.94 | 0.24 | 29.5 |
| 1993 | 1.47 | 0.36 | 30.3 | 5.15 | 0.54 | 17.0 |
| 1994 | 3.13 | 0.53 | 27.4 | 2.21 | 0.42 | 24.9 |
| 1995 | 1.88 | 0.47 | 30.7 | 4.47 | 0.62 | 25.7 |
| 1996 | 1.36 | 0.28 | 30.5 | 5.38 | 1.02 | 29.7 |
| 1997 | 2.22 | 0.43 | 31.0 | 5.10 | 0.77 | 24.9 |
| 1998 | 4.27 | 0.77 | 29.0 | 3.70 | 0.47 | 24.2 |
| *1999* | *3.15* | *0.48* | *28.1* | | | |

Note: During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portuguese polyvalent doors have been used in both surveys. No significant differences in catchability were found for witch flounder, therefore no adjustments have been made (Byrne and Forrester, MS 1991). No significant differences were found between research vessels, and no adjustment have been made (Byrne and Forrester, MS 1991).

Spring surveys during 1973-1981 were accomplished with a 41 Yankee trawl; in all other years, a 36 Yankee trawl was used. No adjustments have been made.

Table A17. Number of witch flounder caught, aged, percent of fish sampled, and the maximum age observed in the NEFSC spring and autumn bottom trawl surveys (strata 22-30, 36-40), 1980-1998, 1999 preliminary.

| | Spring | | | | Autumn | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Caught | Aged | % Sampled | Max. Age | Caught | Aged | % Sampled | Max. Age |
| 1980 | 593 | 361 | 60.9 | 24 | 189 | 146 | 77.2 | 24 |
| 1981 | 557 | 209 | 37.5 | 23 | 202 | 143 | 70.8 | 22 |
| 1982 | 245 | 69 | 28.2 | 18 | 64 | 53 | 82.8 | 24 |
| 1983 | 410 | 176 | 42.9 | 20 | 359 | 154 | 42.9 | 22 |
| 1984 | 171 | 145 | 84.8 | 26 | 293 | 204 | 69.6 | 21 |
| 1985 | 269 | 151 | 56.1 | 25 | 340 | 232 | 68.2 | 30 |
| 1986 | 119 | 118 | 99.2 | 22 | 258 | 218 | 84.5 | 22 |
| 1987 | 108 | 108 | 100.0 | 24 | 30 | 27 | 90.0 | 24 |
| 1988 | 74 | 67 | 90.5 | 12 | 93 | 82 | 88.2 | 20 |
| 1989 | 100 | 91 | 91.0 | 18 | 59 | 55 | 93.2 | 21 |
| 1990 | 33 | 27 | 81.8 | 16 | 131 | 118 | 90.1 | 18 |
| 1991 | 93 | 87 | 93.5 | 15 | 187 | 107 | 57.2 | 11 |
| 1992 | 86 | 75 | 87.2 | 17 | 79 | 67 | 84.8 | 18 |
| 1993 | 88 | 81 | 92.0 | 19 | 414 | 166 | 40.1 | 16 |
| 1994 | 196 | 127 | 64.8 | 16 | 174 | 102 | 58.6 | 21 |
| 1995 | 142 | 106 | 74.6 | 19 | 352 | 174 | 49.4 | 14 |
| 1996 | 84 | 72 | 85.7 | 13 | 295 | 169 | 57.3 | 11 |
| 1997 | 129 | 79 | 61.2 | 12 | 368 | 243 | 66.0 | 12 |
| 1998 | 367 | 281 | 76.6 | 13 | 359 | 217 | 60.4 | 13 |
| *1999* | *169* | *138* | *81.7* | *10* | | | | |

Table A18. Stratified mean number per tow at age of witch flounder in NEFSC bottom trawl spring and autumn surveys (Strata 22-30, 36-40), 1982-1998, *1999 preliminary.*

| | AGE | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total |
| Spring | | | | | | | | | | | | | | | | |
| 1980 | 0.00 | 0.06 | 0.23 | 0.95 | 1.52 | 0.72 | 1.20 | 1.02 | 0.38 | 0.40 | 0.31 | 0.30 | 0.12 | 0.16 | 1.10 | 8.46 |
| 1981 | 0.00 | 0.00 | 0.05 | 0.82 | 0.93 | 2.00 | 1.02 | 0.76 | 0.67 | 0.42 | 0.13 | 0.20 | 0.24 | 0.22 | 0.90 | 8.40 |
| 1982 | 0.00 | 0.04 | 0.01 | 0.56 | 0.57 | 0.34 | 0.21 | 0.64 | 0.41 | 0.08 | 0.26 | 0.15 | 0.03 | 0.03 | 0.30 | 3.64 |
| 1983 | 0.00 | 0.00 | 0.03 | 0.58 | 1.25 | 1.33 | 0.55 | 0.64 | 0.67 | 0.48 | 0.20 | 0.09 | 0.08 | 0.11 | 0.41 | 6.41 |
| 1984 | 0.00 | 0.00 | 0.01 | 0.10 | 0.33 | 0.73 | 0.42 | 0.26 | 0.28 | 0.24 | 0.11 | 0.12 | 0.09 | 0.02 | 0.29 | 3.00 |
| 1985 | 0.00 | 0.00 | 0.00 | 0.02 | 0.43 | 1.11 | 1.19 | 0.86 | 0.45 | 0.13 | 0.06 | 0.14 | 0.09 | 0.04 | 0.67 | 5.18 |
| 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.24 | 0.53 | 0.43 | 0.17 | 0.18 | 0.07 | 0.04 | 0.08 | 0.05 | 0.25 | 2.07 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.12 | 0.12 | 0.26 | 0.17 | 0.03 | 0.06 | 0.03 | 0.00 | 0.00 | 0.15 | 1.01 |
| 1988 | 0.00 | 0.02 | 0.02 | 0.06 | 0.00 | 0.07 | 0.31 | 0.38 | 0.25 | 0.16 | 0.08 | 0.04 | 0.02 | 0.00 | 0.02 | 1.43 |
| 1989 | 0.00 | 0.02 | 0.01 | 0.04 | 0.98 | 0.12 | 0.07 | 0.10 | 0.31 | 0.07 | 0.03 | 0.05 | 0.05 | 0.02 | 0.06 | 1.95 |
| 1990 | 0.00 | 0.01 | 0.00 | 0.04 | 0.09 | 0.32 | 0.02 | 0.02 | 0.02 | 0.06 | 0.01 | 0.00 | 0.01 | 0.00 | 0.03 | 0.63 |
| 1991 | 0.00 | 0.04 | 0.00 | 0.78 | 0.11 | 0.11 | 0.19 | 0.02 | 0.09 | 0.10 | 0.14 | 0.02 | 0.02 | 0.00 | 0.07 | 1.68 |
| 1992 | 0.00 | 0.05 | 0.01 | 0.19 | 0.37 | 0.08 | 0.12 | 0.15 | 0.05 | 0.14 | 0.02 | 0.01 | 0.05 | 0.00 | 0.02 | 1.26 |
| 1993 | 0.00 | 0.15 | 0.11 | 0.14 | 0.46 | 0.33 | 0.06 | 0.08 | 0.00 | 0.02 | 0.02 | 0.00 | 0.06 | 0.00 | 0.04 | 1.47 |
| 1994 | 0.00 | 0.10 | 0.71 | 0.53 | 0.64 | 0.83 | 0.16 | 0.03 | 0.02 | 0.06 | 0.01 | 0.00 | 0.00 | 0.02 | 0.02 | 3.13 |
| 1995 | 0.00 | 0.04 | 0.12 | 0.58 | 0.32 | 0.18 | 0.31 | 0.11 | 0.12 | 0.04 | 0.00 | 0.04 | 0.03 | 0.00 | 0.00 | 1.88 |
| 1996 | 0.00 | 0.02 | 0.04 | 0.24 | 0.41 | 0.33 | 0.22 | 0.07 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 1.36 |
| 1997 | 0.00 | 0.07 | 0.07 | 0.15 | 0.71 | 0.58 | 0.46 | 0.08 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.22 |
| 1998 | 0.00 | 0.11 | 1.06 | 0.73 | 0.41 | 0.79 | 0.70 | 0.21 | 0.15 | 0.08 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 4.27 |
| *1999* | *0.00* | *0.11* | *0.38* | *0.96* | *0.81* | *0.47* | *0.18* | *0.18* | *0.03* | *0.01* | *0.02* | *0.00* | *0.00* | *0.00* | *0.00* | *3.15* |
| Autumn | | | | | | | | | | | | | | | | |
| 1980 | 0.04 | 0.00 | 0.02 | 0.00 | 0.20 | 0.26 | 0.28 | 0.36 | 0.17 | 0.15 | 0.27 | 0.04 | 0.16 | 0.12 | 0.57 | 2.62 |
| 1981 | 0.03 | 0.07 | 0.03 | 0.24 | 0.44 | 0.61 | 0.46 | 0.27 | 0.26 | 0.18 | 0.21 | 0.17 | 0.04 | 0.13 | 0.48 | 3.66 |
| 1982 | 0.02 | 0.00 | 0.00 | 0.06 | 0.01 | 0.02 | 0.08 | 0.25 | 0.13 | 0.01 | 0.03 | 0.03 | 0.00 | 0.06 | 0.29 | 0.99 |
| 1983 | 0.00 | 0.01 | 0.01 | 0.49 | 1.60 | 0.78 | 0.51 | 0.47 | 0.11 | 0.10 | 0.12 | 0.09 | 0.02 | 0.00 | 0.42 | 4.72 |
| 1984 | 0.00 | 0.00 | 0.00 | 0.08 | 0.97 | 1.01 | 0.58 | 0.54 | 0.32 | 0.14 | 0.12 | 0.06 | 0.04 | 0.14 | 0.38 | 4.37 |
| 1985 | 0.00 | 0.00 | 0.01 | 0.07 | 0.06 | 0.60 | 0.62 | 0.58 | 0.24 | 0.13 | 0.09 | 0.01 | 0.03 | 0.10 | 0.22 | 2.76 |
| 1986 | 0.01 | 0.00 | 0.00 | 0.01 | 0.04 | 0.27 | 0.36 | 0.31 | 0.15 | 0.11 | 0.02 | 0.02 | 0.01 | 0.05 | 0.23 | 1.59 |
| 1987 | 0.00 | 0.00 | 0.02 | 0.01 | 0.00 | 0.02 | 0.05 | 0.18 | 0.07 | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 | 0.08 | 0.48 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.71 | 0.07 | 0.00 | 0.03 | 0.22 | 0.06 | 0.05 | 0.03 | 0.06 | 0.02 | 0.03 | 0.08 | 1.38 |
| 1989 | 0.17 | 0.02 | 0.02 | 0.08 | 0.30 | 0.01 | 0.02 | 0.04 | 0.05 | 0.09 | 0.01 | 0.00 | 0.03 | 0.00 | 0.04 | 0.89 |
| 1990 | 0.48 | 0.12 | 0.11 | 0.39 | 0.52 | 0.17 | 0.05 | 0.02 | 0.02 | 0.05 | 0.00 | 0.00 | 0.01 | 0.04 | 0.03 | 2.00 |
| 1991 | 0.22 | 0.02 | 0.17 | 0.67 | 0.35 | 0.27 | 0.15 | 0.09 | 0.06 | 0.02 | 0.04 | 0.03 | 0.00 | 0.00 | 0.00 | 2.08 |
| 1992 | 0.09 | 0.03 | 0.11 | 0.27 | 0.22 | 0.06 | 0.05 | 0.00 | 0.00 | 0.02 | 0.01 | 0.02 | 0.00 | 0.01 | 0.04 | 0.94 |
| 1993 | 2.54 | 0.67 | 0.11 | 0.55 | 0.76 | 0.23 | 0.06 | 0.03 | 0.08 | 0.00 | 0.02 | 0.04 | 0.00 | 0.01 | 0.01 | 5.15 |
| 1994 | 0.42 | 0.17 | 0.28 | 0.50 | 0.20 | 0.39 | 0.04 | 0.11 | 0.00 | 0.04 | 0.01 | 0.00 | 0.01 | 0.00 | 0.04 | 2.21 |
| 1995 | 0.51 | 0.21 | 0.80 | 1.57 | 0.86 | 0.49 | 0.22 | 0.00 | 0.00 | 0.01 | 0.05 | 0.00 | 0.00 | 0.00 | 0.01 | 4.74 |
| 1996 | 0.23 | 0.09 | 0.27 | 0.74 | 2.02 | 1.40 | 0.45 | 0.06 | 0.06 | 0.03 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 5.38 |
| 1997 | 0.89 | 0.34 | 1.00 | 0.53 | 0.86 | 0.77 | 0.40 | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 5.10 |
| 1998 | 0.64 | 0.08 | 0.54 | 1.33 | 0.48 | 0.31 | 0.17 | 0.10 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 |

Table A19. Witch flounder mean length (cm) at age in spring and autumn surveys NEFSC NEFSC bottom trawl surveys (Strata 22-30, 36-40), 1982-1998, *1999 preliminary.*

| | AGE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
| Spring | | | | | | | | | | | | | | | |
| 1980 | - | 9.7 | 16.4 | 20.6 | 26.2 | 30.6 | 34.8 | 38.6 | 40.6 | 45.0 | 48.6 | 49.2 | 49.3 | 52.5 | 55.2 |
| 1981 | - | - | 13.4 | 20.2 | 28.5 | 32.4 | 35.4 | 39.7 | 44.4 | 49.4 | 52.4 | 49.9 | 54.5 | 54.1 | 57.6 |
| 1982 | - | 8.0 | 15.5 | 20.0 | 27.1 | 32.3 | 35.7 | 40.4 | 44.1 | 48.6 | 50.5 | 51.3 | 57.5 | 53.5 | 57.2 |
| 1983 | - | - | 17.8 | 20.7 | 26.4 | 31.3 | 35.8 | 40.3 | 43.4 | 47.6 | 52.3 | 54.7 | 49.5 | 55.9 | 54.5 |
| 1984 | - | - | 15.5 | 17.7 | 29.6 | 32.7 | 37.5 | 41.8 | 43.3 | 47.2 | 51.4 | 50.9 | 53.0 | 53.5 | 57.0 |
| 1985 | - | - | - | 19.5 | 28.7 | 33.4 | 36.9 | 41.1 | 44.8 | 46.3 | 45.5 | 51.0 | 49.1 | 55.5 | 56.4 |
| 1986 | - | - | - | - | 26.8 | 35.0 | 38.3 | 41.8 | 45.8 | 49.1 | 51.4 | 51.9 | 54.1 | 57.1 | 57.1 |
| 1987 | - | - | - | - | 27.6 | 34.2 | 40.3 | 41.3 | 44.1 | 47.0 | 51.1 | 47.5 | - | - | 55.7 |
| 1988 | - | 9.5 | 15.5 | 19.2 | - | 33.4 | 39.3 | 43.0 | 45.9 | 50.7 | 54.3 | 49.9 | 59.5 | - | 57.5 |
| 1989 | - | 7.5 | 14.5 | 21.5 | 28.6 | 33.1 | 40.1 | 43.5 | 44.9 | 50.2 | 50.4 | 53.0 | 57.7 | 47.5 | 59.5 |
| 1990 | - | 9.5 | - | 19.5 | 28.0 | 32.6 | 39.5 | 41.5 | 49.5 | 50.2 | 51.5 | - | 53.5 | - | 54.8 |
| 1991 | - | 7.5 | - | 20.4 | 27.5 | 35.4 | 37.8 | 43.5 | 48.1 | 49.6 | 51.9 | 53.5 | 53.5 | - | 51.3 |
| 1992 | - | 8.8 | 11.5 | 22.0 | 29.1 | 35.2 | 38.3 | 42.5 | 45.0 | 49.5 | 45.5 | 51.5 | 56.0 | - | 55.5 |
| 1993 | - | 7.7 | 18.2 | 23.6 | 30.0 | 34.5 | 38.2 | 40.4 | - | 49.5 | 49.5 | - | 50.9 | - | 59.6 |
| 1994 | - | 10.4 | 17.9 | 21.4 | 29.3 | 33.8 | 37.9 | 41.9 | 45.5 | 48.0 | 47.5 | - | - | 57.5 | 57.5 |
| 1995 | - | 9.8 | 17.2 | 22.3 | 27.0 | 34.3 | 37.1 | 43.6 | 45.8 | 49.8 | - | 54.5 | 58.1 | - | - |
| 1996 | - | 9.5 | 19.5 | 22.3 | 28.3 | 32.4 | 37.0 | 40.6 | - | - | - | 55.8 | - | - | - |
| 1997 | - | 10.9 | 15.9 | 22.2 | 29.5 | 31.7 | 36.1 | 42.7 | 44.8 | - | - | - | - | - | - |
| 1998 | - | 11.2 | 20.1 | 24.5 | 30.0 | 33.3 | 35.7 | 38.9 | 42.8 | 45.5 | - | - | - | 51.1 | - |
| *1999* | | *10.0* | *19.5* | *24.9* | *28.5* | *34.0* | *37.1* | *40.6* | *45.5* | *44.0* | *50.0* | | | | |
| Autumn | | | | | | | | | | | | | | | |
| 1980 | 5.5 | - | 19.5 | - | 27.3 | 32.0 | 34.9 | 39.1 | 43.3 | 47.7 | 48.8 | 50.1 | 51.6 | 53.7 | 56.7 |
| 1981 | 5.5 | 12.6 | 17.4 | 23.3 | 30.6 | 33.1 | 38.3 | 41.4 | 44.8 | 47.0 | 51.4 | 53.6 | 52.7 | 55.0 | 56.4 |
| 1982 | 5.5 | - | - | 22.7 | 31.5 | 29.3 | 36.7 | 41.9 | 43.0 | 47.5 | 50.7 | 48.8 | - | 52.1 | 56.1 |
| 1983 | - | 13.5 | 19.5 | 24.6 | 30.1 | 34.6 | 38.8 | 42.2 | 45.5 | 48.5 | 51.1 | 51.8 | 51.5 | - | 58.8 |
| 1984 | - | - | - | 24.9 | 30.6 | 34.4 | 38.2 | 42.9 | 45.2 | 47.0 | 50.3 | 51.4 | 55.7 | 53.5 | 58.1 |
| 1985 | - | - | 19.5 | 26.3 | 29.2 | 34.4 | 38.5 | 42.9 | 46.5 | 49.4 | 49.8 | 53.5 | 55.5 | 51.7 | 58.6 |
| 1986 | 5.5 | - | - | 27.5 | 29.5 | 35.3 | 38.2 | 42.9 | 45.4 | 49.1 | 51.5 | 51.4 | 49.5 | 54.5 | 57.4 |
| 1987 | - | - | 15.5 | 27.5 | - | 35.5 | 38.9 | 41.4 | 43.6 | - | 49.5 | - | 55.5 | - | 60.4 |
| 1988 | - | - | - | 25.4 | 30.9 | - | 43.7 | 44.3 | 47.2 | 47.9 | 49.8 | 54.2 | 55.5 | 53.5 | 56.2 |
| 1989 | 5.9 | 15.5 | 18.5 | 24.2 | 31.2 | 35.5 | 43.5 | 45.5 | 47.0 | 49.4 | 51.5 | - | 54.7 | - | 64.7 |
| 1990 | 6.2 | 16.7 | 17.4 | 26.7 | 30.0 | 36.2 | 39.5 | 43.5 | 47.5 | 50.4 | - | - | 57.5 | 51.5 | 60.3 |
| 1991 | 5.7 | 14.7 | 20.5 | 26.2 | 30.4 | 36.6 | 41.6 | 47.2 | 47.5 | 45.5 | 54.8 | 55.5 | - | - | - |
| 1992 | 5.9 | 16.1 | 22.8 | 27.9 | 32.0 | 37.7 | 38.6 | - | - | 45.5 | 49.5 | 47.5 | - | 49.5 | 56.4 |
| 1993 | 5.6 | 14.1 | 22.4 | 28.8 | 32.3 | 35.9 | 42.2 | 43.6 | 46.2 | - | 55.5 | 51.5 | - | 63.5 | 57.5 |
| 1994 | 6.0 | 16.2 | 20.8 | 23.3 | 32.3 | 36.7 | 43.5 | 44.4 | - | 54.2 | 49.5 | - | 51.5 | - | 57.2 |
| 1995 | 6.6 | 16.3 | 22.2 | 26.4 | 29.9 | 35.4 | 39.2 | - | - | 53.5 | 50.6 | - | - | - | 55.5 |
| 1996 | 5.3 | 14.0 | 19.0 | 25.1 | 29.5 | 33.8 | 39.8 | 42.3 | 47.0 | 49.3 | - | 53.5 | - | - | - |
| 1997 | 6.2 | 16.2 | 19.9 | 25.8 | 30.6 | 35.1 | 37.9 | 42.4 | - | - | - | - | 46.3 | - | - |
| 1998 | 5.7 | 15.8 | 21.9 | 25.7 | 30.7 | 34.9 | 39.2 | 42.1 | 44.5 | 45.9 | - | - | - | - | - |

Table A20. Mean weight (kg) at age of Witch flounder from the Gulf of Maine-Georges Bank region (SA 510-515, 520-522, 525-526, 561-562), derived from NEFSC spring and autumn surveys (Strata 22-30, 36-40), 1982-1998.

| | | Age | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
| Spring | 1982 | 0.0000 | 0.0018 | 0.0155 | 0.0435 | 0.1210 | 0.2248 | 0.3001 | 0.4743 | 0.6471 | 0.8945 | 1.0048 | 1.0486 | 1.5536 | 1.2022 | 1.5897 |
| | 1983 | 0.0000 | | 0.0303 | 0.0498 | 0.1067 | 0.1870 | 0.2969 | 0.4469 | 0.5764 | 0.7973 | 1.0712 | 1.2571 | 0.8985 | 1.3696 | 1.3819 |
| | 1984 | 0.0000 | | 0.0152 | 0.0283 | 0.1588 | 0.2259 | 0.3526 | 0.5156 | 0.5774 | 0.7781 | 1.0480 | 1.0267 | 1.1686 | 1.2020 | 1.5470 |
| | 1985 | 0.0000 | | | 0.0368 | 0.1396 | 0.2318 | 0.3286 | 0.4761 | 0.6411 | 0.7159 | 0.6582 | 1.0047 | 0.8676 | 1.3221 | 1.4149 |
| | 1986 | 0.0000 | | | | 0.1115 | 0.2629 | 0.3554 | 0.4810 | 0.6438 | 0.8369 | 0.9694 | 1.0053 | 1.1611 | 1.3875 | 1.4363 |
| | 1987 | 0.0000 | | | | 0.1278 | 0.2560 | 0.4377 | 0.4728 | 0.5965 | 0.7548 | 1.0246 | 0.7617 | | | 1.4519 |
| | 1988 | 0.0000 | 0.0025 | 0.0142 | 0.0364 | | 0.2177 | 0.3888 | 0.5395 | 0.6759 | 0.9301 | 1.1715 | 0.9209 | 1.5574 | | 1.3838 |
| | 1989 | 0.0000 | 0.0010 | 0.0139 | 0.0449 | 0.1261 | 0.1971 | 0.3957 | 0.5357 | 0.5960 | 0.8765 | 0.8891 | 1.0404 | 1.4238 | | 1.6465 |
| | 1990 | 0.0000 | 0.0026 | | 0.0392 | 0.1319 | 0.2157 | 0.4347 | 0.5139 | 0.9159 | 0.9573 | 1.0481 | 0.0000 | 1.1408 | | 1.2886 |
| | 1991 | 0.0000 | 0.0014 | | 0.0429 | 0.1258 | 0.2777 | 0.3440 | 0.5668 | 0.7839 | 0.8905 | 1.0684 | 1.1566 | 1.1566 | | 1.0003 |
| | 1992 | 0.0000 | 0.0024 | 0.0050 | 0.0528 | 0.1450 | 0.2654 | 0.3545 | 0.5237 | 0.6403 | 0.8966 | 0.6425 | 0.9597 | 1.3531 | | 1.2742 |
| | 1993 | 0.0000 | 0.0016 | 0.0256 | 0.0661 | 0.1506 | 0.2379 | 0.3376 | 0.4098 | | 0.8219 | 0.8219 | | 0.8818 | | 1.6168 |
| | 1994 | 0.0000 | 0.0049 | 0.0279 | 0.0520 | 0.1472 | 0.2364 | 0.3557 | 0.5129 | 0.6685 | 0.8023 | 0.7520 | | | 1.4078 | 1.4078 |
| | 1995 | 0.0000 | 0.0032 | 0.0236 | 0.0575 | 0.1093 | 0.2425 | 0.3121 | 0.5410 | 0.6389 | 0.8524 | | 1.1302 | 1.4264 | | |
| | 1996 | 0.0000 | 0.0037 | 0.0351 | 0.0562 | 0.1292 | 0.2010 | 0.3182 | 0.4275 | | | | 1.3229 | | | |
| | 1997 | 0.0000 | 0.0046 | 0.0184 | 0.0539 | 0.1391 | 0.1770 | 0.2783 | 0.4841 | 0.5703 | | | | | | |
| | 1998 | 0.0000 | 0.0054 | 0.0402 | 0.0774 | 0.1542 | 0.2189 | 0.2763 | 0.3782 | 0.5115 | 0.6492 | | | | 0.9561 | |
| | Mean | 0.0000 | 0.0029 | 0.0221 | 0.0492 | 0.1327 | 0.2280 | 0.3451 | 0.4882 | 0.6456 | 0.8303 | 0.9361 | 0.9719 | 1.2158 | 1.1941 | 1.4184 |

Table A20. Continued.

| | | Age | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
| Autumn | 1982 | 0.0004 | | | 0.0650 | 0.2006 | 0.1355 | 0.3519 | 0.5413 | 0.6042 | 0.8601 | 1.0542 | 0.9325 | | 1.1450 | 1.5352 |
| | 1983 | | 0.0123 | 0.0350 | 0.0887 | 0.1739 | 0.2761 | 0.4146 | 0.5488 | 0.6837 | 0.8625 | 1.0430 | 1.0884 | 1.0481 | | 1.7014 |
| | 1984 | | | | 0.0918 | 0.1816 | 0.2678 | 0.3844 | 0.5706 | 0.6833 | 0.7779 | 0.9723 | 1.0443 | 1.3815 | 1.1931 | 1.6480 |
| | 1985 | | | 0.0391 | 0.0982 | 0.1496 | 0.2563 | 0.3698 | 0.5383 | 0.7203 | 0.8782 | 0.9041 | 1.1771 | 1.3004 | 1.0301 | 1.5836 |
| | 1986 | 0.0007 | | | 0.1310 | 0.1659 | 0.2995 | 0.3868 | 0.5744 | 0.6977 | 0.9112 | 1.0621 | 1.0572 | 0.9105 | 1.3158 | 1.5631 |
| | 1987 | | | 0.0195 | 0.1327 | | 0.3141 | 0.4250 | 0.5204 | 0.6203 | | 0.9040 | | 1.3432 | | 1.9129 |
| | 1988 | 0.0036 | | | 0.0889 | 0.1713 | | 0.5793 | 0.5299 | 0.7621 | 0.8081 | 0.9112 | 1.2072 | 1.2904 | 1.1808 | 1.3875 |
| | 1989 | 0.0007 | 0.0155 | 0.0326 | 0.0791 | 0.1893 | 0.3111 | 0.6190 | 0.6979 | 0.8100 | 0.9369 | 1.0579 | | 1.2782 | | 2.2664 |
| | 1990 | 0.0008 | 0.0231 | 0.0269 | 0.1151 | 0.1702 | 0.3120 | 0.4196 | 0.5688 | 0.7716 | 1.0079 | | | 1.5407 | 1.0922 | 1.8824 |
| | 1991 | 0.0006 | 0.0155 | 0.0491 | 0.1095 | 0.1803 | 0.3383 | 0.5222 | 0.7915 | 0.8201 | 0.6711 | 1.2865 | 1.3420 | | | |
| | 1992 | 0.0006 | 0.0181 | 0.0654 | 0.1288 | 0.2028 | 0.3662 | 0.3861 | | | 0.6915 | 0.8788 | 0.7444 | | 0.8788 | 1.3961 |
| | 1993 | 0.0006 | 0.0133 | 0.0600 | 0.1431 | 0.2108 | 0.3065 | 0.5220 | 0.5773 | 0.7122 | | 1.2822 | 0.9898 | | 2.0425 | 1.4493 |
| | 1994 | 0.0006 | 0.0202 | 0.0467 | 0.0676 | 0.2050 | 0.3138 | 0.5493 | 0.5874 | | 1.2046 | 0.9017 | | 0.9650 | | 1.4391 |
| | 1995 | 0.0008 | 0.0209 | 0.0566 | 0.0999 | 0.1490 | 0.2684 | 0.3821 | | | 1.1259 | 0.9099 | | | | 1.2754 |
| | 1996 | 0.0005 | 0.0124 | 0.0326 | 0.0837 | 0.1471 | 0.2332 | 0.4038 | 0.5046 | 0.7315 | 0.8537 | | 1.1060 | | | |
| | 1997 | 0.0008 | 0.0200 | 0.0399 | 0.0949 | 0.1714 | 0.2697 | 0.3491 | 0.5110 | | | | | 0.7050 | | |
| | 1998 | 0.0006 | 0.0187 | 0.0565 | 0.0928 | 0.1700 | 0.2664 | 0.3951 | 0.4948 | 0.5964 | 0.6677 | | | | | |
| | mean | 0.0009 | 0.0173 | 0.0431 | 0.1006 | 0.1774 | 0.2834 | 0.4388 | 0.5705 | 0.7087 | 0.8755 | 1.0129 | 1.0689 | 1.1763 | 1.2348 | 1.6185 |

Table A21. Proportion mature at age for female witch flounder derived from probit analysis of NEFSC spring bottom trawl surveys, 1980-1998.

| | Age | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11+ |
| 1980-1982 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.15 | 0.49 | 0.82 | 0.97 | 1.00 | 1.00 |
| 1983-1984 | 0.00 | 0.00 | 0.00 | 0.04 | 0.20 | 0.52 | 0.80 | 0.97 | 1.00 | 1.00 | 1.00 |
| 1985-1990 | 0.00 | 0.00 | 0.01 | 0.15 | 0.65 | 0.96 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1991-1993 | 0.00 | 0.00 | 0.00 | 0.01 | 0.10 | 0.40 | 0.80 | 0.97 | 1.00 | 1.00 | 1.00 |
| 1994-1998 | 0.00 | 0.00 | 0.00 | 0.08 | 0.45 | 0.85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Note: No maturity at age data before 1980.

Table A22. Stratified mean weight (kg) per tow of mature witch flounder (spawning stock biomass) in the NEFSC spring bottom trawl survey in the Gulf of Maine-Georges Bank region (Strata 22-30, 36-40), 1963-1998.

| Year | Spring |
|---|---|
| 1963 | - |
| 1964 | - |
| 1965 | - |
| 1966 | - |
| 1967 | - |
| 1968 | 2.930 |
| 1969 | 2.300 |
| 1970 | 4.073 |
| 1971 | 1.907 |
| 1972 | 3.772 |
| 1973 | 5.868 |
| 1974 | 3.289 |
| 1975 | 2.499 |
| 1976 | 3.248 |
| 1977 | 1.522 |
| 1978 | 2.278 |
| 1979 | 1.480 |
| 1980 | 2.964 |
| 1981 | 3.104 |
| 1982 | 1.519 |
| 1983 | 2.166 |
| 1984 | 1.383 |
| 1985 | 2.607 |
| 1986 | 1.329 |
| 1987 | 0.638 |
| 1988 | 0.836 |
| 1989 | 0.637 |
| 1990 | 0.200 |
| 1991 | 0.455 |
| 1992 | 0.356 |
| 1993 | 0.186 |
| 1994 | 0.325 |
| 1995 | 0.377 |
| 1996 | 0.174 |
| 1997 | 0.251 |
| 1998 | 0.499 |

Note: 1977-1982, 1983-1984, 1985-1990, 1991-1993, 1994-1998 ogives were used; No maturity at length data before 1977; the 1977-1982 period was applied to the 1963-1976 period.

Note: During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portuguese polyvalent doors have been used in both surveys. No significant differences in catchability were found for witch flounder, therefore no adjustments have been made (Byrne and Forrester, MS 1991). No significant differences were found between research vessels, and no adjustment have been made (Byrne and Forrester, MS 1991). Spring surveys during 1973-1981 were accomplished with a 41 Yankee trawl; in all other years, a 36 Yankee trawl was used. No adjustments have been made.

Table A23. Estimates of instantaneous total mortality (Z) for witch flounder in the Gulf of Maine-Georges Bank region, 1980-1998, derived from NEFSC spring and autumn bottom trawl survey data.

| | AGE | | | | | | | LN(7+/ 8+) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3+ | 4+ | 5+ | 6+ | 7+ | 8+ | Time Period | Spring | Autumn | Geometric Mean |
| Spring | | | | | | | | | | |
| 1980 | 8.18 | 7.23 | 5.71 | 4.99 | 3.79 | 2.77 | | | | |
| 1981 | 8.31 | 7.49 | 6.56 | 4.56 | 3.54 | 2.78 | | | | |
| 1982 | 3.58 | 3.02 | 2.45 | 2.11 | 1.90 | 1.26 | 1982-1985 | 0.46 | 0.32 | 0.38 |
| 1983 | 6.39 | 5.81 | 4.56 | 3.23 | 2.68 | 2.04 | | | | |
| 1984 | 2.99 | 2.89 | 2.56 | 1.83 | 1.41 | 1.15 | | | | |
| 1985 | 5.19 | 5.17 | 4.74 | 3.63 | 2.44 | 1.58 | | | | |
| 1986 | 2.08 | 2.08 | 2.04 | 1.80 | 1.27 | 0.84 | 1986-1989 | 0.79 | 0.72 | 0.75 |
| 1987 | 1.00 | 1.00 | 0.94 | 0.82 | 0.70 | 0.44 | | | | |
| 1988 | 1.39 | 1.33 | 1.33 | 1.26 | 0.95 | 0.57 | | | | |
| 1989 | 1.90 | 1.86 | 0.88 | 0.76 | 0.69 | 0.59 | | | | |
| 1990 | 0.62 | 0.58 | 0.49 | 0.17 | 0.15 | 0.13 | 1990-1993 | 0.55 | 0.40 | 0.47 |
| 1991 | 1.65 | 0.87 | 0.76 | 0.65 | 0.46 | 0.44 | | | | |
| 1992 | 1.20 | 1.01 | 0.64 | 0.56 | 0.44 | 0.29 | | | | |
| 1993 | 1.21 | 1.07 | 0.61 | 0.28 | 0.22 | 0.14 | | | | |
| 1994 | 2.32 | 1.79 | 1.15 | 0.32 | 0.16 | 0.13 | 1994-1997 | 0.51 | 0.57 | 0.54 |
| 1995 | 1.73 | 1.15 | 0.83 | 0.65 | 0.34 | 0.23 | | | | |
| 1996 | 1.30 | 1.06 | 0.65 | 0.32 | 0.10 | 0.03 | | | | |
| 1997 | 2.08 | 1.93 | 1.22 | 0.64 | 0.18 | 0.10 | | | | |
| 1998 | 3.10 | 2.37 | 1.96 | 1.17 | 0.47 | 0.26 | | | | |
| Autumn | | | | | | | | | | |
| 1980 | 2.58 | 2.58 | 2.38 | 2.12 | 1.84 | 1.48 | | | | |
| 1981 | 3.49 | 3.25 | 2.81 | 2.20 | 1.74 | 1.47 | | | | |
| 1982 | 0.97 | 0.91 | 0.90 | 0.88 | 0.80 | 0.55 | | | | |
| 1983 | 4.71 | 4.22 | 2.62 | 1.84 | 1.33 | 0.86 | | | | |
| 1984 | 4.38 | 4.30 | 3.33 | 2.32 | 1.74 | 1.20 | | | | |
| 1985 | 2.75 | 2.68 | 2.62 | 2.02 | 1.40 | 0.82 | | | | |
| 1986 | 1.58 | 1.57 | 1.53 | 1.26 | 0.90 | 0.59 | | | | |
| 1987 | 0.44 | 0.43 | 0.43 | 0.41 | 0.36 | 0.18 | | | | |
| 1988 | 1.36 | 0.65 | 0.58 | 0.58 | 0.55 | 0.33 | | | | |
| 1989 | 0.67 | 0.59 | 0.29 | 0.28 | 0.26 | 0.22 | | | | |
| 1990 | 1.30 | 0.91 | 0.39 | 0.22 | 0.17 | 0.15 | | | | |
| 1991 | 1.68 | 1.01 | 0.66 | 0.39 | 0.24 | 0.15 | | | | |
| 1992 | 0.70 | 0.43 | 0.21 | 0.15 | 0.10 | 0.10 | | | | |
| 1993 | 1.79 | 1.24 | 0.48 | 0.25 | 0.19 | 0.16 | | | | |
| 1994 | 1.34 | 0.84 | 0.64 | 0.25 | 0.21 | 0.10 | | | | |
| 1995 | 3.21 | 1.64 | 0.78 | 0.29 | 0.07 | 0.07 | | | | |
| 1996 | 4.80 | 4.06 | 2.04 | 0.64 | 0.19 | 0.13 | | | | |
| 1997 | 2.90 | 2.37 | 1.51 | 0.73 | 0.34 | 0.02 | | | | |
| 1998 | 2.45 | 1.12 | 0.64 | 0.33 | 0.16 | 0.06 | | | | |

Table A24. Parameter estimates (with associated statistics) and estimates of terminal F from alternative ADAPT formulations for witch flounder.

| | Run 45 | Run 46 | Run 51 | Run 52 | Run 50 | Run 54 | Run 55 | Run 56 | Run 57 |
|---|---|---|---|---|---|---|---|---|---|
| CAA | 10+ | 10+ | 10+ | 10+ | 11+ | 11+ | 11+ | 11+ | 11+ |
| Est.Ages | 4,7,8,9 | 4,7,8,9 | 4,7,8,9 | 4,7,8,9 | 3- 10 | 4 - 10 | 3 - 10 | 4 - 10 | 3 - 10 |
| NMFS-s | 3, 9 | 3 , 9 | 3 - 9 | 3 - 9 | 3 - 11+ | 3 - 11+ | 3 - 11+ | 3 - 11+ | 3 - 11+ |
| NMFS-a | 3, 9 | 3, 9 | 3 - 9 | 3 - 9 | 3 - 11 + | 3 - 11+ | 3 - 11+ | 3 - 11+ | 3 - 11+ |
| LPUE-as | 7, 8, 9 | 7, 8, 9 | 7, 8, 9 | - | 7,8,9,10,11+ | - | - | - | - |
| Note: | lpue 82-98 update of 1994 assessment | lpue 82-93 | no discards lpue 82-93 | | lpue 82-93 | Appendix A | SARC: Age 3 | SARC: no 1998 shrimp discards | SARC: Age 3 no 1998 shrimp discards |
| M.S.R. | .780 | .789 | 1.857 | .894 | .697 | .811 | .812 | .899 | .812 |
| N3 (cv) | | | | | 8.37e4 | | 8.37e4 | | 8.37e4 |
| N4 (cv) | 6.28e4 .46 | 6.02e4 .46 | 4.02e4 .71 | 6.02e4 .49 | 5.92e4 | 5.99e4 | 5.92e4 | 5.39e4 | 5.92e4 |
| N5 (cv) | | | | | 1.45e4 | 1.46e4 | 1.45e4 | 1.37e4 | 1.45e4 |
| N6 (cv) | | | | | 1.45e4 | 1.46e4 | 1.45e4 | 1.41e4 | 1.45e4 |
| N7 (cv) | 1.23e4 .34 | 1.19e4 .34 | 1.24e4 .49 | 1.19e4 .36 | 1.17e4 | 1.17e4 | 1.17e4 | 1.15e4 | 1.17e4 |
| N8 (cv) | 2.78e3 .32 | 2.39e3 .36 | 1.59e4 .40 | 2.40e3 .39 | 2.49e3 | 2.23e3 | 2.50e3 | 4.52e3 | 2.50e3 |
| N9 (cv) | 1.37e3 .34 | 1.00e3 .41 | 5.09e3 .44 | 1.00e3 .44 | 1.03e3 | 9.68e2 | 1.04e3 | 1.61e3 | 1.04e3 |
| N10 (cv) | | | | | 4.20e2 | 3.90e2 | 4.20e2 | 6.94e2 | 4.20e2 |
| | | | | | | | | | |
| F 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F 2 | .003 | .003 | .001 | .003 | .003 | .002 | .003 | .001 | 0 |
| F 3 | .002 | .002 | .0 | .002 | .002 | .002 | .003 | .002 | .001 |
| F 4 | .02 | .02 | .005 | .02 | .04 | .04 | .04 | .04 | .04 |
| F 5 | .08 | .01 | .02 | .10 | .08 | .08 | .08 | .08 | .08 |
| F 6 | .11 | .11 | .09 | .11 | .11 | .11 | .11 | .11 | .11 |
| F 7 | .42 | .47 | .09 | .48 | .46 | .51 | .46 | .28 | .46 |
| F 8 | .22 | .29 | .07 | .29 | .29 | .30 | .29 | .19 | .29 |
| F 9 | .32 | .39 | .08 | .39 | .27 | .29 | .27 | .17 | .27 |
| F10 | .32 | .39 | .08 | .39 | .34 | .37 | .34 | .21 | .34 |
| F11+ | | | | | .34 | .37 | .34 | .21 | .34 |

Table A25. Results from the regression of VPA and NEFSC spring and autumn survey (RCT3 program) to estimate stock sizes at age 3 and 4 in 1999.

Analysis by RCT3 ver3.1 of data from file : RCTWIT3.DAT

**Yearclass = 1995**

| Survey/ Series | Slope | Inter- cept | Std Error | Rsquare | No. Pts | Index Value | Predicted Value | Std Error | WAP Weights |
|---|---|---|---|---|---|---|---|---|---|
| NESP3 | .64 | 7.62 | .54 | .582 | 16 | 4.30 | 10.39 | .632 | .595 |
| NEFL3 | .66 | 7.22 | .66 | .487 | 16 | 4.90 | 10.48 | .765 | .405 |
| | | | | | | VPA Mean = | 9.32 | .621 | .000 |

**Yearclass = 1996**

| Survey/ Series | Slope | Inter- cept | Std Error | Rsquare | No. Pts | Index Value | Predicted Value | Std Error | WAP Weights |
|---|---|---|---|---|---|---|---|---|---|
| NESP3 | .64 | 7.62 | .54 | .582 | 16 | 4.57 | 10.56 | .642 | 1.000 |
| NEFL3 | | | | | | | | | |
| | | | | | | VPA Mean = | 9.32 | .621 | .000 |

| Year Class | Weighted Average Prediction | Log WAP | Int Std Error | Ext Std Error | Var Ratio | VPA | Log VPA |
|---|---|---|---|---|---|---|---|
| 1995 | 33693 | 10.43 | .49 | .04 | .01 | | |
| 1996 | 38706 | 10.56 | .64 | .00 | .00 | | |

Data for 2 surveys over 18 years : 1979 - 1996
Regression type = C
Tapered time weighting not applied
Survey weighting not applied
Final estimates not shrunk towards mean
Estimates with S.E.'S greater than that of mean included
Minimum S.E. for any survey taken as .00
Minimum of 16 points used for regression
Forecast/Hindcast variance correction used

Analysis by RCT3 ver3.1 of data from file : rctwit4r.dat

**Yearclass = 1995**

| Survey/ Series | Slope | Inter- cept | Std Error | Rsquare | No. Pts | Index Value | Predicted Value | Std Error | WAP Weights |
|---|---|---|---|---|---|---|---|---|---|
| NESP4 | .68 | 6.89 | .53 | .604 | 15 | 4.41 | 9.88 | .601 | 1.000 |
| NEFL4 | | | | | | | | | |
| | | | | | | VPA Mean = | 9.10 | .626 | .000 |

| Year Class | Weighted Average Prediction | Log WAP | Int Std Error | Ext Std Error | Var Ratio | VPA | Log VPA |
|---|---|---|---|---|---|---|---|
| 1995 | 19457 | 9.88 | .60 | .00 | .00 | | |

Data for 2 surveys over 18 years : 1979 - 1996
Regression type = C
Tapered time weighting not applied
Survey weighting not applied
Final estimates not shrunk towards mean
Estimates with S.E.'S greater than that of mean included
Minimum S.E. for any survey taken as .00
Minimum of 15 points used for regression
Forecast/Hindcast variance correction used.

Table A26. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F) and spawning stock biomass (mt) for witch flounder estimated form virtual population analysis, 1982-1998. **Bold values** in 1999 are estimated from RCT3 (regressions of VPA stock sizes and corresponding NEFSC surveys); **bold value** in 1998 was back-calculated.

STOCK NUMBERS (Jan 1) in thousands

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 15434 | 17862 | 15866 | 7326 | 4876 | 2950 | 9502 | 6359 | 6871 | 8949 | 15279 | 10906 | 13869 | 27833 | 26142 | 20549 | **22686** | **38706** |
| 4 | 12807 | 13107 | 15061 | 13520 | 6191 | 4176 | 2519 | 7622 | 5059 | 5595 | 7293 | 12780 | 9000 | 11898 | 23361 | 22390 | 17590 | **19457** |
| 5 | 9766 | 10035 | 10033 | 11603 | 10546 | 4979 | 3426 | 2038 | 6155 | 3764 | 4437 | 5108 | 9322 | 6816 | 9668 | 19224 | 18322 | **14573** |
| 6 | 7903 | 7285 | 7227 | 6777 | 8022 | 7669 | 3852 | 2704 | 1693 | 4270 | 2430 | 3015 | 3079 | 5461 | 4756 | 6486 | 15185 | **14577** |
| 7 | 4566 | 5433 | 4809 | 4606 | 4037 | 4330 | 5414 | 2705 | 2035 | 1218 | 3135 | 1216 | 1742 | 1453 | 3102 | 2867 | 4296 | **11693** |
| 8 | 2990 | 3313 | 3201 | 2760 | 2550 | 2021 | 2266 | 3377 | 1621 | 1495 | 827 | 2028 | 492 | 731 | 462 | 1342 | 1525 | **2228** |
| 9 | 2341 | 1965 | 1944 | 1366 | 1218 | 1420 | 931 | 879 | 2086 | 955 | 1057 | 523 | 1201 | 241 | 381 | 153 | 605 | **968** |
| 10 | 1372 | 1644 | 1007 | 1027 | 613 | 665 | 776 | 429 | 431 | 1483 | 547 | 743 | 247 | 533 | 117 | 128 | 55 | **390** |
| 11+ | 9014 | 5364 | 4581 | 3459 | 2073 | 1280 | 1728 | 1203 | 938 | 1213 | 1711 | 1034 | 700 | 307 | 230 | 178 | 246 | **179** |
| 3+ | 66193 | 66008 | 63729 | 52444 | 40126 | 29490 | 30414 | 27316 | 26889 | 28942 | 36716 | 37353 | 39652 | 55273 | 68219 | 73317 | 80510 | 102771 |

FISHING MORTALITY

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.07 | 0.08 | 0.06 | 0.05 | 0.03 | 0.04 | 0.00 | 0.03 | 0.00 | 0.01 | 0.00 |
| 4 | 0.09 | 0.12 | 0.11 | 0.10 | 0.07 | 0.05 | 0.06 | 0.06 | 0.15 | 0.08 | 0.21 | 0.17 | 0.13 | 0.06 | 0.04 | 0.05 | 0.04 |
| 5 | 0.14 | 0.18 | 0.24 | 0.22 | 0.17 | 0.11 | 0.09 | 0.04 | 0.22 | 0.29 | 0.24 | 0.36 | 0.38 | 0.21 | 0.25 | 0.09 | 0.08 |
| 6 | 0.22 | 0.27 | 0.30 | 0.37 | 0.47 | 0.20 | 0.20 | 0.13 | 0.18 | 0.16 | 0.54 | 0.40 | 0.60 | 0.42 | 0.36 | 0.26 | 0.11 |
| 7 | 0.17 | 0.38 | 0.41 | 0.44 | 0.54 | 0.50 | 0.32 | 0.36 | 0.16 | 0.24 | 0.29 | 0.76 | 0.72 | 1.00 | 0.69 | 0.48 | 0.51 |
| 8 | 0.27 | 0.38 | 0.70 | 0.67 | 0.44 | 0.62 | 0.80 | 0.33 | 0.38 | 0.20 | 0.31 | 0.37 | 0.57 | 0.50 | 0.95 | 0.65 | 0.30 |
| 9 | 0.20 | 0.52 | 0.49 | 0.65 | 0.45 | 0.45 | 0.62 | 0.56 | 0.19 | 0.41 | 0.20 | 0.60 | 0.66 | 0.57 | 0.94 | 0.88 | 0.29 |
| 10 | 0.21 | 0.41 | 0.51 | 0.55 | 0.50 | 0.53 | 0.46 | 0.37 | 0.23 | 0.26 | 0.27 | 0.52 | 0.68 | 0.79 | 0.75 | 0.55 | 0.37 |
| 11+ | 0.21 | 0.41 | 0.51 | 0.55 | 0.50 | 0.53 | 0.46 | 0.37 | 0.23 | 0.26 | 0.27 | 0.52 | 0.68 | 0.79 | 0.75 | 0.55 | 0.37 |
| 7-9 | 0.21 | 0.43 | 0.53 | 0.59 | 0.48 | 0.53 | 0.58 | 0.42 | 0.24 | 0.28 | 0.27 | 0.58 | 0.65 | 0.69 | 0.86 | 0.67 | 0.37 |

Table A26. Continued.

MEAN BIOMASS

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 2164 | 2447 | 2214 | 863 | 402 | 221 | 384 | 694 | 385 | 502 | 1441 | 1211 | 900 | 1481 | 1477 | 1123 | 1978 |
| 4 | 2750 | 2323 | 3036 | 2837 | 1146 | 724 | 461 | 1167 | 819 | 994 | 1411 | 2214 | 1587 | 1837 | 3290 | 3976 | 3191 |
| 5 | 2785 | 2310 | 2722 | 2959 | 2700 | 1309 | 949 | 597 | 1325 | 1049 | 1395 | 1275 | 2022 | 1763 | 1865 | 4298 | 4896 |
| 6 | 2775 | 2438 | 2450 | 2269 | 2443 | 2804 | 1408 | 1000 | 632 | 1547 | 805 | 1003 | 931 | 1798 | 1586 | 1908 | 5600 |
| 7 | 2148 | 2186 | 1989 | 1965 | 1553 | 1788 | 2322 | 1215 | 1026 | 584 | 1561 | 428 | 622 | 485 | 1164 | 1052 | 1729 |
| 8 | 1775 | 1574 | 1431 | 1303 | 1305 | 965 | 978 | 1827 | 866 | 887 | 491 | 1051 | 243 | 371 | 198 | 581 | 829 |
| 9 | 1747 | 1139 | 1174 | 792 | 780 | 883 | 531 | 515 | 1500 | 612 | 732 | 325 | 684 | 156 | 198 | 83 | 414 |
| 10 | 1134 | 1231 | 679 | 713 | 441 | 474 | 569 | 324 | 377 | 1183 | 394 | 555 | 152 | 337 | 75 | 95 | 42 |
| 11+ | 10652 | 5580 | 4484 | 3306 | 2016 | 1213 | 1713 | 1272 | 1134 | 1412 | 1735 | 1007 | 601 | 247 | 187 | 166 | 253 |
| 3+ | 27930 | 21228 | 20179 | 17007 | 12786 | 10381 | 9315 | 8611 | 8064 | 8770 | 9965 | 9069 | 7742 | 8475 | 10040 | 13282 | 18934 |

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

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 0 | 0 | 0 | 5 | 2 | 1 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 88 | 107 | 368 | 145 | 79 | 47 | 96 | 109 | 6 | 8 | 17 | 108 | 100 | 172 | 189 | 136 |
| 5 | 55 | 486 | 483 | 1872 | 1729 | 769 | 522 | 328 | 787 | 89 | 114 | 127 | 913 | 719 | 814 | 1638 | 1746 |
| 6 | 423 | 1297 | 1175 | 2238 | 2453 | 2501 | 1255 | 901 | 577 | 534 | 344 | 446 | 854 | 1466 | 1345 | 1493 | 3658 |
| 7 | 1105 | 1859 | 1648 | 2037 | 1719 | 1858 | 2417 | 1239 | 964 | 460 | 1185 | 415 | 724 | 589 | 1319 | 1184 | 1617 |
| 8 | 1589 | 1708 | 1579 | 1469 | 1429 | 1074 | 1184 | 1888 | 932 | 877 | 486 | 1152 | 265 | 398 | 242 | 693 | 761 |
| 9 | 1807 | 1336 | 1237 | 894 | 846 | 960 | 614 | 577 | 1499 | 659 | 758 | 373 | 780 | 169 | 244 | 101 | 416 |
| 10 | 1206 | 1393 | 772 | 811 | 499 | 543 | 632 | 350 | 375 | 1258 | 438 | 610 | 192 | 410 | 95 | 107 | 46 |
| 11 | 11939 | 6633 | 5492 | 4085 | 2458 | 1491 | 2069 | 1497 | 1280 | 1609 | 1982 | 1235 | 771 | 326 | 244 | 205 | 272 |
| 1+ | 18124 | 14801 | 12493 | 13779 | 11281 | 9277 | 8743 | 6879 | 6526 | 5492 | 5315 | 4375 | 4608 | 4178 | 4475 | 5611 | 8652 |

Table A27. Yield and Spawning Stock biomass per recruit results for witch flounder.

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

Run Date: 2- 6-1999; Time: 20:32:18.77 Witch flounder 1998

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .150
Initial age is: 1; Last age is: 14
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file: ==> witch-t.dat

Age-specific Input data for Yield per Recruit Analysis

| Age | Fish Mort Pattern | Nat Mort Pattern | Proportion Mature | Average Weights Catch | Average Weights Stock |
|---|---|---|---|---|---|
| 1 | .0010 | 1.0000 | .0000 | .011 | .009 |
| 2 | .0050 | 1.0000 | .0000 | .030 | .018 |
| 3 | .0130 | 1.0000 | .0000 | .094 | .056 |
| 4 | .0730 | 1.0000 | .0800 | .199 | .140 |
| 5 | .2330 | 1.0000 | .4500 | .299 | .247 |
| 6 | .4730 | 1.0000 | .8500 | .419 | .357 |
| 7 | 1.0000 | 1.0000 | 1.0000 | .549 | .484 |
| 8 | 1.0000 | 1.0000 | 1.0000 | .677 | .615 |
| 9 | 1.0000 | 1.0000 | 1.0000 | .846 | .764 |
| 10 | 1.0000 | 1.0000 | 1.0000 | .973 | .907 |
| 11 | 1.0000 | 1.0000 | 1.0000 | 1.104 | 1.040 |
| 12 | 1.0000 | 1.0000 | 1.0000 | 1.236 | 1.170 |
| 13 | 1.0000 | 1.0000 | 1.0000 | 1.381 | 1.309 |
| 14+ | 1.0000 | 1.0000 | 1.0000 | 1.541 | 1.541 |

Summary of Yield per Recruit Analysis for:Witch flounder 1998
Slope of the Yield/Recruit Curve at F=0.00: --> 3.1526
F level at slope=1/10 of the above slope (F0.1): -----> .157
Yield/Recruit corresponding to F0.1: -----> .1834
F level to produce Maximum Yield/Recruit (Fmax): -----> .353
Yield/Recruit corresponding to Fmax: -----> .2030
F level at 20 % of Max Spawning Potential (F20): -----> .371
SSB/Recruit corresponding to F20: --------> .6506

Listing of Yield per Recruit Results for: Witch flounder 1998

| | FMORT | TOTCTHN | TOTCTHW | TOTSTKN | TOTSTKW | SPNSTKN | SPNSTKW | % MSP |
|---|---|---|---|---|---|---|---|---|
| | .00 | .00000 | .00000 | 7.1792 | 3.5838 | 3.5290 | 3.2535 | 100.00 |
| | .05 | .11648 | .10680 | 6.4045 | 2.5600 | 2.7572 | 2.2381 | 68.79 |
| | .10 | .18710 | .15641 | 5.9355 | 1.9824 | 2.2912 | 1.6673 | 51.25 |
| | .15 | .23477 | .18103 | 5.6194 | 1.6203 | 1.9781 | 1.3107 | 40.29 |
| F0.1 | .16 | .24034 | .18336 | 5.5825 | 1.5798 | 1.9416 | 1.2710 | 39.07 |
| | .20 | .26931 | .19349 | 5.3908 | 1.3764 | 1.7524 | 1.0715 | 32.94 |
| | .25 | .29564 | .19961 | 5.2168 | 1.2034 | 1.5815 | .9025 | 27.74 |
| | .30 | .31648 | .20229 | 5.0794 | 1.0755 | 1.4471 | .7780 | 23.91 |
| | .35 | .33347 | .20304 | 4.9676 | .9777 | 1.3383 | .6832 | 21.00 |
| Fmax | .35 | .33429 | .20305 | 4.9622 | .9732 | 1.3330 | .6788 | 20.86 |
| F20% | .37 | .33960 | .20300 | 4.9272 | .9440 | 1.2992 | .6506 | 20.00 |
| | .40 | .34765 | .20271 | 4.8744 | .9010 | 1.2481 | .6091 | 18.72 |
| | .45 | .35971 | .20176 | 4.7952 | .8393 | 1.1720 | .5497 | 16.90 |
| | .50 | .37015 | .20047 | 4.7269 | .7887 | 1.1068 | .5013 | 15.41 |
| | .55 | .37930 | .19900 | 4.6671 | .7465 | 1.0500 | .4610 | 14.17 |
| | .60 | .38741 | .19746 | 4.6141 | .7107 | 1.0001 | .4271 | 13.13 |
| | .65 | .39468 | .19589 | 4.5668 | .6800 | .9558 | .3981 | 12.24 |
| | .70 | .40124 | .19433 | 4.5240 | .6534 | .9161 | .3731 | 11.47 |
| | .75 | .40722 | .19281 | 4.4851 | .6300 | .8803 | .3512 | 10.80 |
| | .80 | .41270 | .19133 | 4.4495 | .6093 | .8478 | .3320 | 10.20 |
| | .85 | .41776 | .18990 | 4.4167 | .5908 | .8181 | .3148 | 9.68 |
| | .90 | .42245 | .18851 | 4.3863 | .5741 | .7908 | .2995 | 9.21 |
| | .95 | .42681 | .18718 | 4.3580 | .5590 | .7655 | .2857 | 8.78 |
| | 1.00 | .43090 | .18590 | 4.3316 | .5453 | .7422 | .2732 | 8.40 |

Table A28. Yield per recruit results for witch flounder where catch mean weight at age have been dis-aggregated by landings, large-mesh otter trawl discards, and shrimp fishery discards.

```
The NEFC Yield and Stock Size per Recruit Program - PDBYPRCM
 PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
          Run Date:  1- 6-1999;  Time: 15:58:07.43 Witch flounder 1998
Proportion of F before spawning:  .1667
Proportion of M before spawning:  .1667
Natural Mortality is Constant at:  .150
Initial age is:  1; Last age is: 14
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:==> witch.dat
Age-specific Input data for Yield per Recruit Analysis
```

| Age | Fish Mort Pattern | Nat Mort Pattern | Prop Mat | Proportion of F Lndgs | LMOT | Shmp | Average Weights Catch | Lndgs | LMDsc | ShDsc |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0010 | 1.0000 | .00 | .00 | .00 | 1.00 | .011 | .000 | .014 | .012 |
| 2 | .0050 | 1.0000 | .00 | .00 | .01 | .99 | .030 | .000 | .041 | .029 |
| 3 | .0130 | 1.0000 | .00 | .00 | .23 | .77 | .094 | .208 | .103 | .053 |
| 4 | .0730 | 1.0000 | .08 | .11 | .85 | .04 | .199 | .279 | .154 | .114 |
| 5 | .2330 | 1.0000 | .45 | .38 | .62 | .00 | .299 | .347 | .185 | .199 |
| 6 | .4730 | 1.0000 | .85 | .88 | .12 | .00 | .419 | .427 | .220 | .256 |
| 7 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | .549 | .549 | .220 | .256 |
| 8 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | .677 | .677 | .220 | .256 |
| 9 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | .846 | .846 | .220 | .256 |
| 10 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | .973 | .973 | .220 | .256 |
| 11 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | 1.104 | 1.104 | .220 | .256 |
| 12 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | 1.236 | 1.236 | .220 | .256 |
| 13 | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | 1.381 | 1.381 | .220 | .256 |
| 14+ | 1.0000 | 1.0000 | 1.00 | 1.00 | .00 | .00 | 1.541 | 1.541 | .220 | .256 |

```
Summary of Yield per Recruit Analysis for: Witch flounder 1998

 Slope of the Yield/Recruit Curve at F=0.00: -->       3.1156
   F level at slope=1/10 of the above slope (F0.1): ----->       .149
     Yield/Recruit corresponding to F0.1: ----->       .1754
   F level to produce Maximum Yield/Recruit (Fmax): ----->       .299
     Yield/Recruit corresponding to Fmax: ----->       .1920
```

Listing of Yield per Recruit Results for: Witch flounder 1998

| | FMORT | ALL COMPONENTS NUMBER | WEIGHT | LANDINGS ONLY NUMBER | WEIGHT | LM OT DISCARD NUMBER | WEIGHT | SHRIMP DISCARD NUMBER | WEIGHT |
|---|---|---|---|---|---|---|---|---|---|
| | .000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| | .050 | .11648 | .10680 | .10902 | .10497 | .00679 | .00123 | .00067 | .00003 |
| | .100 | .18710 | .15641 | .17232 | .15279 | .01343 | .00243 | .00135 | .00007 |
| F0.1 | .149 | .23416 | .18077 | .21232 | .17544 | .01983 | .00359 | .00201 | .00010 |
| | .150 | .23477 | .18103 | .21282 | .17568 | .01993 | .00361 | .00202 | .00010 |
| | .200 | .26931 | .19349 | .24034 | .18644 | .02628 | .00475 | .00269 | .00014 |
| | .250 | .29564 | .19961 | .25979 | .19091 | .03249 | .00587 | .00336 | .00017 |
| Fmax | .299 | .31602 | .20225 | .27358 | .19197 | .03842 | .00693 | .00402 | .00020 |
| | .300 | .31648 | .20229 | .27388 | .19197 | .03857 | .00696 | .00403 | .00021 |
| | .350 | .33347 | .20304 | .28425 | .19115 | .04451 | .00802 | .00470 | .00024 |
| | .400 | .34765 | .20271 | .29194 | .18928 | .05033 | .00906 | .00537 | .00027 |
| | .402 | .34811 | .20268 | .29218 | .18920 | .05054 | .00910 | .00539 | .00027 |
| | .450 | .35971 | .20176 | .29765 | .18683 | .05603 | .01008 | .00604 | .00031 |
| | .500 | .37015 | .20047 | .30184 | .18408 | .06160 | .01107 | .00670 | .00034 |
| | .550 | .37930 | .19900 | .30487 | .18119 | .06706 | .01204 | .00737 | .00037 |
| | .600 | .38741 | .19746 | .30697 | .17825 | .07240 | .01299 | .00803 | .00041 |
| | .650 | .39468 | .19589 | .30835 | .17532 | .07763 | .01391 | .00869 | .00044 |
| | .700 | .40124 | .19433 | .30913 | .17244 | .08276 | .01482 | .00936 | .00048 |
| | .750 | .40722 | .19281 | .30943 | .16962 | .08777 | .01570 | .01002 | .00051 |
| | .800 | .41270 | .19133 | .30934 | .16687 | .09269 | .01656 | .01068 | .00054 |
| | .850 | .41776 | .18990 | .30892 | .16420 | .09750 | .01741 | .01134 | .00058 |
| | .900 | .42245 | .18851 | .30824 | .16161 | .10221 | .01823 | .01200 | .00061 |
| | .950 | .42681 | .18718 | .30733 | .15910 | .10683 | .01904 | .01265 | .00064 |
| | 1.000 | .43090 | .18590 | .30623 | .15666 | .11136 | .01983 | .01331 | .00067 |

Table A29. Surplus production model analysis (ASPIC) of witch flounder.

CONTROL PARAMETERS USED (FROM INPUT FILE)

| | | | |
|---|---|---|---|
| Number of years analyzed: | 36 | Number of bootstrap trials: | 0 |
| Number of data series: | 2 | Lower bound on MSY: | 8.333E-02 |
| Objective function computed: | in EFFORT | Upper bound on MSY: | 7.500E+01 |
| Relative conv. criterion (simplex): | 1.000E-08 | Lower bound on r: | 2.000E-02 |
| Relative conv. criterion (restart): | 3.000E-08 | Upper bound on r: | 1.000E+01 |
| Relative conv. criterion (effort): | 1.000E-04 | Random number seed: | 1964285 |
| Maximum F allowed in fitting: | 5.000 | Monte Carlo search trials: | 50000 |

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) code 0

Normal convergence.

CORRELATION AMONG INPUT SERIES EXPRESSED AS CPUE (NUMBER OF PAIRWISE OBSERVATIONS BELOW)

| | 1 | 2 |
|---|---|---|
| 1 Fall Survey | 1.000<br>36 | |
| 2 Spring Survey (lagged) | 0.646<br>32 | 1.000<br>32 |

GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS

| Loss component number and title | Weighted SSE | N | Weighted MSE | Current weight | Suggested weight | R-squared in CPUE |
|---|---|---|---|---|---|---|
| Loss(-1) SSE in yield | 0.000E+00 | | | | | |
| Loss( 0) Penalty for B1R > 2 | 3.075E-02 | 1 | N/A | 1.000E+00 | N/A | |
| Loss( 1) Fall Survey | 7.728E+00 | 36 | 2.273E-01 | 1.000E+00 | 1.043E+00 | 0.617 |
| Loss( 2) Spring Survey (lagged) | 7.473E+00 | 32 | 2.491E-01 | 1.000E+00 | 9.517E-01 | 0.403 |

TOTAL OBJECTIVE FUNCTION: 1.52316826E+01

NOTE: B1-ratio constraint term contributing to loss. Sensitivity analysis advised.

| | |
|---|---|
| Number of restarts required for convergence: | 3 |
| Est. B-ratio coverage index (0 worst, 2 best): | 1.7246 |
| Est. B-ratio nearness index (0 worst, 1 best): | 1.0000 |

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

| Parameter | | Estimate | Starting guess | Estimated | User guess |
|---|---|---|---|---|---|
| B1R | Starting biomass ratio, year 1963 | 2.383E+00 | 1.000E+00 | 1 | 1 |
| MSY | Maximum sustainable yield | 2.684E+00 | 2.500E+00 | 1 | 1 |
| r | Intrinsic rate of increase | 2.126E-01 | 3.000E-01 | 1 | 1 |
| ........ | Catchability coefficients by fishery: | | | | |
| q( 1) | Fall Survey | 6.544E-02 | 6.544E-02 | 0 | 1 |
| q( 2) | Spring Survey (lagged) | 6.225E-02 | 6.226E-02 | 0 | 1 |

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

| Parameter | | Estimate | Formula | |
|---|---|---|---|---|
| MSY | Maximum sustainable yield | 2.684E+00 | Kr/4 | |
| K | Maximum stock biomass | 5.049E+01 | | |
| Bmsy | Stock biomass at MSY | 2.525E+01 | K/2 | |
| Fmsy | Fishing mortality at MSY | 1.063E-01 | r/2 | |
| F(0.1) | Management benchmark | 9.567E-02 | 0.9*Fmsy | |
| Y(0.1) | Equilibrium yield at F(0.1) | 2.657E+00 | 0.99*MSY | |
| B-ratio | Ratio of B(1999) to Bmsy | 2.507E-01 | | |
| F-ratio | Ratio of F(1998) to Fmsy | 2.621E+00 | | |
| Y-ratio | Proportion of MSY avail in 1999 | 4.386E-01 | 2*Br-Br^2 | Ye(1999) = 1.177E+00 |
| ........ | Fishing effort at MSY in units of each fishery: | | | |
| fmsy( 1) | Fall Survey | 1.624E+00 | r/2q( 1) | f(0.1) = 1.462E+00 |

Table A29. Continued.

RESULTS OF BOOTSTRAPPED ANALYSIS

| Param name | Bias-corrected estimate | Ordinary estimate | Relative bias | Approx 80% lower CL | Approx 80% upper CL | Approx 50% lower CL | Approx 50% upper CL | Inter-quartile range | Relative IQ range |
|---|---|---|---|---|---|---|---|---|---|
| B1ratio | 2.760E+00 | 2.383E+00 | -13.64% | 2.090E+00 | 3.425E+00 | 2.410E+00 | 3.282E+00 | 8.726E-01 | 0.316 |
| K | 4.873E+01 | 5.049E+01 | 3.61% | 4.465E+01 | 5.596E+01 | 4.650E+01 | 5.203E+01 | 5.526E+00 | 0.113 |
| r | 2.175E-01 | 2.126E-01 | -2.23% | 1.795E-01 | 2.527E-01 | 1.975E-01 | 2.342E-01 | 3.679E-02 | 0.169 |
| q(1) | 6.544E-02 | 6.544E-02 | 0.00% | 6.544E-02 | 6.544E-02 | 6.544E-02 | 6.544E-02 | 0.000E+00 | 0.000 |
| q(2) | 6.225E-02 | 6.225E-02 | 0.00% | 6.225E-02 | 6.226E-02 | 6.225E-02 | 6.225E-02 | 2.026E-14 | 0.000 |
| MSY | 2.632E+00 | 2.684E+00 | 1.96% | 2.475E+00 | 2.794E+00 | 2.554E+00 | 2.710E+00 | 1.557E-01 | 0.059 |
| Ye(1999) | 1.231E+00 | 1.177E+00 | -4.35% | 8.363E-01 | 1.662E+00 | 1.000E+00 | 1.427E+00 | 4.264E-01 | 0.347 |
| Bmsy | 2.437E+01 | 2.525E+01 | 3.61% | 2.232E+01 | 2.798E+01 | 2.325E+01 | 2.601E+01 | 2.763E+00 | 0.113 |
| Fmsy | 1.087E-01 | 1.063E-01 | -2.23% | 8.975E-02 | 1.263E-01 | 9.873E-02 | 1.171E-01 | 1.839E-02 | 0.169 |
| fmsy(1) | 1.662E+00 | 1.624E+00 | -2.23% | 1.371E+00 | 1.931E+00 | 1.509E+00 | 1.790E+00 | 2.811E-01 | 0.169 |
| fmsy(2) | 1.746E+00 | 1.708E+00 | -2.23% | 1.442E+00 | 2.029E+00 | 1.586E+00 | 1.881E+00 | 2.955E-01 | 0.169 |
| F(0.1) | 9.785E-02 | 9.567E-02 | -2.01% | 8.077E-02 | 1.137E-01 | 8.885E-02 | 1.054E-01 | 1.655E-02 | 0.169 |
| Y(0.1) | 2.606E+00 | 2.657E+00 | 1.94% | 2.450E+00 | 2.766E+00 | 2.529E+00 | 2.683E+00 | 1.541E-01 | 0.059 |
| B-ratio | 2.651E-01 | 2.507E-01 | -5.43% | 1.842E-01 | 3.727E-01 | 2.190E-01 | 3.216E-01 | 1.026E-01 | 0.387 |
| F-ratio | 2.487E+00 | 2.621E+00 | 5.42% | 1.802E+00 | 3.675E+00 | 2.134E+00 | 3.091E+00 | 9.572E-01 | 0.385 |
| Y-ratio | 4.604E-01 | 4.386E-01 | -4.73% | 3.344E-01 | 6.065E-01 | 3.900E-01 | 5.397E-01 | 1.497E-01 | 0.325 |
| f0.1(1) | 1.495E+00 | 1.462E+00 | -2.01% | 1.234E+00 | 1.738E+00 | 1.358E+00 | 1.611E+00 | 2.530E-01 | 0.169 |
| f0.1(2) | 1.572E+00 | 1.537E+00 | -2.01% | 1.297E+00 | 1.826E+00 | 1.427E+00 | 1.693E+00 | 2.659E-01 | 0.169 |
| q2/q1 | 9.513E-01 | 9.513E-01 | 0.00% | 9.513E-01 | 9.513E-01 | 9.513E-01 | 9.513E-01 | 3.096E-13 | 0.000 |

NOTES ON BOOTSTRAPPED ESTIMATES:

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

| | |
|---|---|
| Trials replaced for lack of convergence: | 0 |
| Trials replaced for MSY out-of-bounds: | 0 |
| Trials replaced for r out-of-bounds: | 0 |
| Residual-adjustment factor: | 1.0228 |

Table A30. Summary of short-term stochastic projection results for witch flounder. Projected median estimates of landings (mt), discards (mt, spawning stock biomass (mt), total biomass 3+ (mt) are provided for status quo fishing mortality ($F_{99}$ = 0.20 given 1999 catches = 1998 catches) and for the control rule fishing mortality ($F_{10th\ \%tile}$ = 0.19).

Projection input:

| Age | Fish Mort Pattern | Proportion Mature | Discard Fraction | Average Weights Catch | Stock | Discards |
|---|---|---|---|---|---|---|
| 3 | .0130 | .0000 | 1.00 | .094 | .056 | 0.030 |
| 4 | .0730 | .0800 | 0.89 | .199 | .140 | 0.078 |
| 5 | .2330 | .4500 | 0.62 | .299 | .247 | 0.149 |
| 6 | .4730 | .8500 | 0.12 | .419 | .357 | 0.189 |
| 7 | 1.0000 | 1.0000 | 0.00 | .549 | .484 | 0.235 |
| 8 | 1.0000 | 1.0000 | 0.00 | .677 | .615 | 0.235 |
| 9 | 1.0000 | 1.0000 | 0.00 | .846 | .764 | 0.235 |
| 10 | 1.0000 | 1.0000 | 0.00 | .973 | .907 | 0.235 |
| 11+ | 1.0000 | 1.0000 | 0.00 | 1.319 | 1.319 | 0.235 |

Projection results (weight reported in '000 mt)

| Scenario | Year | F full | F wb3+ | Median Landings | Median Discards | Median SSB | Median Biomass (3+) |
|---|---|---|---|---|---|---|---|
| | 1999 | 0.20 | 0.096 | 2.18 | 0.16 | 14.65 | 25.63 |
| F status quo | 2000 | 0.20 | 0.096 | 3.03 | 0.17 | 18.92 | 29.69 |
| | 2001 | 0.20 | 0.096 | 3.77 | 0.19 | 23.44 | 31.96 |
| | 1999 | 0.20 | 0.096 | 2.18 | 0.16 | 14.65 | 25.63 |
| F control rule | 2000 | 0.19* | 0.09 | 2.98 | 0.17 | 18.95 | 29.78 |
| | 2001 | 0.19* | 0.09 | 3.62 | 0.18 | 23.62 | 32.21 |

* assumes current age structure (not equilibrium age structure).

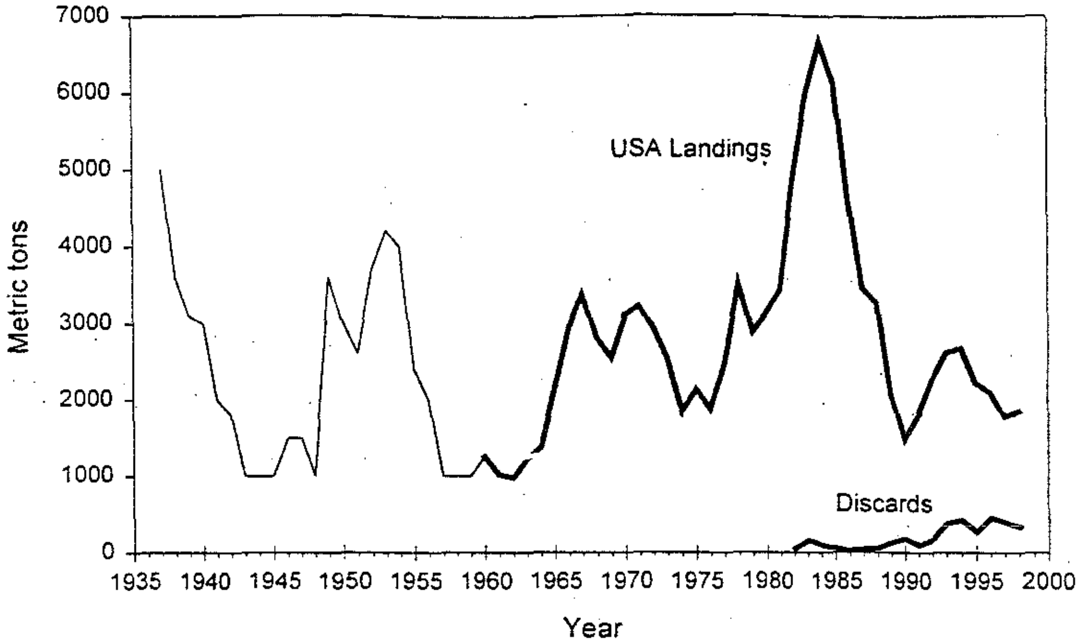



Figure A1. Historical USA witch flounder landings (mt), excluding USA landings from the Grand Banks in the mid-1980's. Thin line represents provisional landings data taken from Lange and Lux (1978). Discards from the shrimp and large-mesh otter trawl fishery.

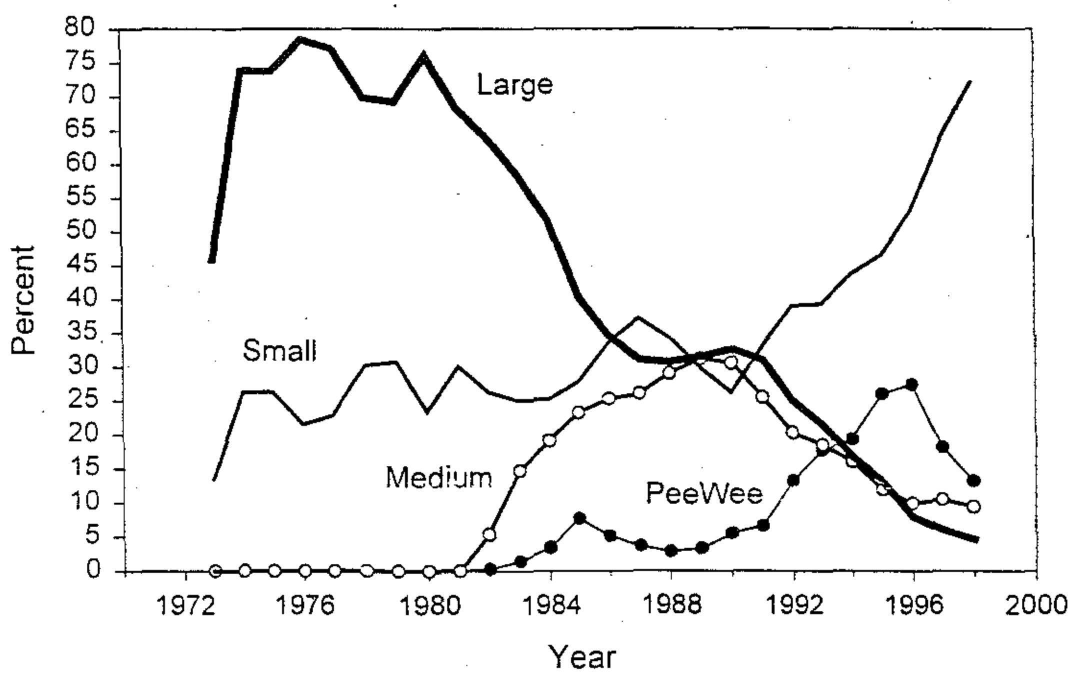



Figure A2. Commercial landings of witch flounder by maket category, 1973 - 1998.

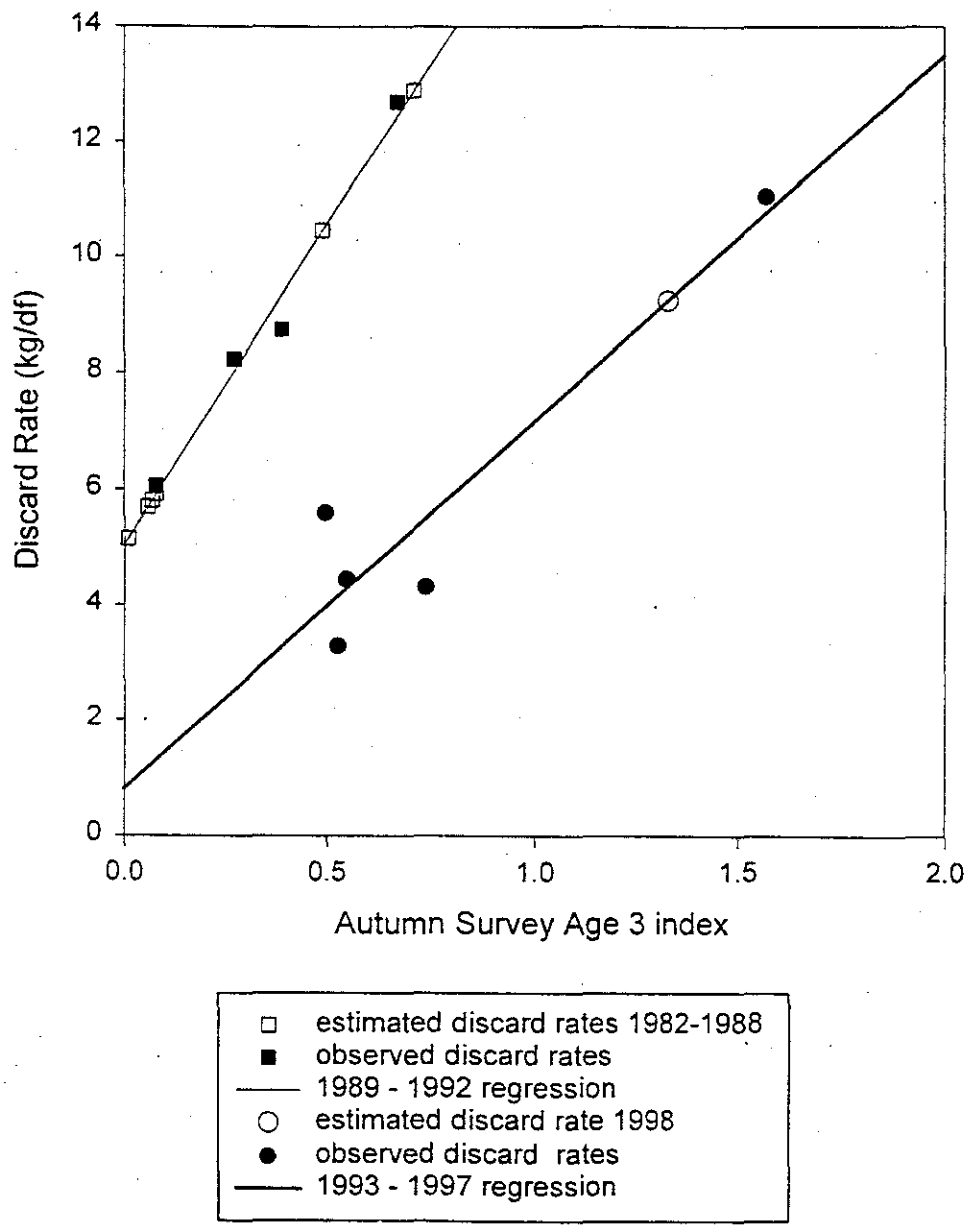



Figure A3. Observed witch flounder discard rates (kilogram per day fished, closed symbols) from the Domestic Sea Sampling Program data, and estimated discard rates (kg/df, open symbols) in the northern shrimp fishery estimated from linear regressions (solid line) of observed discard rates and NEFSC autumn survey age 3 index.

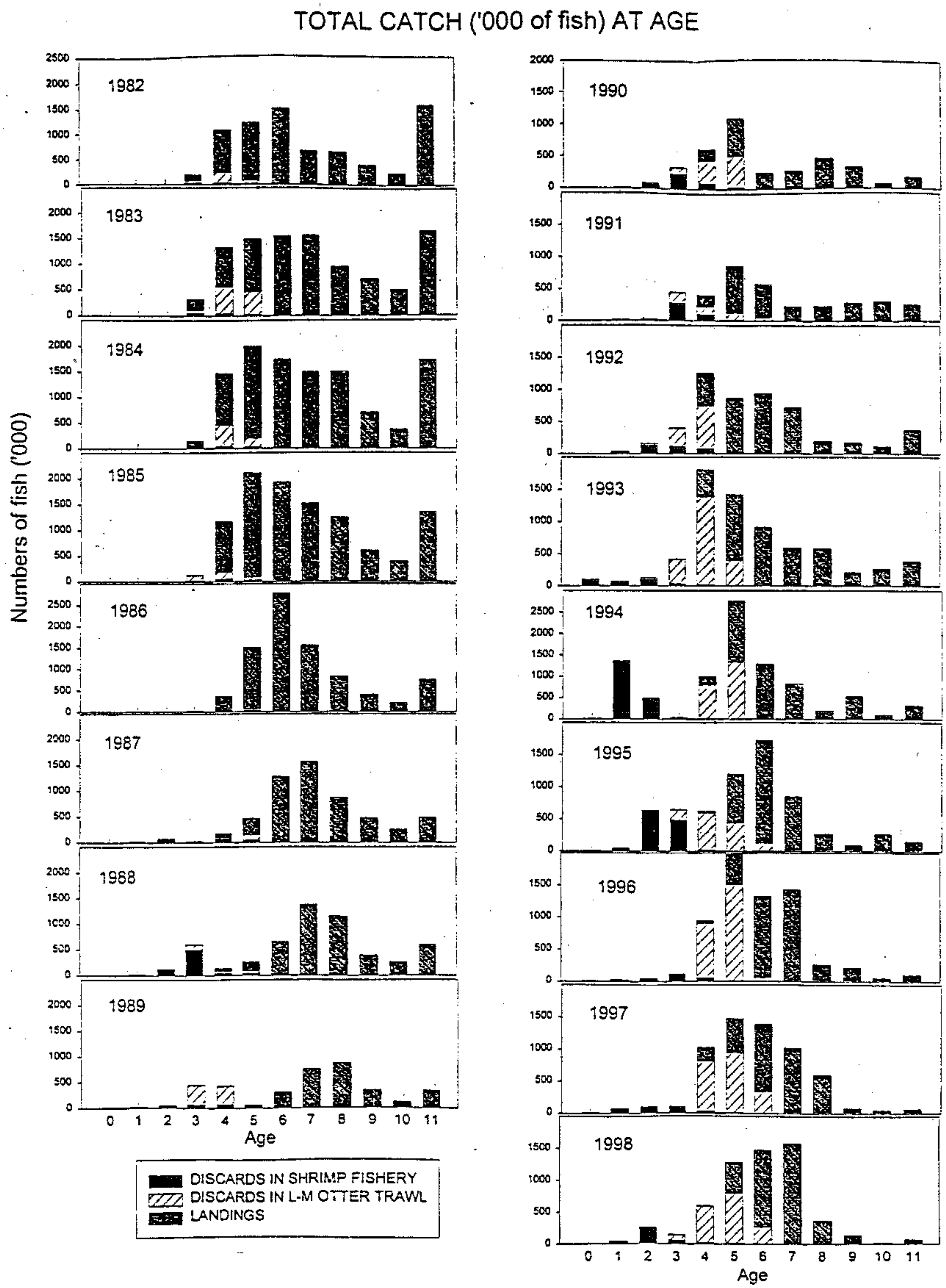



Figure A4. Number of witch flounder ('000 of fish) at age in the total catch from the Gulf of Maine - Georges Bank region, 1982-1998.

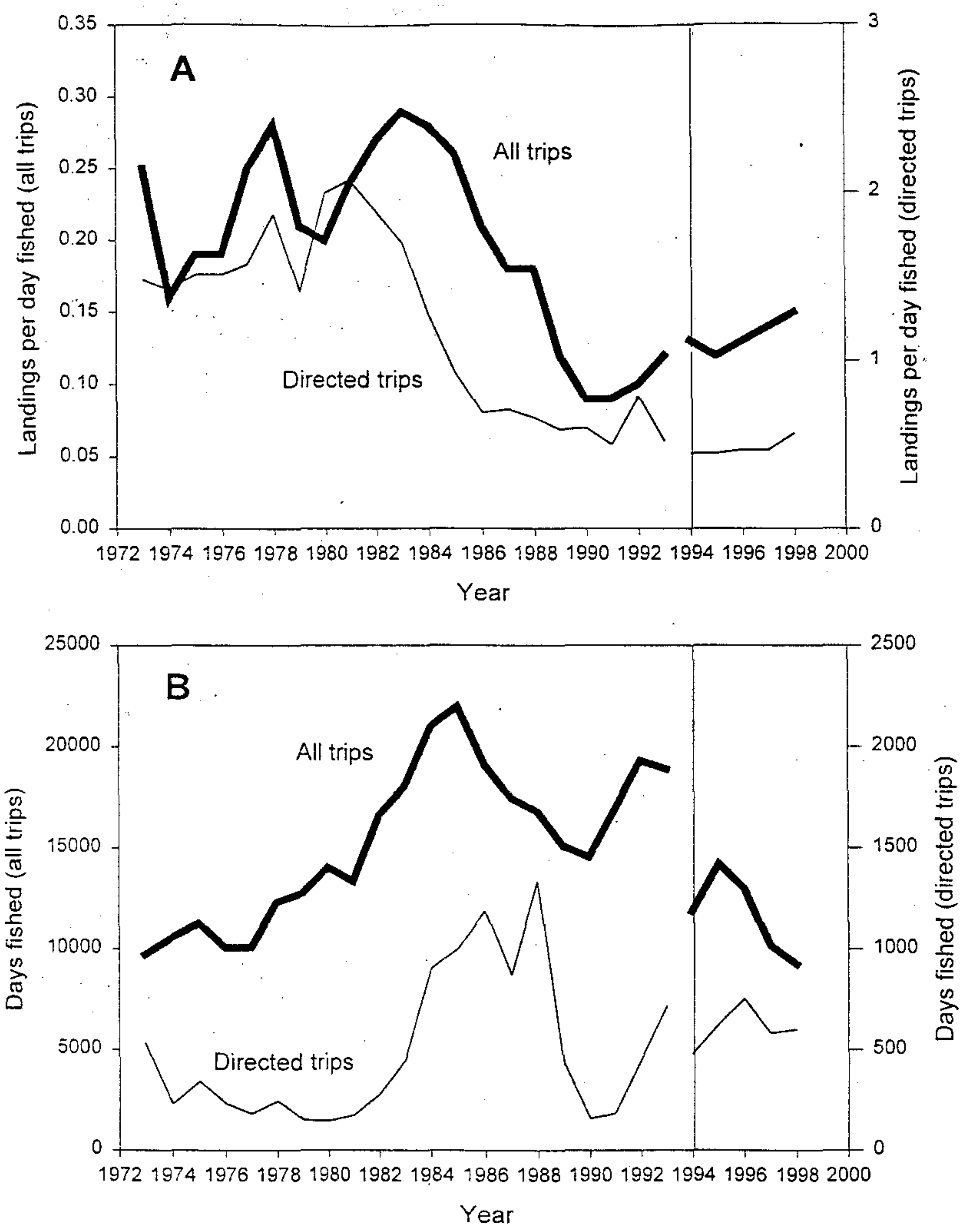



Figure A5. Trends in USA landings per day fished (A) and effort (B) of witch flounder, 1973-1998. Data are based on all otter trawl trips which witch flounder were caught (all trips) and for otter trawl trips in which witch flounder constituted 40% or more of the trip catch, by weight (directed trips). Data from 1994-1998 are base on preliminary VTR data , thus total effort (DF) may be underestimated in these years.

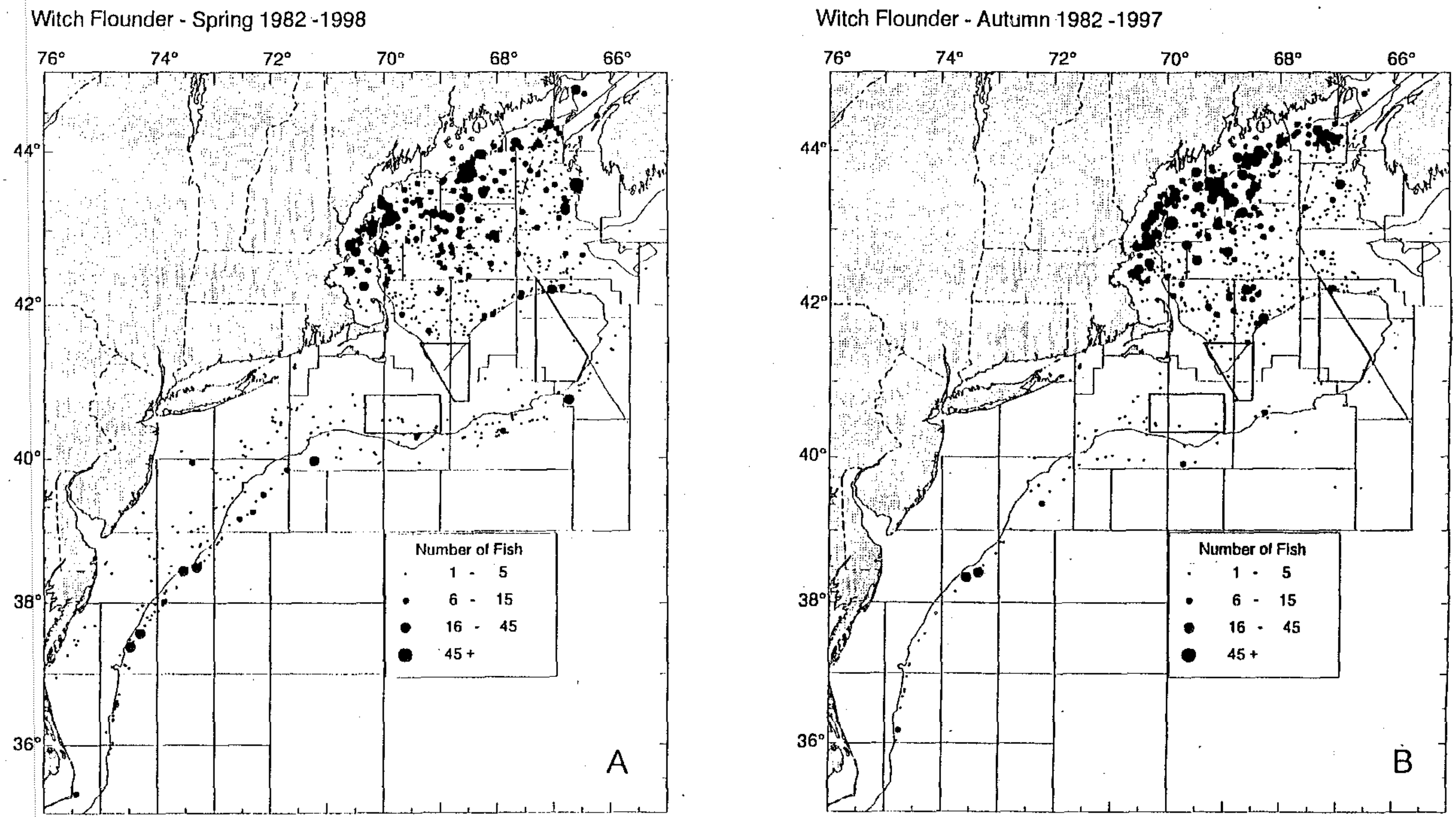



Figure A6. Distribution of witch flounder in the Northeast Fisheries Science Center spring (A) and autumn (B) research vessel bottom trawl surveys, 1982 to present.

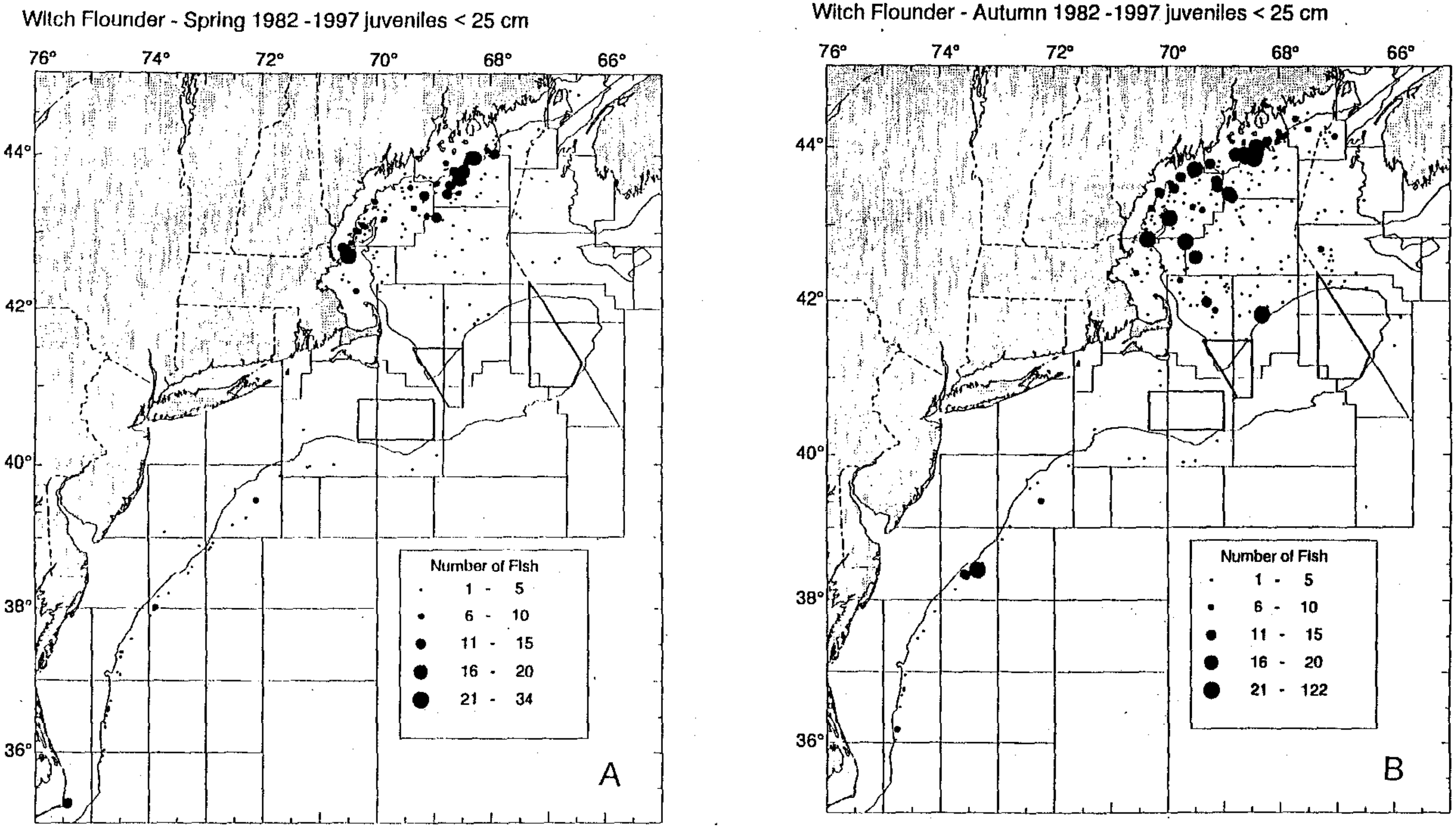



Figure A7 Distribution of juvenile (< 25 cm) witch flounder in the Northeast Fisheries Science Center spring (A) and autumn (B) research vessel bottom trawl surveys, 1982 to present.

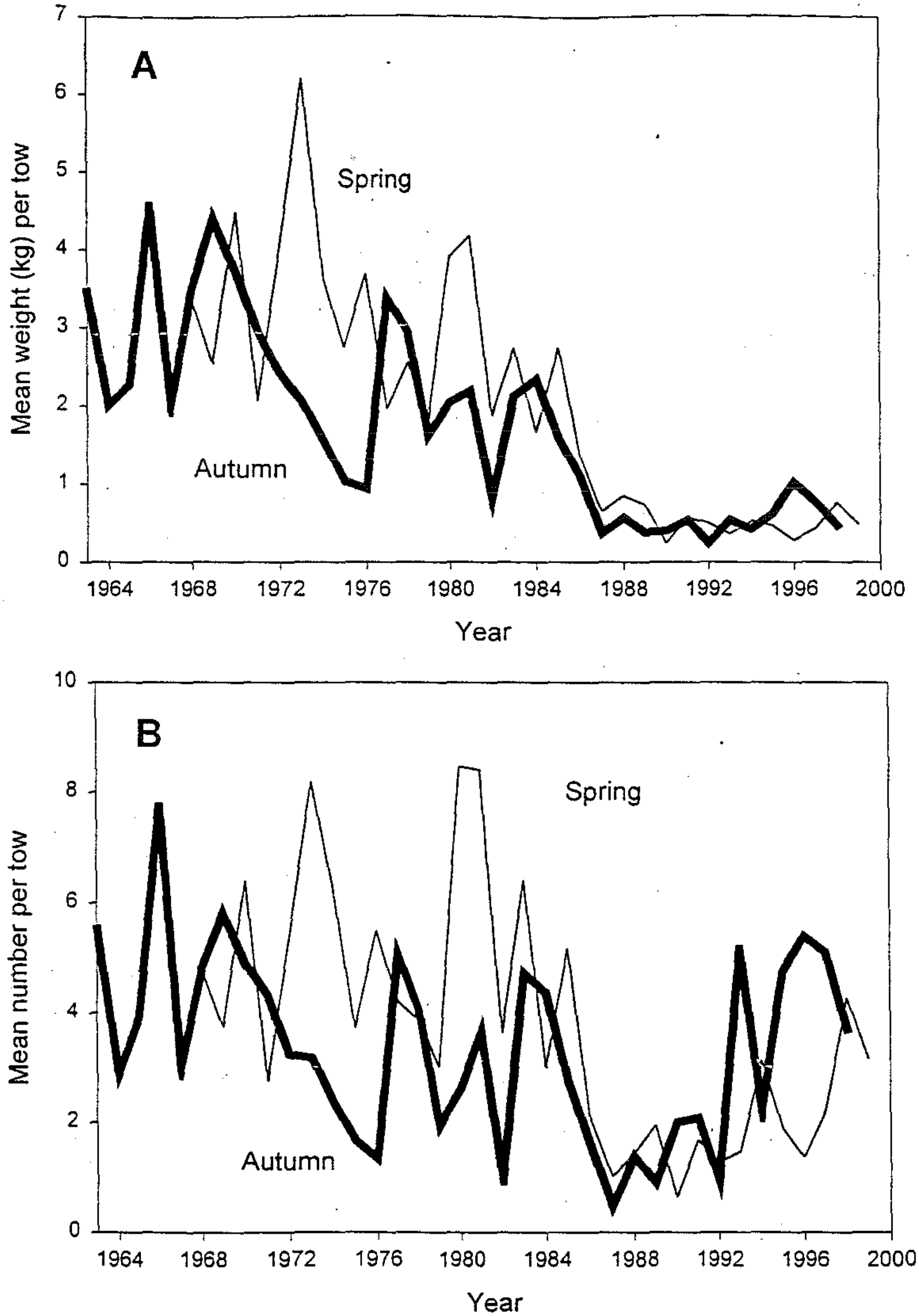



Figure A8. Stratified mean catch (kg) per tow (A) and mean number per tow (B) of witch flounder in NEFSC spring and autumn research vessel bottom trawl surveys in the Gulf of Maine-Georges Bank region, 1963 - 1998; 1999 values are preliminary.

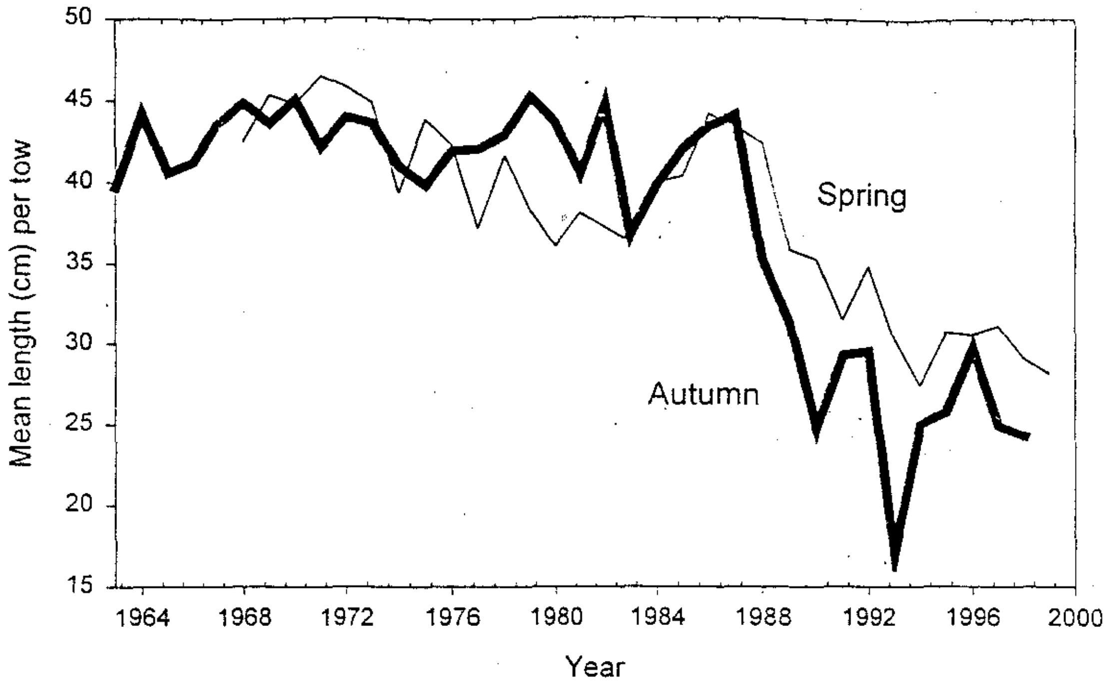



Figure A9. Stratified mean length (cm) per tow of witch flounder in NEFSC spring and autumn research vessel bottom trawl surveys in the Gulf of Maine-Georges Bank region, 1963 - 1998; 1999 value is preliminary.

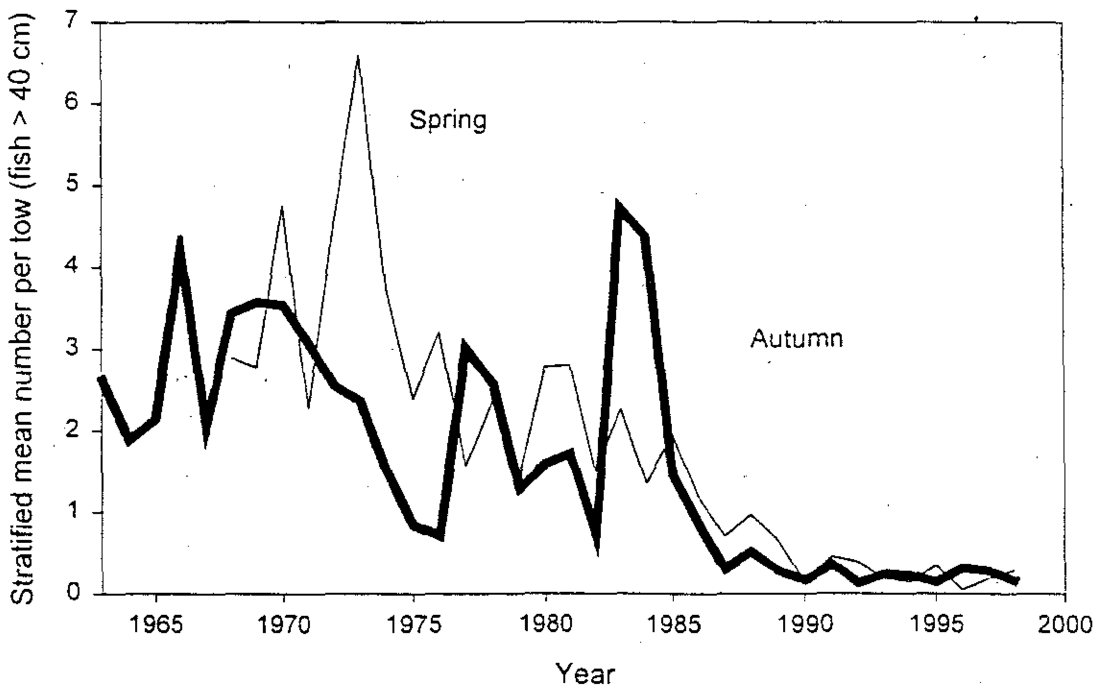



Figure A10. Stratified mean number per tow of witch flounder greater than 40 cm from the NEFSC spring and autumn bottom trawl surveys, 1963 - 1998.

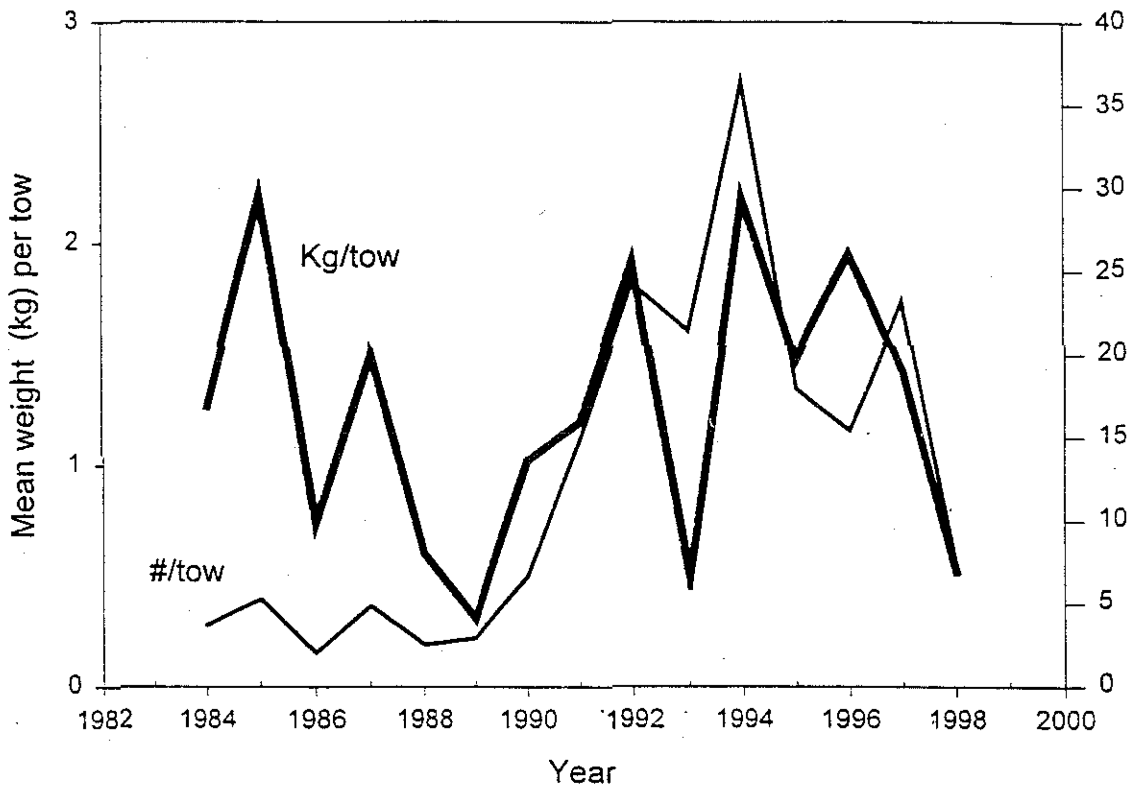



Figure A11. Stratified mean catch per tow, in weight (kg) and numbers, of witch flounder in the Atlantic States Marine Fisheries Commission summer northern shrimp trawl survey, 1984 - 1998.

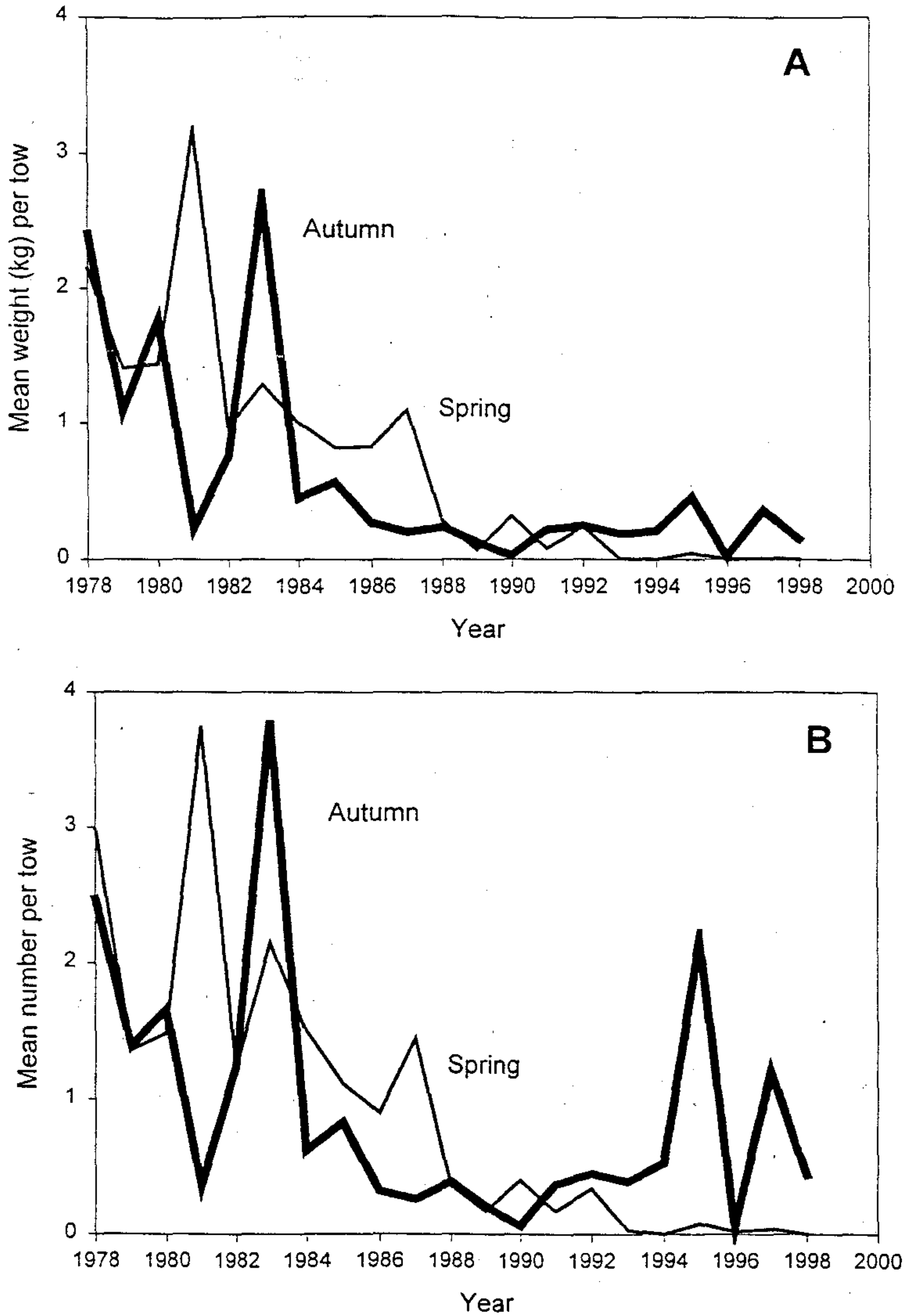
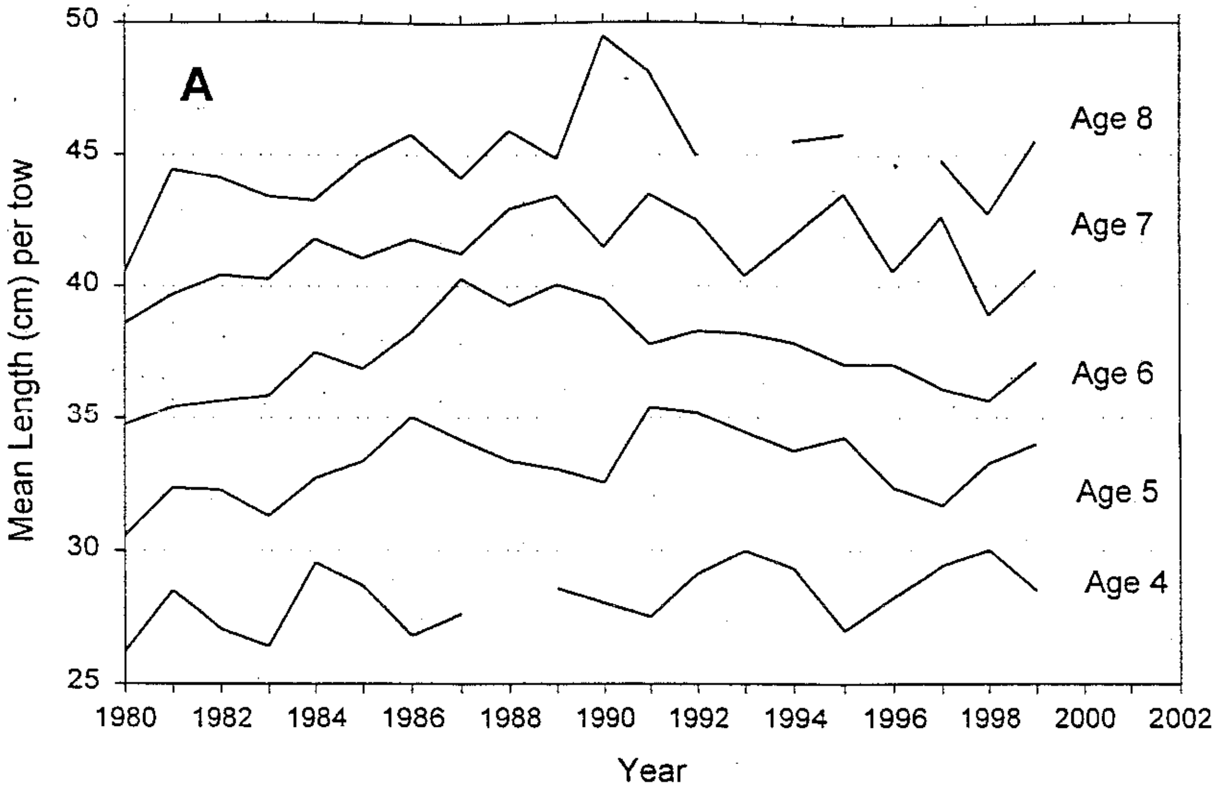



Figure A12. Stratified mean catch (kg) per tow (A) and mean number per tow (B) of witch flounder in Massachusetts Division of Marine Fisheries spring and autumn research vessel bottom trawl surveys in the Cape Cod Bay - Massachusetts Bay region, 1978 - 1998.



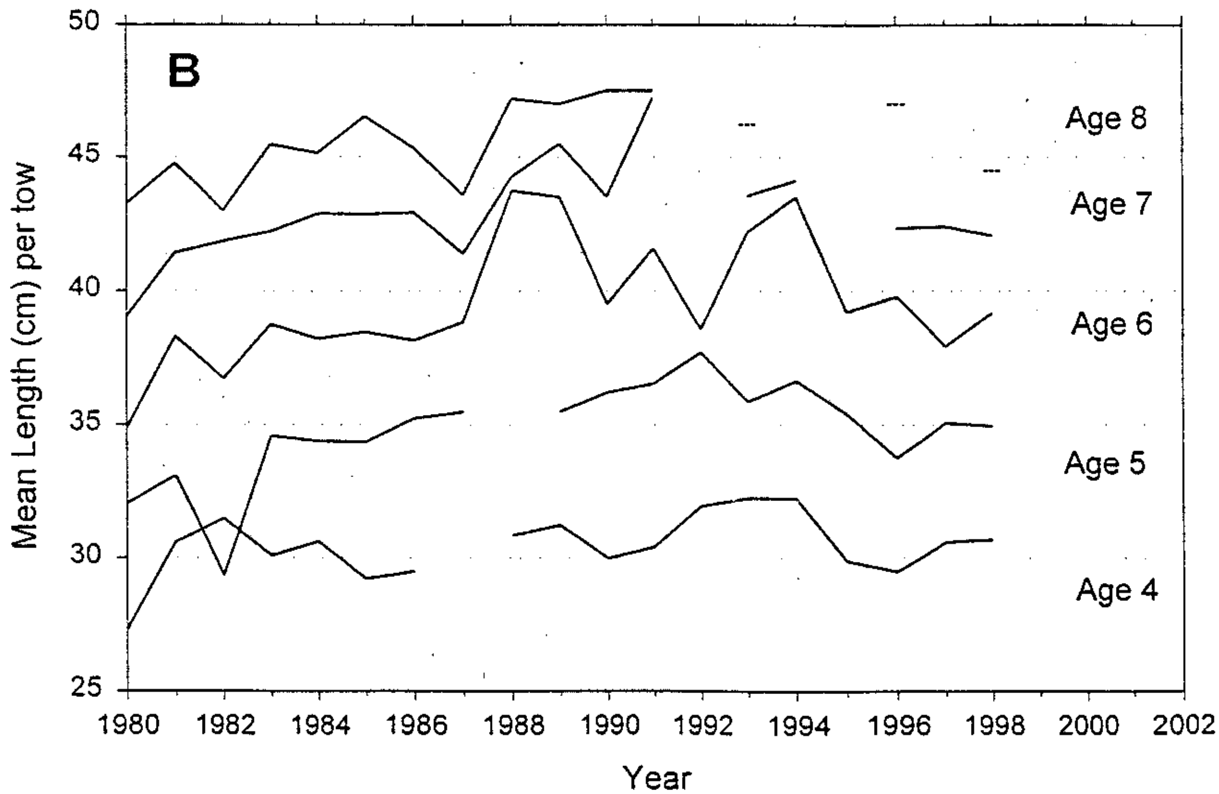




Figure A13. Mean length (cm) at age for age groups 4-8 of witch flounder in spring (A) and autumn (B) NEFSC research vessel bottom trawl surveys, 1980 - 1998, 1999 values are preliminary.

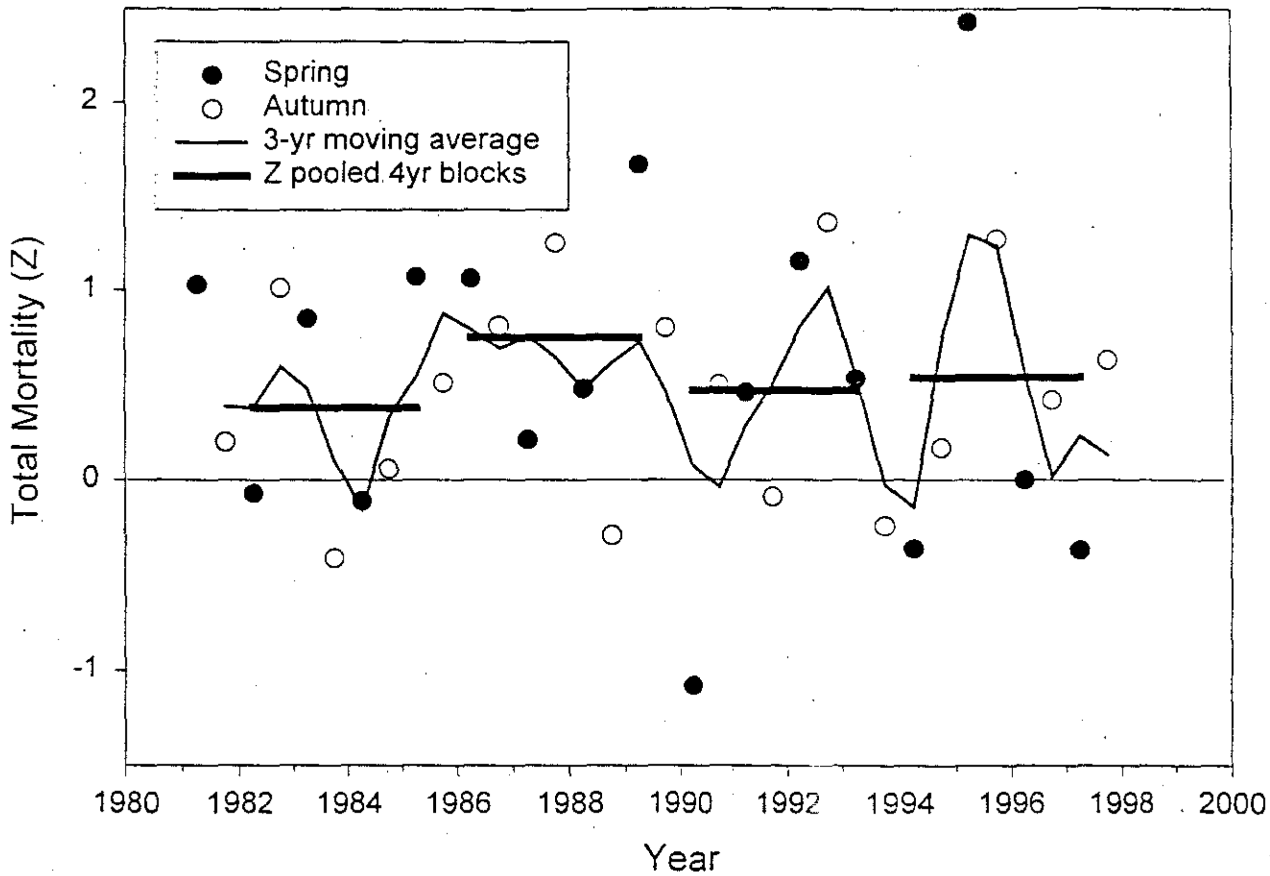



Figure A14. Estimates of instantaneous total mortality (Z) derived from NEFSC spring and autumn bottom trawl survey catch per tow at age (log ratio: 7+ / 8+), a three year moving average, and 4 year pooled estimates of Z. Natural mortality assumed to be 0.15.

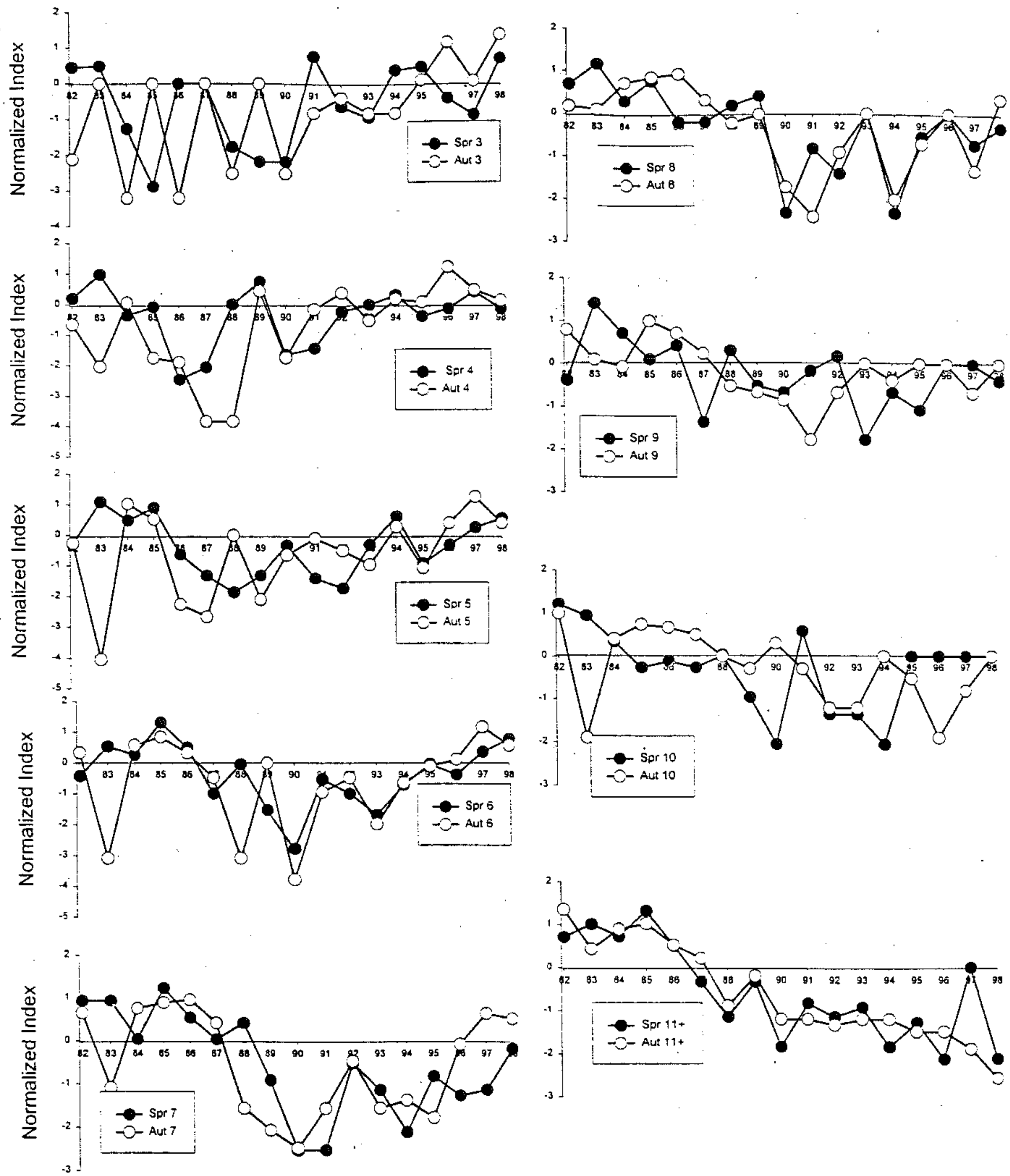



Figure A15. Normalized (ln(obs/mean)) indices of abundance (spring and autumn) at age for witch flounder.

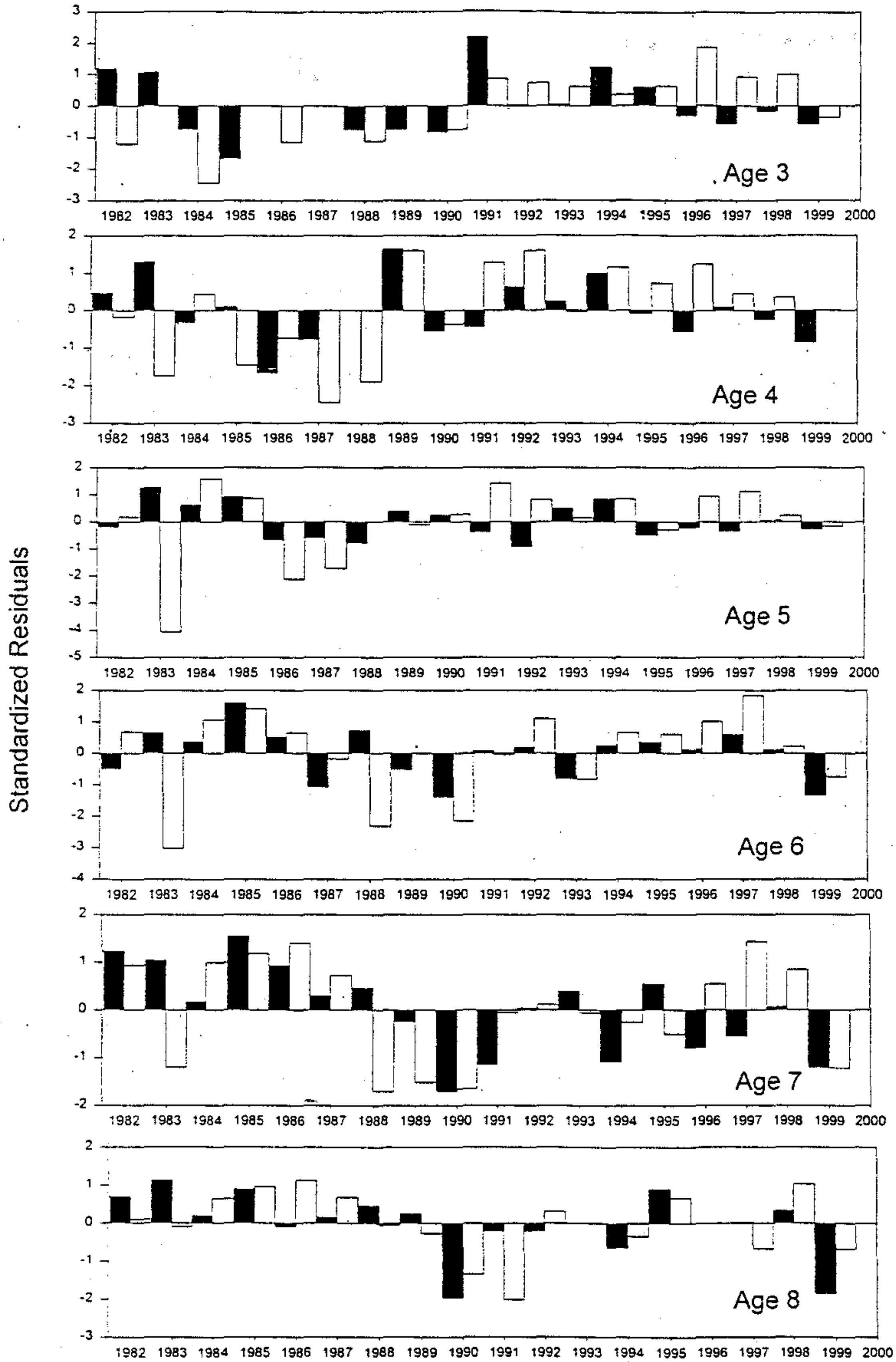



Figure A16. Standardized residuals for survey indices(spring solid bar and autumn open bar) at age includes in the ADAPT VPA calibration for the 1982-1998 witch flounder assessment.

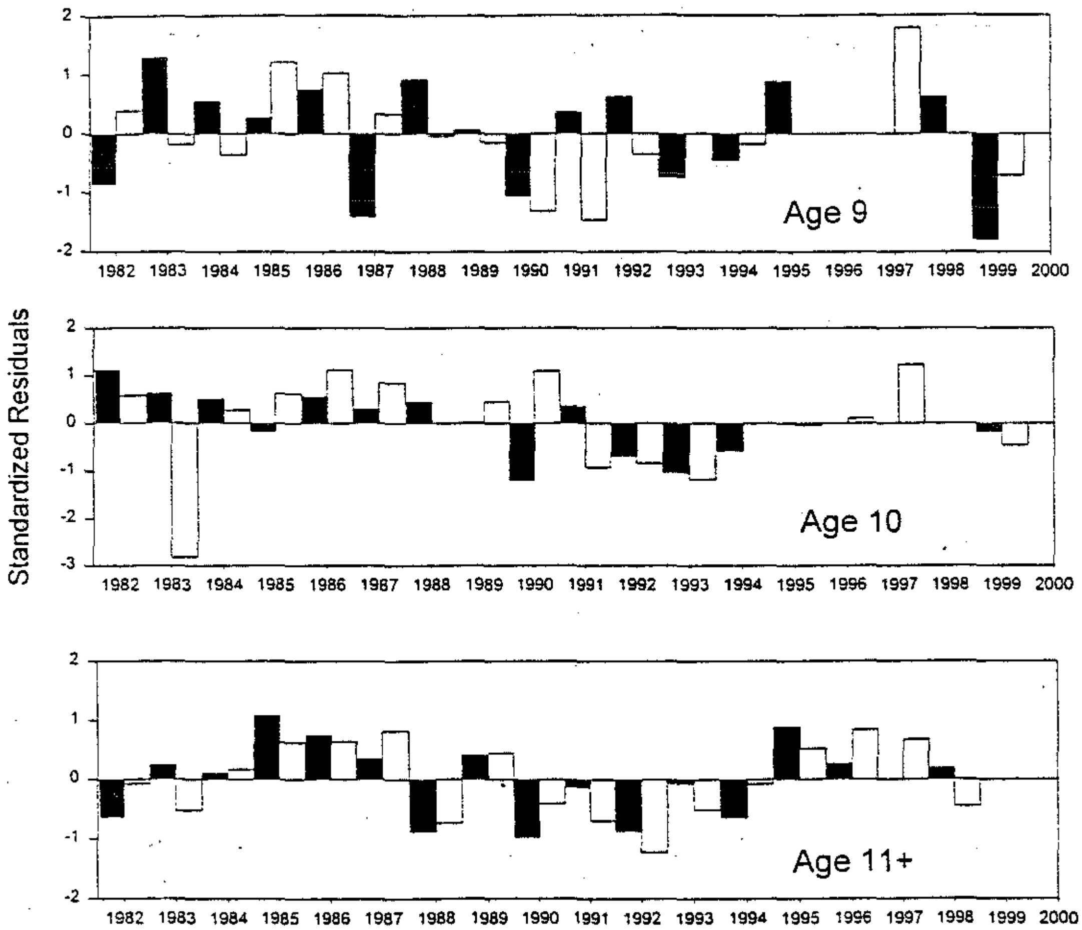



Figure A16 continued. Standardized residuals of survey indices (spring solid bar and autumn open bar) at age included in the ADAPT VPA calibration for the 1982-1998 witch flounder assessment.

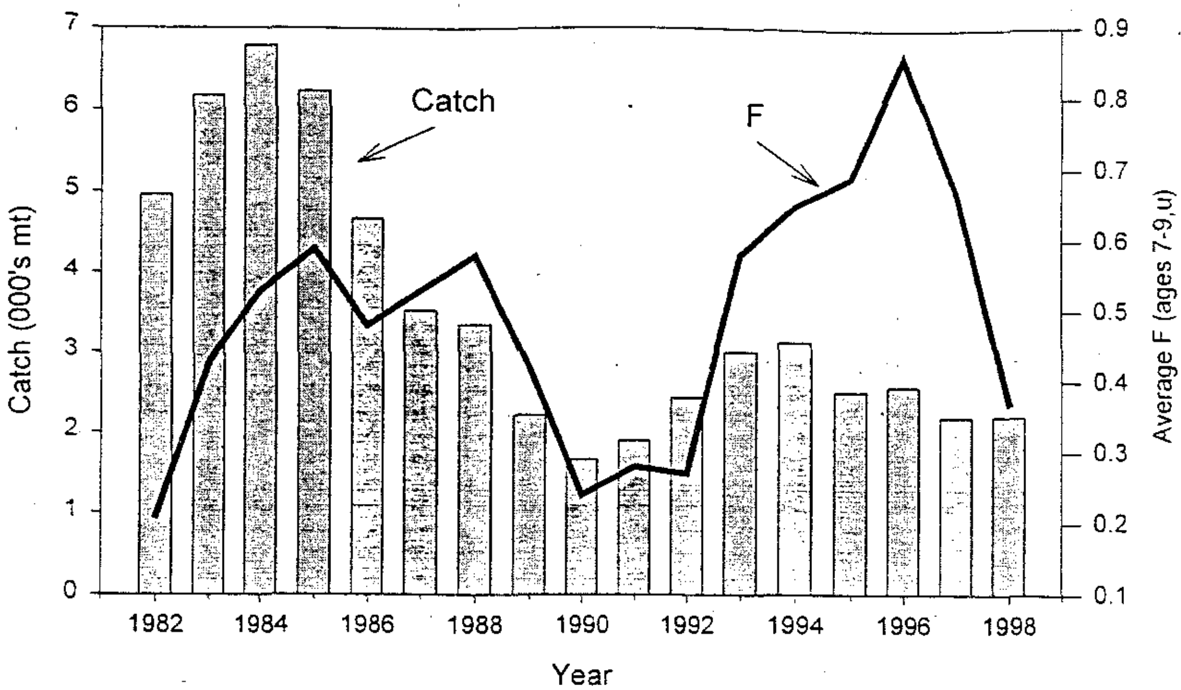



Figure A17. Trends in total catch and fishing mortality for witch flounder, 1982 - 1998.

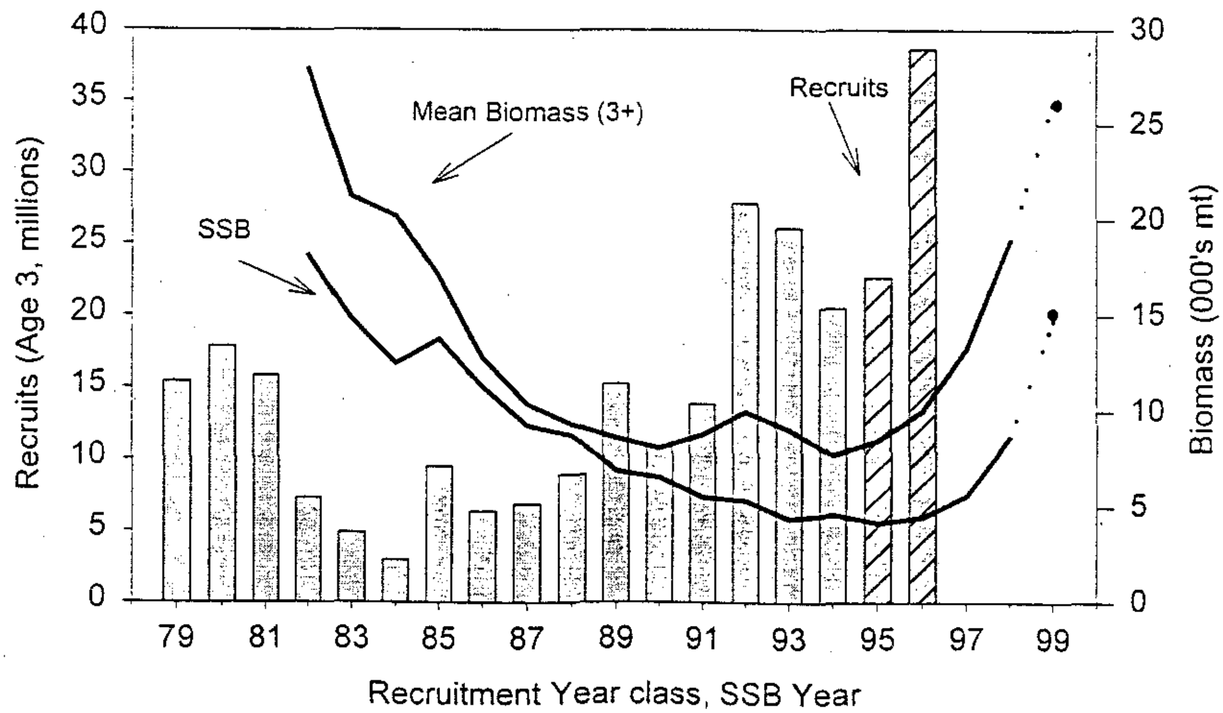



Figure A18. Trends in spawning stock biomass, mean biomass (3+) and recruitment for witch flounder, recruitment of the 1995 and 1996 year classes (hatched bars) estimated from log-log regression of survey and VPA stock size estimates.

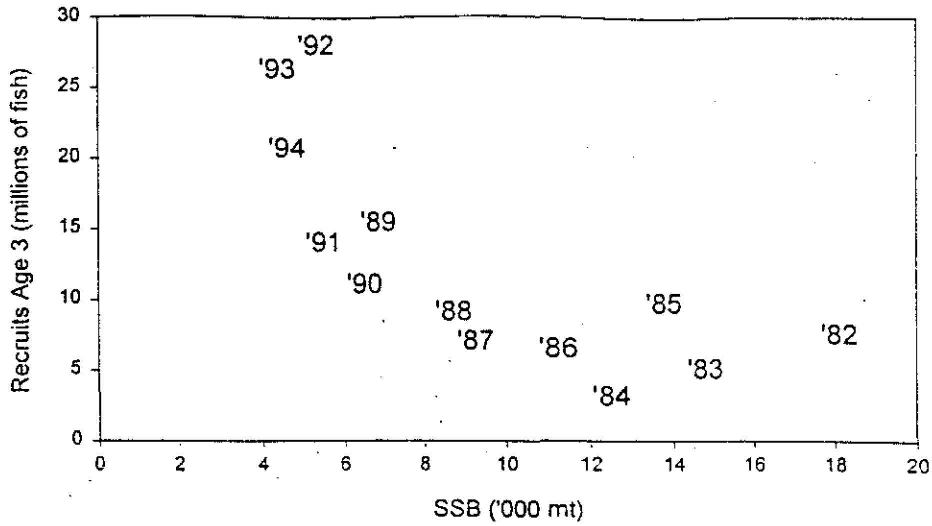



Figure A19 . Spawning stock biomass and recruits (age 3) for witch flounder.

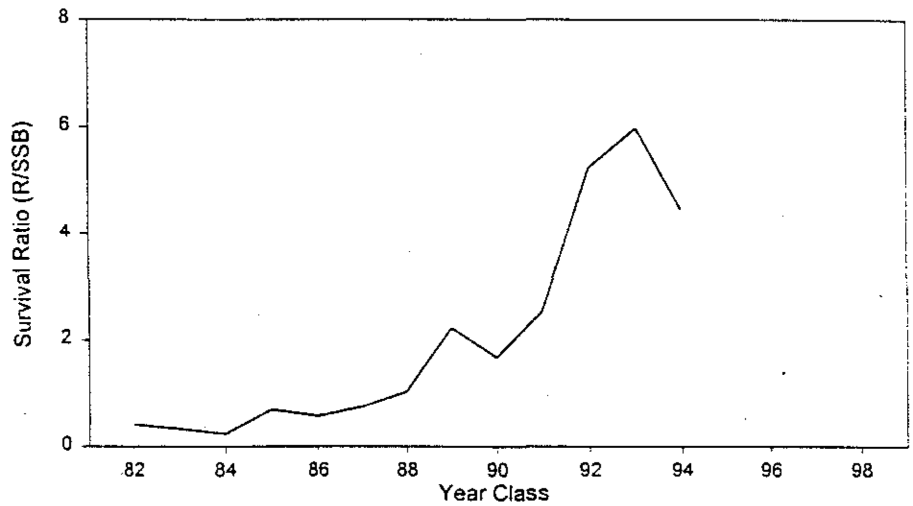



Figure A20. Survival ratios (R/SSB) estimated as the ratio of recruits at age 3 over the spawning stock biomass which produced the recruits. The survival ratios plotted for each year class,1982 - 1994.

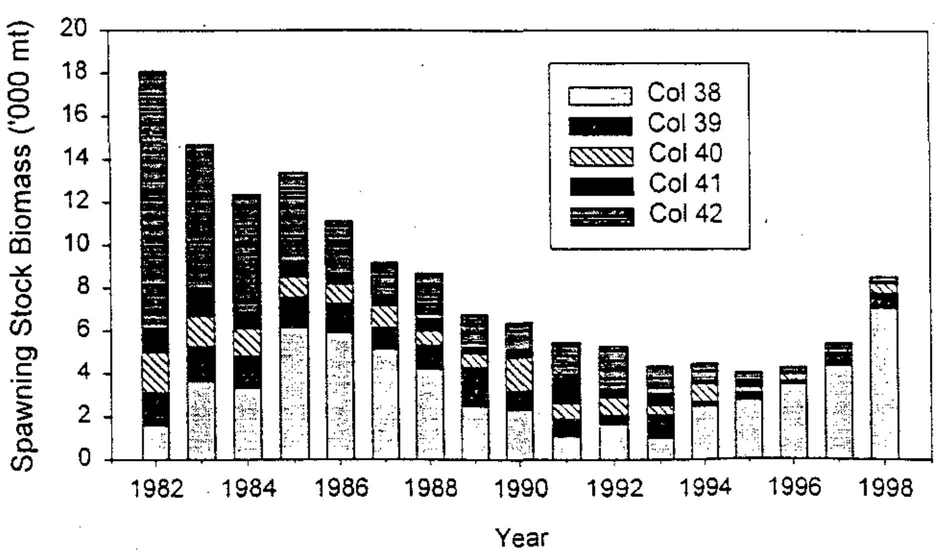



Figure A21. Age composition of spawning stock biomass for witch flounder, 1982 - 1998.

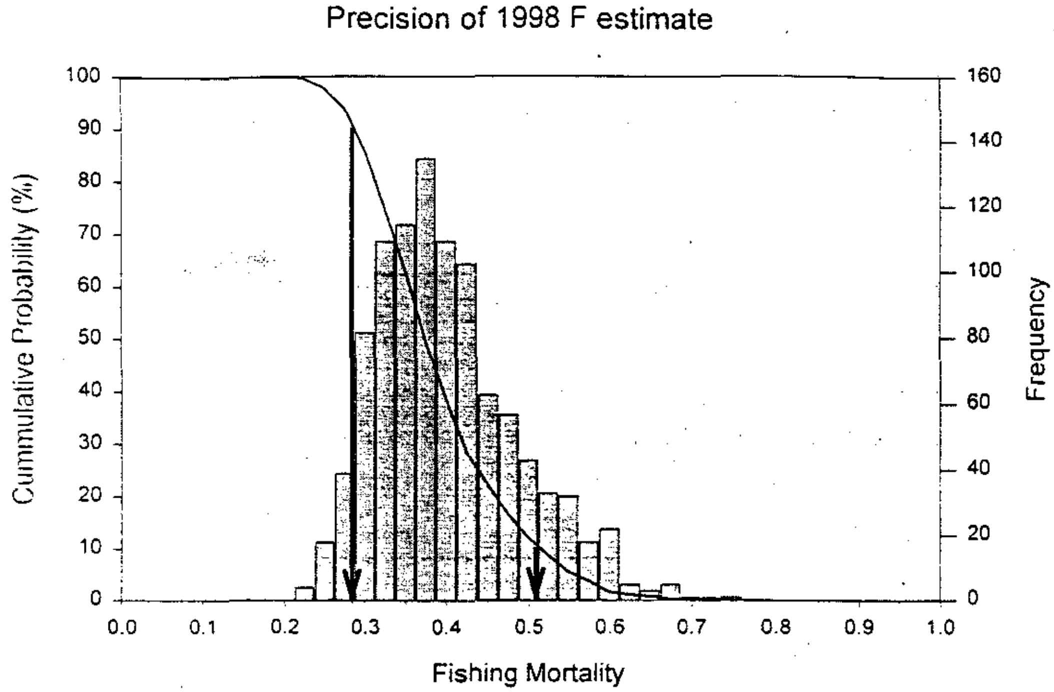



Figure A22. Precision estimates of the instantaneous rate of fishing mortality (F) on the fully recruited ages (7+) in 1998 for witch flounder. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that F is greater than any selected value on the X-axis. The solid arrows indicate the approximate 90% and 10% confidence levels for F. The precision estimates were derived from 1000 bootstrap replications of the final ADAPT VPA formulation.

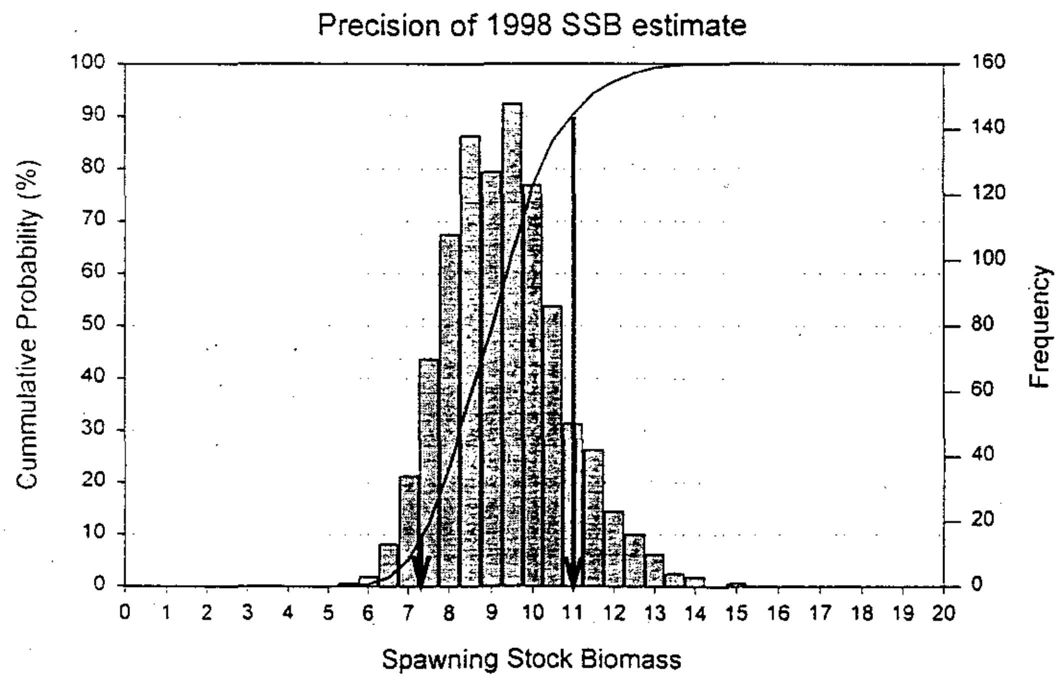



Figure A23. Precision estimates of spawning stock biomass at the beginning of spawning season (March) in 1998 for witch flounder. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that SSB is less than any selected value on the X-axis. The solid arrows indicate the approximate 90% and 10% confidence levels for SSB. The precision estimates were derived from 1000 bootstrap replications of the final ADAPT VPA formulation.

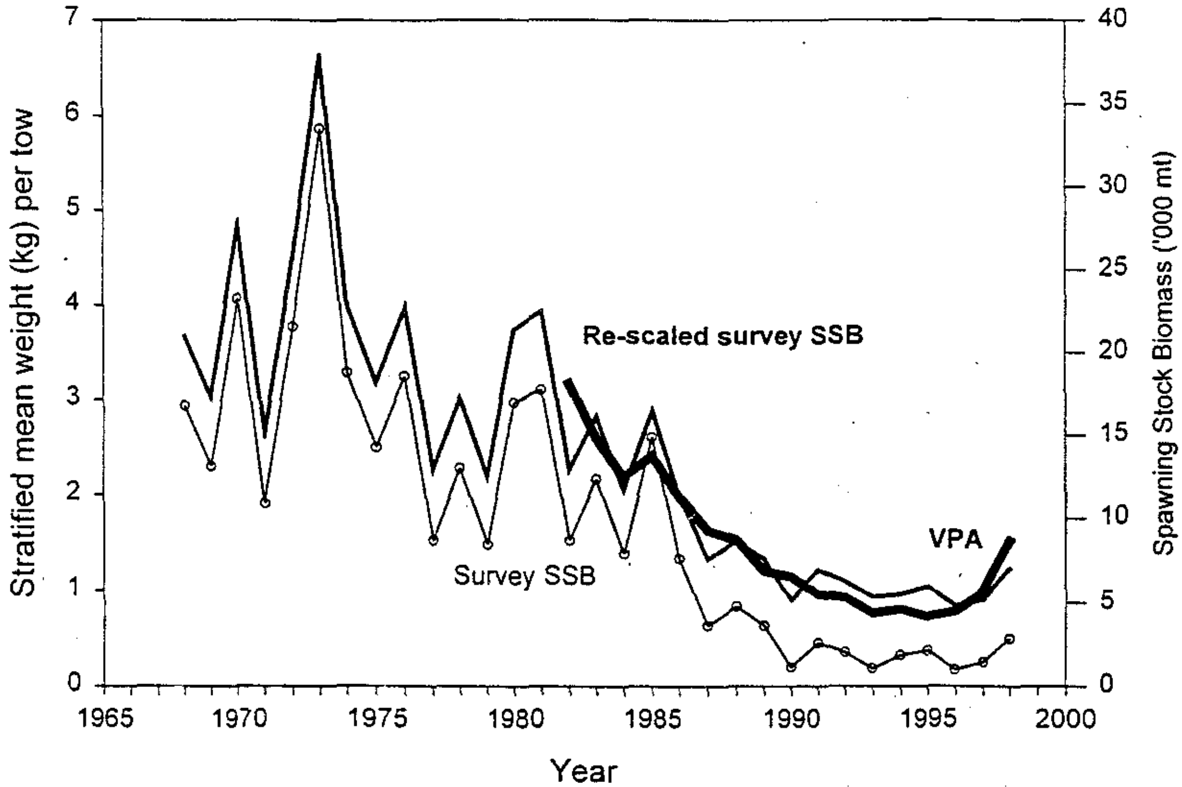



Figure A24. Stratified mean weight (kg) of mature witch flounder (spawning stock biomass) per tow from NEFSC spring bottom trawl surveys, re-scaled survey SSB, 1968 - 1998; and VPA estimated SSB, 1982 -1998.

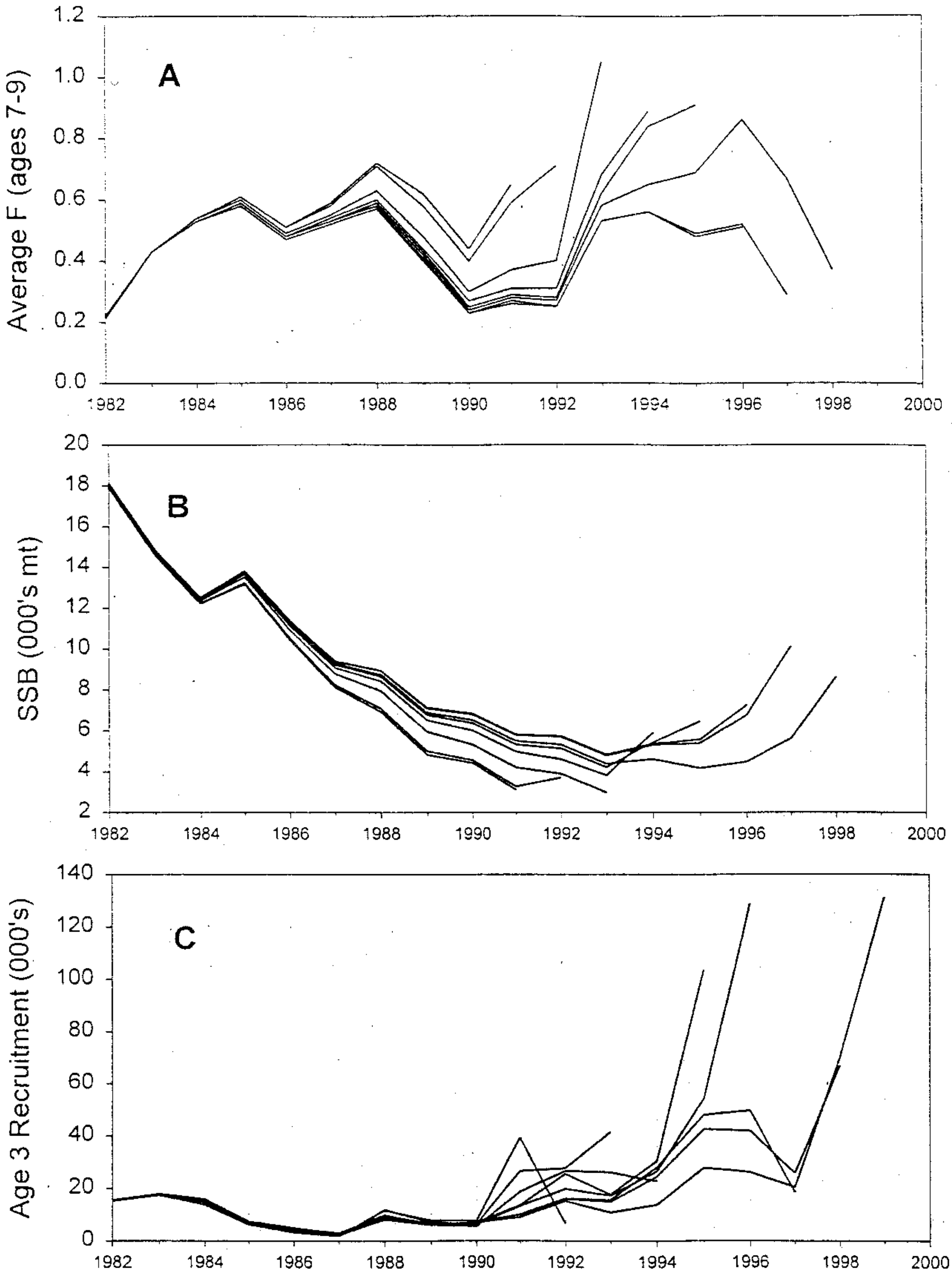
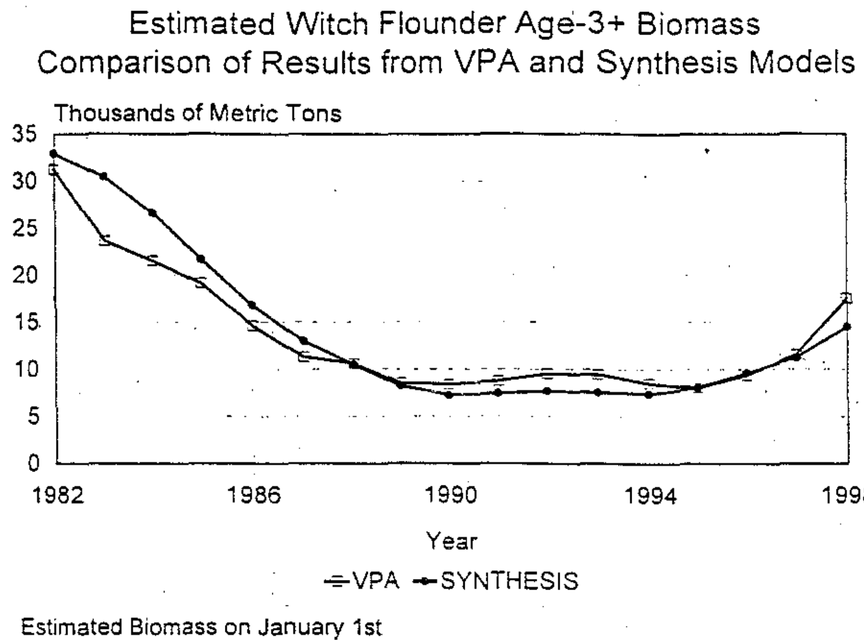



Figure A25. Retrospective analysis results of fishing mortality (A), spawning stock biomass (B) and age 3 recruitment (C) for the witch flounder assessment, 1982-1998.



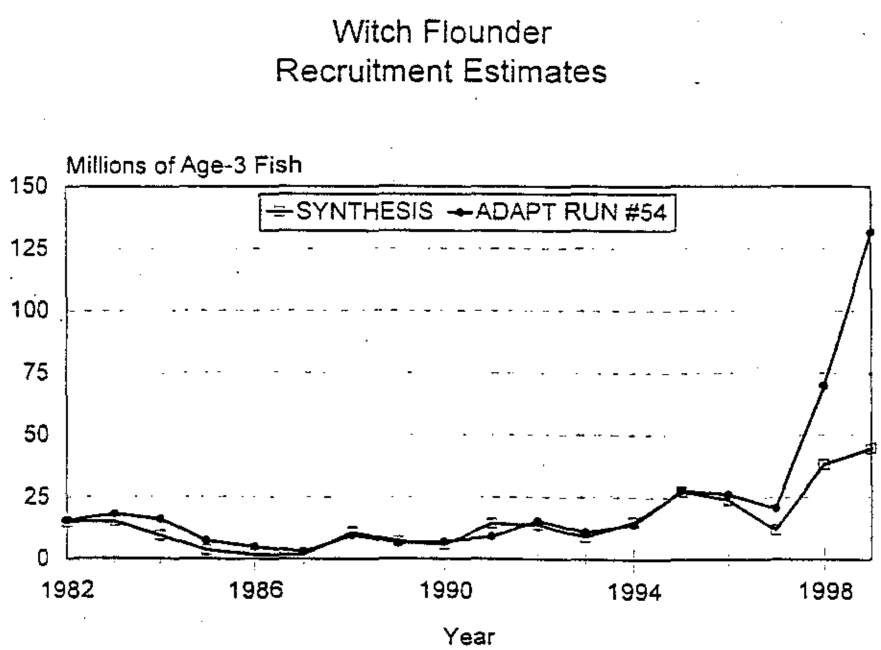




Figure A26. Comparison of ADAPT VPA and Stock Synthesis results for witch flounder.

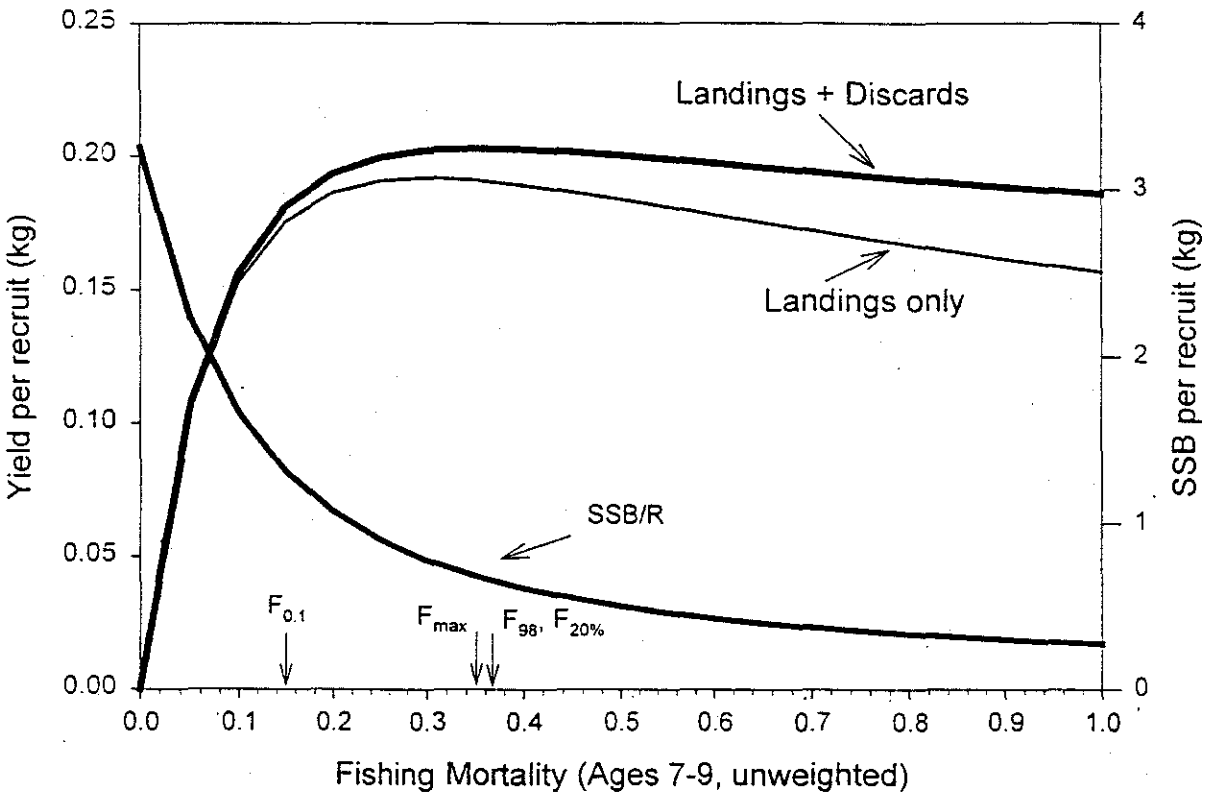



Figure A27. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) estimates for witch flounder. Yield (total catch= landings and discards) thick line; landings only thin line.

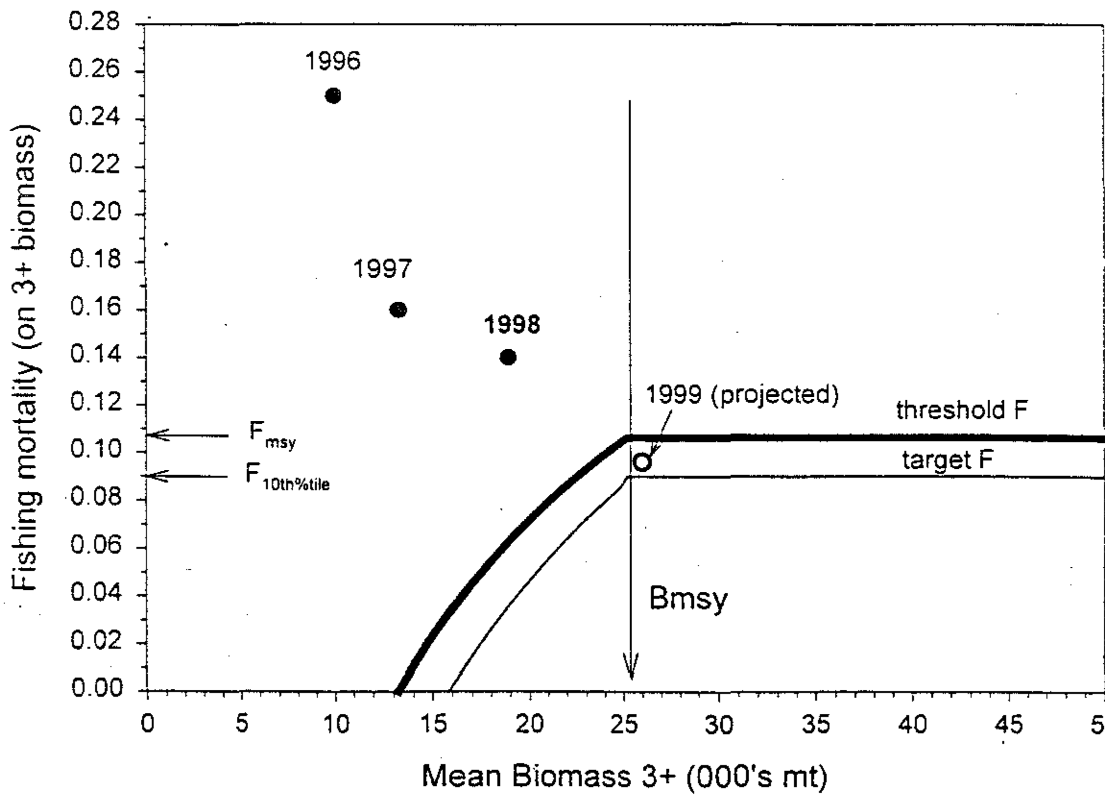



Figure A28. MSY-based reference points and control rule for witch flounder.

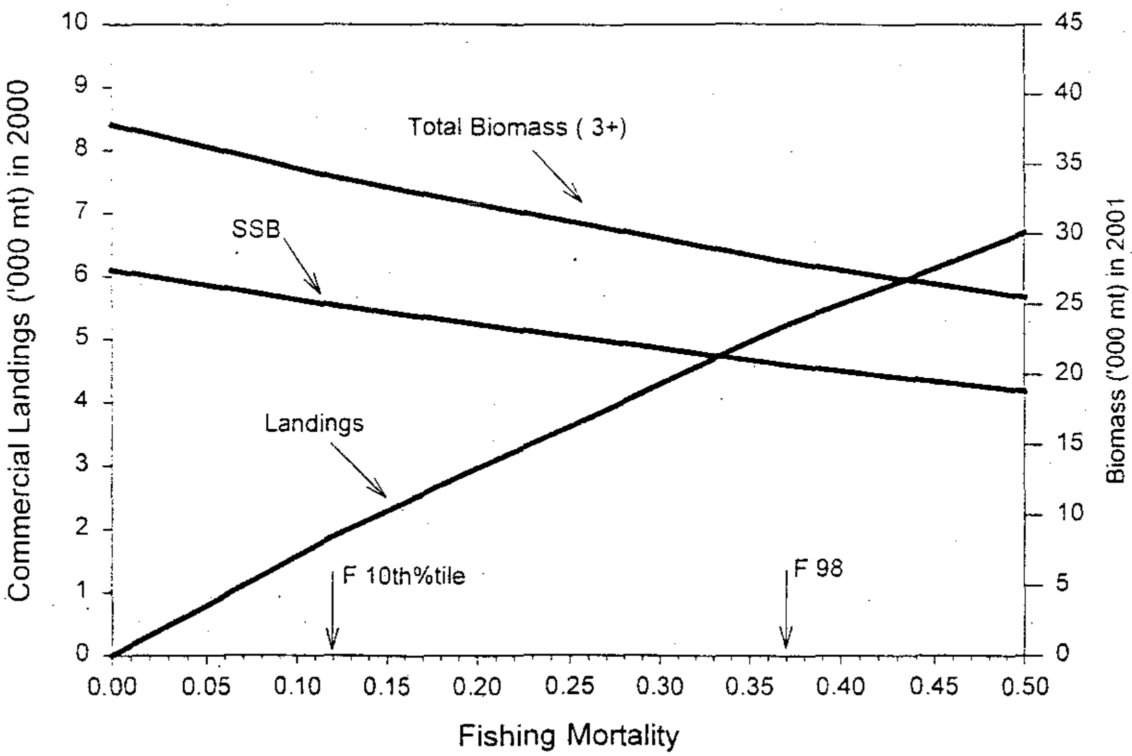



Figure A29. Results of short-term stochastic projections for witch flounder. Projected landings (mt) in 2000, spawning stock biomass (mt) and total biomass (3+; mt) in 2001 as a function of fishing mortality from F = 0.0 to F = 0.5.

## B. Sea Scallops (*Placopecten magellanicus*)

### TERMS OF REFERENCE

a. Update the status of Georges Bank and Mid-Atlantic sea scallop populations through 1998, providing estimates of fishing mortality and stock biomass, and characterize the variability in these estimates.

b. To the extent possible, provide estimates of scallop biomass in various closed areas and the distribution of shell sizes and associated meat counts both inside and outside the closed areas.

c. Comment on and revise, if necessary, the overfishing definition reference points for sea scallop recommended by the Overfishing Definition Review Panel.

d. Evaluate methods for estimating population sizes and biological characteristics of scallop populations in closed areas, based on area-swept surveys using commercial and/or research vessels.

### INTRODUCTION

Sea Scallops, *Placopecten magellanicus*, are found in the Northwest Atlantic Oçean from North Carolina to Newfoundland along the continental shelf. They are harvested at depths between 40 and 200 m (22 and 110 fm) in the Georges Bank and Mid-Atlantic regions (NEFSC 1993). 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. Maximum size is about 23 cm, but animals larger than 17 cm are rare in commercial and survey landings.

Merill et al. (1966) reported problems with identification of annual rings on the external surface of the left valve and proposed to use ring counts in the resilium (hinge ligament) to age scallops. The method was validated by comparison with data from tagging studies. The age determinations by ring counts conflicted with results from oxygen isotope studies by Krantz (1983) and Krantz et al. (1984). Tan et al. (1988) reported the consistence between the results of isotope studies and ring count method. Oxygen isotope studies were based on very few samples.

New meat weight-shell height relationships for scallops in the Georges Bank and Mid-Atlantic regions used in this assessment (see below) were based on the samples collected from the NEFSC sea scallop survey in 1998. The new relationships suggest smaller mean meat weight at a given shell height than the relationship reported by Serchuk and Rak (1983) and used in previous assessments. The differences may be due, however, to spatial and temporal differences among samples.

Sexual maturity starts at age 2 (25 mm) but scallops younger than 4 years may contribute little to total egg production (NEFSC 1993). Spawning generally occurs in late summer and earlier autumn. DuPaul et al. (1989) found earlier spawning in spring in the DELMARVA area and Almeida et al. (1994) found evidence of winter-early spring spawning in Georges Bank. Eggs are buoyant, and the larvae remain in the water column for 4-6 weeks before settlement occurs. During this stage, considerable transport of eggs and larvae can occur due to water currents.

Significant improvements have been made since 1994 to methods (Wigley et al. 1998) used to process vessel trip report (VTR) and dealer logs (DL). Nonetheless, problems, such as linkage between VTR and DL and verification of data filled in VTR and DL remain for sea scallop data.

Concerns that the modified Delury model used in previous assessments underestimated stock size for sea scallops (SARC23, NEFSC 1997) were addressed in two ways. A new two-stage dynamic model was developed for this stock assessment that used all available data in likelihood calculations or as prior information in a Bayesian framework. The second approach was a commercial vessel survey carried out in August-September 1998 that included depletion experiments in Closed Area 2. Results from depletion experiments can be used to estimate gear efficiency and catchability coefficients. The SARC agreed that work in these two areas was valuable but, after considerable discussion, decided that additional analyses and data collection are required before the new model and efficiency estimates are used directly in stock assessment work (see SARC comments section). These are important areas for future research over the next several years.

## FISHERIES

### *Regulations*

Sea scallop fisheries in U.S. EEZ are managed under the Sea Scallop Fishery Management Plan (FMP) initially implemented on May 15, 1982. In June 1983, the Regional Director invoked the temporary adjustment provision in the FMP by setting a 35 average meat count (35 meats per pound) and a 3 ⅜ inch minimum shell height. Minimum shell height was raised to 3 ½ inches in June 1988 (Fig. B1).

The FMP Amendment #4 (NEFMC 1993) implemented in 1994 changed the management strategy from meat count regulation to effort control for the entire U.S. EEZ. New measures included a day-at-sea (DAS) reduction schedule, increase of minimum ring size by increments to 2 ½ inches, decrease of crew members to seven persons, and several restrictions on dredge gears (Fig. B1).

In December 1994, three groundfish closed areas ("closures") were implemented in the U.S. portion of Georges Bank (Fig. B2). Scallop dredge gears were prohibited in the closures to reduce bycatch of groundfish and to protect groundfish habitat. The closures resulted in movement of fishing effort from the Georges Bank region to the Mid-Atlantic region in 1994 and probably caused increased fishing mortality and decreased abundance in Mid-Atlantic region (NEFSC, 1997). In March 1998, two areas (Virginia Beach and Hudson Canyon South, Fig. B3) with substantial abundance of young sea scallops were closed for harvesting for three years to increase yield per recruit and spawning biomass.

Major changes in collection of commercial fishing data occurred in June 1994. Changes included the new mandatory reporting system comprised of dealer reports (DR) and vessel trip reports (VTR). DR data contains total landings, broken down by market category. VTR data contains information about area fished, fishing effort, and retained catches of sea scallops. The link between DR and VTR was not well defined due to incomplete recordings. Difficulties linking DR and VTR data compromised catch-per-unit-effort data and made stock assessment work more difficult (NEFMC 1993).

Beginning in 1994, sea scallop in the U.S. EEZ were divided into Georges Bank, Mid-Atlantic, South New England, and Gulf of Maine stocks. Since SARC 23 (NEFSC 1997), stock assessments have been carried out for the Georges Bank and Mid-Atlantic stocks because catches and abundance are highest there.

Amendment 7 to the Sea Scallop FMP was implemented in 1998 to implement an overfishing definition required by Sustainable Fishery Act (SFA). At the time of this assessment, FMP Framework Adjustment 11 was under development to implement mechanisms for re-opening parts of Closed Area 2 and the Nantucket Lightship closure.

*Catch history*

Commercial harvest data were based on the interview weighout database prior to April 1994 and on the DR and VTR databases after April 1994. The proration of commercial sea scallop landings into Georges Bank, Mid-Atlantic, South New England, and Gulf of Maine regions generally followed procedures in Wigley et al. (1998).

Table B1 summarizes the total U.S. landings by gear type and by calendar year in the Georges Bank, Mid-Atlantic, Gulf of Maine, and Southern New England regions. Sea scallop dredges were the major harvesting tool in all regions but trawl gears have increased their share of landings recently, especially in Mid-Atlantic region (Table B1). Although commercial data were incomplete in 1998, 35% and 47% of total landings were taken from the Georges Bank and Mid-Atlantic regions. Landings in the Gulf of Maine increased to 1,133 mt in 1998, a 62% increase from 1997.

Fishing effort for scallops is problematic in the VTR database. However, a crude summary of catch per unit effort (CPUE) from the medium (51-150 gross tons) and large (151-500 gross tons) dredge vessels, which comprised the majority of fishing vessels and total landings for scallops, indicated a general decreasing trend after 1982 in both the Georges Bank and Mid-Atlantic regions (Table B8 and Fig. B4). There is a discontinuity in the CPUE series in 1994 due to changes in data collecting system and other factors, such as fishery regulations, indirect scallop trips, monkfish bycatch, etc. The ratio of days fished and days-at-sea was almost constant over the years in Georges Bank region but increased in Mid-Atlantic region. This is a subject for future research.

Sea scallop landings in the U.S. and Canada along the Northwest Atlantic Ocean increased substantially after the mid-1940's (Fig. B5). U.S. and Canadian landings fluctuated with similar trends after 1950's and peaked in 1978 with a total of 26,671 mt landed.

*Shell height distributions*

Size compositions of landed sea scallops were collected from both port and sea samples (Burns and Schultz 1991, NEFSC 1992-1997). Port sampling protocols required 200 shells from the last tow of the trip. Numbers of trips and shells sampled by the port sampling are summarized in Table B2. There was a significant reduction in port sampling after 1995, especially in the Georges Bank region, because port agents were directed to assist fishers in filling out VTR forms. Data from the sea sampling were used in lieu of port samplings.

The NEFSC Sea Sampling Program was fully implemented in 1992. Table B3 shows the numbers of sampled trips, tows, and kept and discarded shells in 1992-1998. The size compositions for kept and discarded sea scallops are summarized in Fig. B6. Discarded scallops were primarily those with shell heights less than 80 mm. Some abnormalities in discarded size compositions appeared in survey years 1993 and 1994 for Georges Bank region and in 1997 for the Mid-Atlantic region. The abnormalities were due to small sample sizes (59 scallops) in 1994 and possible problems with data recorded on original data sheets. In both Georges Bank and the Mid-Atlantic regions, size compositions of retained sea scallops included one mode. Modal shell height increased after 1992 (Fig. B6).

Reductions in port sampling effort caused problems in constructing size compositions for commercial landings after 1994. Size compositions after 1992 were from both port and sea samples. Size composition for sea scallops from each trip sampled in the Sea Sampling Program was scaled to a 200 scallop sample, which is equivalent to the sampling level of a fishing trip requested by port sampling. Size compositions for commercial landings in 1982-1991 were from port sampling. Size compositions for commercial landings from Georges Bank region are shown in Fig. B7 and from Mid-Atlantic region in Fig. B8.

Potential sampling errors for size composition from port and sea samplings that would affect the precision and accuracy of size compositions were discussed in SARC 20 and SARC 23 (NEFSC 1995, 1997). Despite the limitations of data, size compositions for commercial landings reflected the strength of incoming partial recruits and mean shell height of full recruits obtained from surveys.

There are secondary modes in the length composition data for surveys on Georges Bank in 1991-1993 likely from partial recruits observed in 1990-1992 (see Survey section). Landings in survey year 1994 from Georges Bank region were the lowest since 1982 due to area closures and movement of effort to the Mid-Atlantic region. Thus, partial recruits observed in 1994 might have survived to form a second mode in 1995. The narrow size composition in 1998 might be due to high fishing pressure in

1997 (when multiple modes occurred) when large-size scallops were harvested.

In the Mid-Atlantic region, the first modes of commercial size compositions were smaller than 100 mm from 1985 to 1995, and greater after 1996. In 1998, the majority of partial recruits were protected in the two closed areas of the Mid-Atlantic region and the fishery targeted larger full recruits in areas open to fishery.

*Discards*

The NEFSC sea sampling program collected hail weights of discarded sea scallops from sampled tows. Discards consisted of scallops that were not shuckable and not retained by the crew, mainly because they were under-sized. Discard-to-kept ratios for Georges Bank and Mid-Atlantic regions were estimated using a ratio estimator (Cochran 1977). Table B4 summarizes the discard-to-kept ratio from the observed tows by survey years. The discard rate in the Mid-Atlantic region in 1993 was the highest (18%) observed since 1992. Abundance of partial recruits in the Mid-Atlantic region was high in 1993 and might have caused the high discard-to-kept ratio. Ratios in both regions were less than 2% since 1996.

Discard-to-kept ratios might under-estimate the discard rate for sea scallops because observers may have recorded only un-damaged, under-sized sea scallops. Scallops not landed due to damage might not be recorded.

**SURVEYS**

NEFSC sea scallop surveys were carried out in 1975 and annually after 1977 to assess abundance, size composition, and recruitment of sea scallop resources in the Georges Bank (including the Canadian portion of Georges Bank for some years) and Mid-Atlantic regions. The R/V Albatross IV was used except in 1990-1993 when the R/V Oregon replaced it. In 1989, the survey in the Georges Bank region was incomplete; the R/V Oregon was used in northern part of Great South Channel and the R/V Chapman in southern part of Great South Channel and a section of Southeast Part. Catch rates for the three research vessels were compared using data for 39 tows (3 vessels x 13 stations) in Stratum 34 based on random complete block design. ANOVA revealed no significant differences (Serchuk and Wigley 1989). Therefore, survey indices for the period 1990-1993 based on data from the R/V Oregon were used without adjustment.

The survey design and estimation of sea scallop abundance from survey data were based on stratified random sampling techniques (Serchuk and Wigley 1989, Wigley and Serchuk 1996, Richards 1996, Lai and Henderson 1997). The original strata used for the survey are described by Serchuk and Wigley (1989). The closed areas implemented in Georges Bank region in December 1994 and Mid-Atlantic region in March 1998 changed the patterns of spatial and temporal patterns in abundance and fishing strategies. To reflect impacts of closed areas, strata used for survey data in this assessment were revised to incorporate closures in the two regions (Table B5). After 1997, sampling stations were reallocated among open and closed strata and the total number of sampling stations increased. Abundance indices and size compositions prior to 1996 were re-estimated according to the revised strata set by post-stratification.

*Survey and commercial dredge selectivity*

Since 1979, sea scallop surveys used a 2.44-m (8-ft) wide dredge equipped with 5.1-cm (2-in) rings. Survey dredges were equipped with a 3.8-cm (1.5 in) polypropylene mesh liner and were towed for 15 minutes at 6.5 km/hr (3.5 knots) with 3:1 wire scope (Serchuk and Smolowitz 1980). Serchuk and Smolowitz (1980), Jamieson and Lundy (1979) and Worms and Lanteigne (1986) reported that the liner reduced catchability for scallops less than 75 mm in shell height.

The selectivity of a lined survey dredge was examined through maximum likelihood estimation (SARC 20 and SARC 23). The estimated selectivity curve for the unlined dredge was

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

and for the lined dredge was

(2)
$$\hat{q}_h = \frac{0.7148\exp[(0.9180)(0.7148)(x-106.3091)]+\exp[0.9180(x-106.3091)]}{\exp[(0.9180)(0.7148)(x-106.3091)]+\exp[0.9180(x-106.3091)]}$$

where x = 160 – h (Fig. B9).

The size composition of a given survey tow (denoted by $\tilde{y}_h$) was measured in number per tow for all given shell height categories (h). Survey size compositions were adjusted for selectivity due to lined dredge ($\hat{q}_h$) using the equation:

(3) $$y_h = \tilde{y}_h / \hat{q}_h$$

Adjusted abundance indices for each tow were partitioned into partial recruit and full recruit components by applying a commercial selectivity function developed by consensus at SAW 14 (NEFSC 1992, Fig. B10)

(4)
$$s_h = \begin{cases} 0 & \text{if } h < h_{\min} \\ \dfrac{h-h_{\min}}{h_{full}-h_{\min}} & \text{if } h_{\min} < h < h_{full} \\ 1 & \text{if } h > h_{full} \end{cases}$$

where $h_{min}$ = 65 mm and $h_{full}$ = 88 mm. For the *i*th survey tow in year t, the abundance index for partial recruits in numbers if scallops per tow ($r_{it}$) was calculated by

(5) $$r_{it} = \sum_{h\geq 42mm}(1-s_h)y_h$$

For full recruits ($n_{it}$), number per tow was

(6) $$n_{it} = \sum_{h\geq 42mm} s_h y_h$$

The corresponding biomass indices in weight per tow were

(7) $$b_{rit} = \sum_{h\geq 42mm}(1-s_h)y_h\overline{w}_h$$ for partial recruits and

(8) $b_{nit} = \sum_{h \geq 42mm} s_h y_h \overline{w}_h$ for full recruits

where $w_h$ was weight at length. Data from different tows were combined assuming stratified random sampling (Cochran 1977) to compute abundance and biomass indices for partial and full recruits in the Georges Bank and Mid-Atlantic regions as a whole.

*Abundance indices*

Abundance and biomass indices with swept area estimates of population size and biomass are summarized in Table B6 for the Georges Bank region. In 1991, partial recruits peaked in all areas of Georges Bank region except Closed Area 1 (CL1) where 1992 was higher. Indices for full recruits were highest in the same year when indices for partial recruits peaked. High abundance indices abruptly dropped after 1993. A change in abundance indices occurred between 1997-1998 in CL1 where the abundance of full recruits increased substantially in 1998 but abundance of partial recruits in 1997 was relatively low.

Percent distribution of swept area estimates for population size and biomass in the six resource areas in Georges Bank are shown in Fig. B11. Swept area estimates are proportional to absolute abundance or biomass. Differences between the two types of data mainly due to the area of regions used to compute swept area estimates. Prior to 1992, more partial recruits were found in the South Channel open area (SCH) during most years. In 1993, more than 75% of partial recruits were found in Closed Area 1 and abundance of full recruits was at the second highest level. After 1993, percent partial recruits in SCH declined and percent in the three closed areas (CL1, CL2, and NLC) and other two open areas (NEP and SEP) increased.

From 1982 to 1988, more full recruits were generally found in the three open areas, except in 1985 and 1988 when the R/V Oregon was used instead of the R/V Albatross. Although the survey in 1989 was incomplete, high partial recruits found in 1988 in CL2 seem to support the apparent peaks in percent of full recruits during 1990-1992. During 1992-1993 and 1995, more full recruits were found in the three open areas. After 1995, the proportion of full recruits and partial recruits increased in the three closed areas and decreased in the three open areas.

Table B6 and Fig. B11 and differences between arithmetic and geometric mean survey values indicate that there is uncertainty in abundance and biomass indices from survey data and in estimates of percent distribution among resources areas. Patchiness in resource distribution and high catches in individual strata seem to cause fluctuation in estimates for some years. In 1998, for example, high abundance indices in the Georges Bank closed areas were due to large catches in CL1 and especially stratum 53. Fig. B12 shows that stratified geometric mean indices for partial recruits in 1990-1991 remained high but decreased to very low levels during 1992-1993 and were very high in 1998. For full recruits, the geometric mean index in 1992 was the highest and the trend was different than for arithmetic mean estimates during 1990-1993. Trends in geometric and arithmetic mean abundance and biomass indices for partial and full recruits differed during 1995 to 1998. Increases in geometric means over this period were not as abrupt as for arithmetic means.

Abundance and biomass indices and swept area estimates of population size and biomass are summarized in Table B7 for Mid-Atlantic region. Prior to 1989, more than 50% of partial and full recruits were in DELMARVA (DMV) and the New York Bight (NYB) which were both opened to fishing after 1998 (Fig. B13). However, this trend reversed after 1989, when partial and full recruits were generally higher in Hudson Canyon S. (HCS) and Virginia Beach (VAB) Closures. The peak in partial recruits observed in VAB during 1997 is visible as a peak in full recruits during 1998.

*Shell height distributions*

Prior to 1994, when all resources areas in Georges Bank region were open to fishing, modal shell heights were generally around 80 mm and seldom greater than 100 mm (Fig. B14). Similar shell height distributions were found in resource areas open to fisheries after 1994. In contrast, shell height distributions for closed areas after 1994 included multiple modes with modal shell heights gradually exceeding 100 mm . Modes associated with individual year-classes can be traced through time in the shell height distributions for closed areas after 1994. In contrast, year class modes can traced only occasionally (e.g. from 1990 to 1992) in open areas of Georges Bank region after strong partial recruits occurred.

Caution is required when interpreting composite size compositions in Fig. B14 because of variability among areas in Georges Bank region and differences in the size of strata. For example, the first mode in size composition for 1998 (around 37 mm in shell height) was from scallops caught in CL2 while the next three modes were from catches in CL1.

Modes in recent size compositions from the Mid-Atlantic region for both open and closed areas were generally at shell heights less than 100 mm (Fig. B15) and similar to both open and closed areas prior to 1994 in the Georges Bank region. Apparently, the relatively recent closures in the Mid-Atlantic region have not yet effected scallop size compositions. Size compositions in the closed areas of Mid-Atlantic region as a whole resembled those for HCS because abundance of scallops and stratum area was greater for HCS than for VAB.

*Shell height-meat weight relationships*

In the 1998 survey, a sample of 3,600 sea scallops were collected from the Georges Bank region and 2,666 from the Mid-Atlantic region. The sampling protocol was to collect a maximum of 50 scallops from a sampled tow until 200 scallops were collected from a given stratum defined in Table 5. The linear relationships of logged shell height (lnH) and logged meat weight (lnW) in the closed areas of Georges Bank region were:

CL1: $\ln W = -10.1224 + 2.7718 \ln H$
$\quad\quad\quad\quad (0.2037) \quad (0.0439)$
$R^2=0.8836 \quad N=528$

CL2: $\ln W = -11.6422 + 3.1162 \ln H$
$\quad\quad\quad\quad (0.0908) \quad (0.0199)$
$R^2=0.9614 \quad N=985$

NLC: $\ln W = -11.0890 + 3.0336 \ln H$
(0.1214) (0.0268)
$R^2=0.9706$ N=390

The relationship for all closed areas combined was:

(9) $\ln W = -11.1254 + 3.0064 \ln H$
(0.0795) (0.0174)
$R^2=0.9403$ N=1903

In the open areas in Georges Bank region, the lnW-lnH relationships were:

SCH: $\ln W = -11.1123 + 3.0017 \ln H$
(0.1292) (0.0295)
$R^2=0.9232$ N=824

SEP: $\ln W = -11.8599 + 3.1590 \ln H$
(0.1705) (0.0396)
$R^2=0.9563$ N=292

NEP: $\ln W = -12.2204 + 3.2483 \ln H$
(0.1285) (0.0297)
$R^2=0.9569$ N=541

The relationship for all open areas combined was:

(10) $\ln W = -11.6942 + 3.1296 \ln H$
(0.0826) (0.0190)
$R^2= 0.9413$ N=1697

The lnW-lnH relationship for the entire Georges Bank Region from the current study was

(11) $\ln W = -11.4403 + 3.0734 \ln H$
(0.0538) (0.0120)
$R^2= 0.9478$ N=3600

and that from Serchuk and Rak (1983, Table 12) based on the samples collected in 1978-82 was

(12) $\ln W = -11.7656 + 3.1693 \ln H$
(0.230) (0.0051)
$R^2 =0.98$ N = 5863

The predicted meat weight for shell height greater than about 30 mm from the current study was smaller than that reported by Serchuk and Rak (1983). At $L_\infty$ (=152.46 mm), difference between the predicted $W_\infty$ from the two studies was around 15% (55.11 g from the current study and 64.47 g from Serchuk and Rak 1983).

The lnW-lnH relationships of the closed areas in Mid-Atlantic region were

VAB: $\ln W = -11.6590 + 3.1468 \ln H$
(0.3651) (0.0830)
$R^2 = 0.8575$ N=241

HCS: $\ln W = -12.4059 + 3.2784 \ln H$
(0.1526) (0.0349)
$R^2 = 0.9390$ N=575

The relationship for all closed areas in Mid-Atlantic region combined was

$\ln W = -12.3890 + 3.2775 \ln H$
(0.1457) (0.0333)
$R^2 = 0.9376$ N=647

In the open areas of the Mid-Atlantic region, the lnW-lnH relationships were

DMV: $\ln W = -12.1067 + 3.2374 \ln H$
(0.1364) (0.0311)
$R^2 = 0.9135$ N=1027

NYB: $\ln W = -12.9702 + 3.3984 \ln H$
(0.1114) (0.0250)
$R^2 = 0.9575$ N=823

The relationship for all open areas of in the Mid-Atlantic region was

$$(13)\quad \ln W = -12.2804 + 3.2646 \ln H$$
$$(0.939) \quad (0.0213)$$
$$R^2 = 0.9212 \quad N=2019$$

The combined lnW-lnH relationship for the entire Mid-Atlantic region from the current study was:

$$(14)\quad \ln W = -12.3405 + 3.2754 \ln H$$
$$(0.794) \quad (0.0180)$$
$$R^2 = 0.9254 \quad N=2666$$

and that from Serchuk and Rak (1983) was:

$$(15)\quad \ln W = -12.1628 + 3.2539 \ln H$$
$$(0.161) \quad (0.0035)$$
$$R^2 = 0.9604 \quad N=11943$$

The predicted meat weight at any given shell height from the current study was less than that from Serchuk and Rak (1983), however, the difference was trivial. The predicted $W_\infty$ from the current study was around 7% (55.11 g) less than that from Serchuk and Rak (1983, 64.47 g). The relationships from Serchuk and Rak (1983) were used in previous stock assessments.

## BIOMASS, POPULATION SIZE, AND FISHING MORTALITY

Abundance (denoted by n) and biomass (b) indices described in the SURVEYS section are proportional to absolute abundance (N) and biomass (B):

$$(16)\quad n = e\frac{a}{A}N \text{ and } b = e\frac{a}{A}B$$

The term $a$/A is the ratio of areas (e.g. squared miles) per unit survey tow to total area. The ratio estimates the probability that a random survey tow will encounter a randomly selected scallop if the spatial distribution of scallops is homogeneous. The coefficient $e$ is the probability of capturing a scallop given that it encounters a randomly selected survey tow. Gulland (1969) describes $e$ as the efficiency of gear and $ea/A=q$ as the catchability coefficient for the survey.

Swept area indices of abundance and biomass presented in Tables B6 and B7 were calculated respectively by $nA/a$ and $bA/a$. Thus, swept area indices were a proportional measure of absolute abundance and biomass, scaled by gear efficiency ($e$). Gear efficiency for commercial scallop dredges was measured experimentally in a series of depletion experiments carried out cooperatively by CMAST (Center for Marine Science and Technology, University of Massachusetts, Dartmouth) and NEFSC in Closed Area 2 during 1998.

### *Depletion experiments*

A total of 39 depletion experiments were conducted by six commercial vessels during August 28 – October 5, 1998. The experiments were designed to estimate gear efficiency for commercial dredges but the information was also potentially useful for estimating catchability of survey dredges because of similarities between commercial and survey gear.

Locations for depletion experiments were selected based on preliminary information on scallop densities. The primary sampling gear was the New Bedford offshore dredge, which was 4.5 m wide, weighed approximately 1,870 kg, equipped with three tickler chains, a 20.3 mm diamond mesh twine top, and 4.5 by 0.8 m bag made of 89 mm steel rings.

In each depletion experiment, 10 minute tows were made repeatedly in the same area until the catch was reduced to less than 25% of the initial tow (Stokesbury et al. 1999.). An inclinometer was attached to the dredge to measure the time of bottom contact and used with GPS position data (Rago et al. 1999) to calculate the actual distance on the bottom for each tow. Position data for the ship during each depletion experiment was used to infer position of the dredge and to calculate the area of overlap (dredged more than once) for each experiment. Area of overlap is an essential part in modeling gear efficiency and in selecting qualified experiments to be analyzed.

Assumptions in traditional approaches (i.e. the Leslie-Davis model, Hilborn and Walters 1992) used for depletion studies are: 1) sampling is from a closed population; (2) all individuals have independent, identical probabilities of being caught in each sample; (3) samples are independent; (4) sampling of individuals is a Poisson process with respect to effort—this assumption implies that remaining individuals redistribute homogeneously after each sample; and (5) all removals are known. All of these assumptions are violated to some extent for sea scallops so modified and new methods were required.

Three analyses and two new models for analyzing depletion experiment data were presented to the SARC. Stokesbury et al. (1999) used a modified Leslie-Davis model. Rago et al. (1999) used a negative binomial "patch" model. Cai (1999) used an approach similar to the patch model but considered a variety of probability distributions for the sampling process.

The patch model approach measured area of overlap as the number of times cells in the study area were sampled. As formulated by Rago et al. (1999), the patch model also accommodates the possibility that dredges reduce catch during repeated sampling by pushing scallops off to the side of the dredge, moving them out of the study area, burying scallops, or dropping them during haul-back of dredge. These processes were modeled using a parameter, $\gamma$. Instead of assuming the negative binomial distribution and using the gamma parameter to model indirect losses of scallops, Cai (1999) used a maximum likelihood regression approach. The regression approach was similar to the patch model but did not explicitly account for the changes in gear during the experiment or the contagious spatial distribution of scallops.

The criteria for selecting depletion experiments for use in estimating gear efficiency were different. Stokesbury et al. (1999) used 20 out of 39 experiments with > 40% area overlap. Rago et al. (1999) used 12 experiments with statistically significant declines in catch and excluded tows in an experiment that were, due to navigation errors, outside the area sampled by the rest of the tows in the experiment. Cai (1999) used only one of the 39 depletion experiments.

The average gear efficiency estimates (*e*) were 0.16 (SE=0.065, Stokesbury et al. 1999) and 0.41 (SE= 0.122, Rago et al. 1999). The value from the single experiment used by Cai (1999) was 0.23, compared to 0.31 and 0.13 for the same experiment estimated by Rago et al. (1999) and Stokesbury et al. (1999). Differences in mean efficiency estimates were due to different models, different model assumptions, criteria for selecting experiments, and inclusion of outlying tows in the analyses.

The SARC reviewed the three analytical approaches and identified the patch model as the best on statistical grounds (see SARC comments) and most reasonable considering the physical and behavioral responses of scallops to dredging and the contagious nature of their spatial distribution.

As described in the SARC comments (see below), the estimate of average gear efficiency from the patch model (e=0.41) was not used in this assessment to estimate survey gear catchability or to convert survey swept area estimates to estimates of population abundance and biomass. The SARC felt that gear efficiencies in Closed Area 2, where depletion experiments were conducted, were likely higher than elsewhere in the Georges Bank or Mid-Atlantic regions and that there was insufficient time and information to make adjustments. These are topics for future research.

*Two-stage Population Model*

The new two-stage population model maximized a log-likelihood from a Bayesian posterior distribution for parameters given observations of data (Appendix A). The new model and modified Delury model used in previous assessments are compared in Appendix B. The model was not used in the assessment for scallops this year but may prove useful in the future after some technical modeling and data related problems are resolved. Results of fitting the basic model always showed pathological residual patterns, implied implausible survey catchability (q) values (i.e. q > 1), and efficiency estimates much different than estimated from field studies. However, trends in estimated abundance and fishing mortality seemed robust and changed little over a wide range of model runs.

For the Georges Bank region, residuals for partial recruits were positively skewed and large residuals were associated with the large observed indices of partial and full recruits in the period of 1990-1992 but not in 1993 (Fig. B16). Coincidentally, the R/V Oregon was used in 1990-1993 surveys. For the Mid-Atlantic region, residuals for partial recruits were greater than zero from 1985 to 1996, especially during 1988-1990 and 1993-1995 (Fig. B17) implying that the change in survey vessels might be a problem.

To address the uncertainties, extensive sensitivity analyses were presented to the SARC. Three were selected to be presented in this document.

(1) *Mixture prior for $q_n$*.-The basic model included the $q_n$-prior from Rago et al. (1999). A supplemental analysis was carried out (Appendix C) that blended prior estimates of $q_n$ from all three sources. Results using mixture

priors were almost identical to results from the basic model.

(2) *Under-estimation of landings.*-Scallop catches might be under-estimated due to: (i) un-reported landings, (ii) biased samples (a tendency to sample large scallops in catches) for commercial size composition that resulted into biased estimates of mean meat weight and catch in number, (iii) decreasing average meat weight (lnW-lnH relationships of current study and Serchuk and Rak, 1983), (iv) discards and deck mortality, (v) dredge-encountered or non-landed mortality, and (vi) high discard rate in the years of strong partial recruits. For lack of other information, the entire time series of landings was increased by 2-, 3-, 4- and 5-fold for the two regions.

For the Georges Bank region, increasing catch by 3-fold gave the best model fit (lowest negative log-likelihood, Fig. B18). The estimated $q_n$ was 0.44 for a three-fold increase in catch, which was similar to the estimate ($q_n$=0.41) from Rago et al. (1999). This result may have been due to the prior estimate ($q_n$=0.41) assumed in the model.

In Mid-Atlantic region, goodness of fit increased as catches were increased but changes in goodness of fit were trivial when catches were increased beyond three-fold (Fig. B19). Once again, the model-estimated $q_n$ = 0.40 at a 3-fold increase of catch was almost identical to Rago et al.'s (1999) depletion study estimate. As described above, this may have been due to the prior estimate ($q_n$=0.41) used in the model.

Under-reporting and non-landing mortality might have been high during 1990-1992 in Georges Bank because partial recruits were very abundant. In another sensitivity analyses, landings for 1990-1992 from the Georges Bank region were increased as described above. Goodness of fit was maximum for a three-fold increase in catch (Fig. B20).

(3) *Assumptions about $q_n$ and $q_r$.*- In the basic model, the fit to indices of full recruits was generally better than that of partial recruits in Georges Bank and Mid-Atlantic regions. These results indicate that a different assumption about relative catchability for partial $q_r$ and full recruits $q_n$ might improve model fit. In 1990-1992, the R/V Oregon replaced the R/V Albatross in the research survey and residuals were large, suggesting that catchability assumptions might depend on vessels used in the surveys. Three different assumptions on $q_n$ and $q_r$ were carried out to address these possibilities. However, the questions about the magnitude of estimated catchability coefficients were not resolved because estimates of $q_r$ were always greater than one.

*Empirical Estimates of Fishing Mortality*

Because of uncertainty in model results, model-independent methods based on catch and survey data were used to estimate fishing mortality rates for sea scallops used to evaluate overfishing definitions. Using swept area abundance indices (Tables 6 and 7) and assuming constant catchability and selectivity for survey gear over time, survey-based estimates of fishing mortality ($F_{S,t}$ for year t) can be calculated:

$$(17)\quad F_{S,t} = -\ln\left(\frac{n_{2,t+1}}{n_{1,t} + n_{2,t}}\right) - M$$

where $n_{i,t}$ is the swept area abundance index for partial recruits (i = 1) or full recruits (i = 2) and M = 0.1 is the natural mortality rate. Under the assumptions listed above, this estimate is unbiased but precision tends to be low because of variability in swept area indices. The SARC chose to assume that the average $F_{S,t}$ value was unbiased and reliable but that trends in $F_{S,t}$ were too variable for use in status determination.

Another simple approach makes use of catch in weight and swept area biomass estimates from surveys. Surveys were carried out in mid-point of a each calendar year, so the biomass based measure of fishing mortality $F_{B,t}$ was calculated:

$$(18) \quad F_{B,t} = C_t /(\bar{b}_t / q)$$

where $\bar{b}_t$ is the swept area biomass index and $q$ is survey catchability. Because q is a scalar in eq. 25, the trends of $F_{B,t}$ would be parallel over the years and be independent of q. Both q and catch were not reliably estimated, however, the SARC chose to use trends in $F_{B,t}$ based on q=0.6. This would not affect the results because estimated trends did not depend on q.

Surveys take place during the middle of each calendar year so estimates of $F_S$ and $F_B$ are for different annual time periods. In particular, $F_S$ estimates fishing mortality during survey years while $F_B$ estimates fishing mortality for calendar years. This minor technical issue was not pursued further by the SARC due to time constraints.

The SARC decided to use the trends in biomass based estimates ($F_{B,t}$) and the average value of survey based estimates ($F_{S,t}$) to estimate fishing mortality for scallops in both stock areas. Constants of proportionality were estimated for both stock areas based on years with both types of fishing mortality estimates and no closed areas:

$$(19) \quad \alpha = \sum_{t=1982}^{1994} F_{S,t} \Big/ \sum_{t=1982}^{1994} F_{B,t}$$

for Georges Bank region, and

$$(20) \quad \alpha = \sum_{t=1982}^{1997} F_{S,t} \Big/ \sum_{t=1982}^{1997} F_{B,t}$$

for Mid-Atlantic region.

The empirical estimate of fishing mortality ($F_{E,t}$) used for status determinations was

$$(21) \quad F_{E,t} = \alpha F_{B,t}$$

Tables B9 and B10 summarize data, estimation, and trends in empirical fishing mortality estimates ($F_E$) for the Georges Bank and Mid-Atlantic regions.

## BIOLOGICAL REFERENCE POINTS

The method of Thompson and Bell (Rick 1973) was used to estimate $F_{max}$ and $B_{max}$ for sea scallops in the Mid-Atlantic and Georges Bank regions. In the yield-per-recruit model, scallops age 3 to 11 were included, selectivity of cohort age 3 was assumed to be 0.5, cohort age 11 was a plus group (that included all scallops cohort age 11 years and older), and all scallops greater than cohort age 3 were sexually mature. Selectivity at age three was less than one for sea scallops because there is variability in size at age and large individuals of cohort age 3 have a higher probability of being retained than smaller individuals according to fishery selectivity curve for scallops (Fig. B10).

Yield-per-recruit analysis prepared for SFA used the average meat weights from Robert and Butler (Pers. Comm.) for cohort ages t + 0.75 (Oct. 1). There is an inflection point in the seasonal growth pattern and the growth rate declines after October 1. In addition, it seemed reasonable to use the growth during the fast growing season to represent growth in the population. The meat weight at cohort age t+0.75 might overestimate mean weight at age in the fishery for scallops in the Mid-Atlantic region where the birthday is August 1. However, the Gonadalsomatic Index and maturity condition in samples during July 1998 did not reveal differences between scallops from the Mid-Atlantic Bight and Georges Bank regions.

It is important to understand aging conventions for scallops in interpreting yield-per-recruit calculations. In this analysis, partial recruits were assumed to be cohort age 3. Following a convention based on biological age, however, partially recruited scallops might have been described differently. Biological ages are counted from the biological birthday (October 1 for the Georges Bank region and August 1 for the Mid-Atlantic region) and incremented on every birthday. Cohort ages are counted from January 1 of each year and incremented at that time. Annual rings used to age scallops form mainly in winter. Thus, cohort age is equal to the number of ring counts. Cohort age is preferred for yield-per-recruit calculations because age data (used to estimate growth curves) is collected as ring counts which are the same as cohort age. In addition, analysis using cohort ages is simplified because biological ages of scallops born in the same year may (or may not) differ between Georges Bank and Mid-Atlantic regions but cohort ages are identical. Figure B23 illustrates the relationship between biological and cohort ages for scallops with hypothetical biological birthday of October 1. The choice of aging convention is not as important as making sure that the assumed growth pattern is realistic.

Figure B21 also shows the calculated average meat weight at age taken from Robert and Butler (Georges Bank region only, per. Comm.), Serchuk and Rak (1983, eqs. 12 and 15), and the current study (eqs. 11 and 14). The growth equations from Robert and Butler incorporated adjustments for seasonal growth. Growth was relatively slower in the first and fourth seasons of a cohort age than in the second and third seasons. The average meat weight at age by Serchuk and Rak were greater than that used for yield-per-recruit calculations in the current study and from Robert and Butler. The differences seem reasonable given natural fluctuations of seasonal, spatial, and population density related factors that probably affect growth and condition of scallops.

In responding to the third term of reference ("Comment on and revise, if necessary, the overfishing definition reference points for sea scallop recommended by the Overfishing Definition Review Panel."), yield-per-recruit analyses were carried out for three meat weight–shell height relationships and various assumed cohort ages (Table B12). Estimates of $F_{max}$ were the same but there were differences in biomass-per-recruit (max. B/R) and yield-per-recruit (max. Y/R) at $F_{max}$. Estimates of $F_{max}$, max. B/R, and max. Y/R were different among runs that made different assumptions about cohort age (t, t+0.5, t+0.75) but differences were smaller than for different assumptions about growth curves. $B_{max}$ (= Median R × max. B/R) was sensitive to the number of years used in estimation of the median and strata used to tabulate survey data.

In summary, $F_{max}$ was more robust to assumptions about growth than $B_{max}$ and max. B/R. The use of $B_{max}$, derived from median recruits (or average recruits), is subject to great uncertainty, especially with short survey histories and variable recruitment. In addition, the recent area closures and the re-opening of part of Closed Area 2 for scallop fishing may have undermined $F_{max}$ derived from yield-per-recruit models as a proxy of $F_{msy}$ (see SARC comments, below).

## STATUS DETERMINATION

The Overfishing Review Panel (Applegate et al. 1998) used $F_{max}$ and $B_{max}$ (biological reference points from yield-per-recruit models) as proxies for $F_{msy}$ and BMSY (biological reference points from surplus production models). The assumed relationships among these reference points are:

$$r = 2F_{\max}$$

$$B_{msy} = B_{\max}$$

$$B_0 = 2B_{\max}$$

where r is the intrinsic rate of increase in a surplus production model.

The target biomass level for fisheries in general according to the Sustainable Fisheries Act (SFA) is $B_{MSY}$. The Overfishing Review Panel (Applegate et al. 1998) used the following control rule to determine the state of stock. The stock is overfished whenever biomass drops below ¼ $B_{MSY}$. Overfishing occurs whenever fishing mortality rates exceed $F_{MSY}$ if standing biomass is greater than $B_{MSY}$. The overfishing threshold F 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 allow the stock to be rebuilt within 10 years.

For scallops, $B_{max}$, as the proxy of $B_{MSY}$, is difficult to calculate in absolute units because recruitment is uncertain because of survey catchability and year-to-year variability. To avoid problems, biomass is represented by survey indices, weight (g) per tow of survey, rather than absolute biomass. The target biomass level

$$B_{max} = \text{Median R} \times \text{max. B/R}$$

where Median R is the median value (in number of partial recruits per tow) obtained from the survey (Table B11) and max. B/R is biomass pre recruit obtained from yield per recruit analysis. In this formulation, $B_{max}$ is measured in grams per tow. Survey data and $B_{max}$ can be compared directly because they are in the same units.

The average of empirical fishing mortality rate estimates ($F_{E,t}$) during 1997-1998 and biomass indices from

1998 survey were also given in Table B21. Comparing biomass indices in 1998 with $B_{max}$, ¼ $B_{max}$ and mean $F_E$ in 1997-98 with $F_{max}$, the Georges Bank stock is not overfished but biomass is below the target $B_{max}$ level. The Mid-Atlantic stock is at or near the ¼ $B_{max}$ threshold. However, the state of stocks is based on fishing mortality rates for the whole stocks in the two regions (including open and closed areas). It is important to note that fishing mortality rates were higher and relative biomass levels relative were lower for scallops in areas open to fishing (see SARC comments).

## SARC COMMENTS

*Commercial Catch*

1) The SARC was concerned about the quality of fishery data for sea scallops. Commercial catch rate data are difficult to use because of changes in the reporting system in 1994 and changes in management regulations. Changes in fishing area may affect trends in commercial catch rates and CPUE should probably be calculated in an area-specific way although the SARC recognizes that this is not currently possible for sea scallops. Catches may have been substantially unreported in some years. Size composition data show peaks likely due to sampling errors such as those discussed in SARC-23. Estimates of mean weights used to calculate total numbers of scallops landed seem implausibly high, probably due to non-random samples of the catch that are biased in favor of large scallops. Discards are estimated from a small number of trips in each year.

2) Problems with fishery data for scallop (particularly catch and catch at length) may make traditional stock assessment models for scallop difficult to use successfully. In future assessments, it may be better to use either simple models that are insensitive to data problems, or more complex models that specifically allow for particular types of problems. For example, simple biomass-based models could be developed to use catch weight or catch in bushels, to avoid dependence on commercial length composition data. Alternatively, a term allowing for possible bias in commercial length composition data might be specifically incorporated into the model. This is an important area for future research.

*Selectivity*

3) It was agreed that the commercial and survey gear selectivity studies reported in SARC-22 were suitable for estimating relative selectivity between gears for a specific size of scallop. However, these studies do not in themselves provide information on how the selectivity of either gear type changes with size of scallop. Based on other field studies and on biological considerations, the SARC was comfortable assuming a flat, asymptotic selectivity curve for large scallops. However, the shape of the size-specific selectivity curve for smaller scallops is uncertain. This issue is important in developing and applying assessment methods. Length stratified depletion studies



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would be helpful for estimating selectivity curves for scallop and for verifying assumed patterns.

4) At present, commercial and survey length composition data are pre-processed with assumed selectivity corrections before being used in assessment. This makes it difficult to examine the effects of different assumptions about selectivity. It might be useful to incorporate a selectivity adjustment parameter into the assessment models, which could then be estimated directly from the raw data.

*Dredge Efficiency*

5) Estimates of dredge efficiency (probability that a scallop will be landed, given it encounters the gear) are very important in assessing scallops, because a reliable estimate of efficiency can be used to convert nominal swept-area indices from surveys into absolute abundance estimates. Efficiency can be estimated from depletion experiments using commercial gear. However, conventional estimates (i.e. the original Leslie-Davis method) are misleading because scallops are fairly immobile. The SARC considered two extensions: a simple overlap adjustment to the conventional Leslie-Davis estimator, and the "Patch model" entailing detailed consideration of the time-sequenced overlaps in a series of trawls.

6) The SARC also reviewed a paper concerning models for sampling error in a simplified Patch model. The results appeared to suggest that results were robust to different assumptions about sampling error as long as reasonable assumptions were made about mean-variance relationships. However, problems were noted with the way that AIC was used in model selection. The paper used data from only one of the depletion experiments in the Patch model paper, and did not allow for non-yield depletion.

7) The SARC recommends use of the full Patch model rather than the overlap adjustment, for the following reasons.

(i) The Patch model is based on a rigorous mathematical argument, rather than ad hoc adjustment.

(ii) The overlap adjustment induces a bias—albeit often small-- which depends on the degree and sequence of overlap, whereas the Patch model is designed to avoid such bias in the first place.

(iii) Only the Patch model includes a parameter ("gamma") which reflects non-yield depletion, e.g. scallops that are buried by the gear and rendered unavailable on subsequent passes.

(iv) The Patch model makes full use of detailed navigational information and makes allowance for "end effects" at the start and finish of each tow.

(v) The Patch model incorporates a realistic model for sampling error, in terms of mean-variance relationships.

8) Choice of grid size for the Patch model was discussed. The appropriate order of magnitude is not obvious, let alone the optimal choice: there are important considerations of navigational accuracy, dredge width, and tow speed. The SARC recommended simulation analyses to investigate this further. Once this is complete, the SARC encourages the developers of the Patch model to take forward the work for journal publication.

9) Results of the Patch model suggest significant non-yield depletion. Although the quantitative results may depend to some extent on grid size, the qualitative conclusion is consistent with other published studies. In the short-term depletion experiments on Georges Bank, "non-yield depletion" means scallops which are made less available to subsequent trawls in the same spot, e.g. through being buried by the gear. The implications for the fishery depend on how much of this non-yield depletion actually results in scallop mortality, rather than just short-term unavailability.

10) There was considerable variation between estimated efficiencies in the various Patch model experiments, larger than would be expected on the basis of sampling noise alone. Together with fishermen's experience and other scientific studies, this suggests that true efficiency may vary over space and/or time, presumably in response to bottom type and other physical factors. On the basis of bottom type, the areas of George's Bank used in the experiments are expected to produce high dredge efficiencies. Extrapolating the experimental results directly to estimate commercial efficiency throughout the region could therefore lead to bias. The SARC therefore decided not to use the Patch model efficiency estimates yet in estimating absolute abundance, until results from different bottom types are available.

*Assessment*

11) The SARC reviewed the new two-life-stage assessment model for scallops, and commended the Stock Assessment Team for its effort and innovation in attempting to combine different sources of information through a Bayesian model. However, the SARC decided not to use results from the model in estimating current fishing mortality rates or abundance, for two main reasons. First, problems were noted with the construction of the model, particularly with respect to multiple use of data in likelihoods and in priors. Second, the model diagnostics indicated serious lack of fit, both in terms of residual patterns (proportions of young scallops) and in mismatches between likelihoods and priors for dredge efficiency. In particular, changes in survey indices suggested efficiencies greater than 100%, contrary to common sense. All in all, these diagnostics point to major incompatibilities between the different data sources and/or the model itself.

12) Despite the problems, the model-based assessment provided important information. In particular, results from one sensitivity run showed that

the problems with estimated efficiency disappeared if the true fishing-related-removals were assumed 2-3 higher than the estimated catches (number of animals) used in the model. Given the magnitude of the necessary alteration in catches, and the simplicity and robustness of the underlying population dynamics model, the problem must lie in the estimated fishing-related-removals. The SARC envisaged four possible explanations, as follows:

i. There is significant non-yield fishing mortality, as suggested by published studies and the George's Bank depletion experiment results.

ii. Commercial size distribution data is unrepresentative of catches, and is biased in favor of large scallops. This would imply that estimates of scallop numbers, based on landings in weight divided by mean weight, were too low.

iii. Total landings in weight have been systematically underreported.

iv. Survey selectivity assumptions are seriously in error, so that incoming recruits are being greatly overestimated, and the true change in numbers from year to year is much less than assumed.

v. Based on experience of data collection and on published studies, the SARC considered that (i) and (ii) were both very likely, but did not have enough information to comment on (iii) or (iv). Resolving this issue will be crucial in interpreting future assessments. Reference point calculations will also require revision if non-yield removals turn out to be substantial (see also ** below).

13) In lieu of model based estimates of fishing mortality, the SARC opted to use robust empirical estimators. Annual estimates of fishing mortality were calculated from F=C/(alpha*B), where B is the swept-area estimate of biomass from mid-year survey, and C is calendar year catch in weight. The parameter alpha, which reflects survey dredge efficiency and commercial selectivity, was chosen to ensure that average fishing mortality from this method matches the average mortality calculated from F'=(N_t+1)/(N_t+R_t)-M, using numbers of full and partial recruits from the survey. F' cannot be used on its own because of excessive variability from sampling error. There are potential problems with both measures of fishing mortality; the catch-to-biomass ratio neglects any non-yield mortality, and the number-ratio method is sensitive to assumptions about selectivity and natural mortality. The SARC also noted that estimates based on C/(alpha*B) would be biased downwards in recent years on George's Bank, because the ratio between average weight in the survey and average weight in the catches has changed since the closed areas were designated. As and when the assessment model and/or data series can be revised to resolve the diagnostic problems, model-based estimates will be preferable.

14) In lieu of model-based estimates of biomass, the SARC opted to use weights-per-tow from the survey, to be compared with the current definitions of reference points also based on weight-per-tow.

15) Projections of future stocks and yields would be useful for scallops. However, the SARC felt unable to carry out projections, because management intentions regarding opening and closing of areas had not been specified. It should be possible for the Council's plan development team to carry out projections once decisions about future closed area management are taken, and to investigate the implications of different possible plans.

*Biological Reference Points*

16) The SARC discussed the appropriateness of basic YPR calculations and YPR-based reference points in the context of exploitation of a non-mobile stock that lies substantially within closed areas. Many difficulties arise, particularly if the closed areas last for several years. Current fishing mortality calculated for the stock *as a whole* will underestimate fishing mortality on scallops in the open areas, i.e. those scallops currently available to the fishery. Further, the basic YPR curve will misrepresent yields as a function of whole-stock F. Management that ignores these factors could lead to policy contradictions. As an example, in a transitional situation where biomass is increasing in the closed areas, whole-stock fishing mortality will no longer be proportional to fishing effort. It would be possible to increase effort so that whole-stock F declines to levels far below $F_{max}$, so that the fishery appears sustainable, while the open-area stock is fished so hard that total fishery yield collapses.

17) Closed areas also induce a mismatch between reference points on F and the supposedly-corresponding biomass reference points, even in a non-transitional equilibrium context. For example, fishing at whole-stock $F_{max}$ does not imply that the whole stock will equilibrate to the whole-stock $B_{max}$ suggested by basic YPR calculations.

18) Further complications are induced when considering the implications of opening closed area. Even if overall fishing effort does not change, the distribution of effort will likely shift towards the newly-opened areas where abundance is higher. Since whole-stock fishing mortality is an abundance-weighted combination of mortalities in the different areas, the overall fishing mortality will likely increase. This can be illustrated by a simple example, where the stock is assumed to have reached a steady state under a open-and-closed area regime. Suppose that the closed portion is of area A and contains Nc scallops, the open region is of area Ao and contains No scallops, fishing effort (area swept by trawls) is E, and dredge efficiency is q. While the closed areas are in effect, total catch in numbers is qE(No/Ao), total abundance is No+Nc, and fishing mortality is

$$qE(No/Ao)/(No+Nc)$$

After the areas are opened fishing (and assuming all fishing immediately moves into the more lucrative previously-closed areas), total catch will be qE(Nc/Ac) while total abundance is still No+Nc, so that fishing mortality is now

qE(Nc/Ac)/(No+Nc)

The number density of scallops will presumably be much higher in the previously-closed areas (as in George's Bank), so the whole-stock fishing mortality will increase greatly without any change in fishing effort or capacity. The implication is that a false sense of security may result from a basic YPR-based assessment in a region with open-and-closed areas, aside from the problems with growth overfishing mentioned above. If the assessment leads to the conclusion that "current fishing mortality is sustainable", then it is important to remember that the conclusion rests on the presumption that the closed areas remain closed in future.

19) For all these reasons, basic YPR calculations do not provide appropriate reference points for whole-stock fishing mortality. However, the reference points are still relevant for determining growth overfishing of the open-area component of the stock, assuming that existing closure regimes persist.

20) The existence of short-term or long-term area closures does not in itself preclude calculations of yield under different strategies, or of yield-based reference points. Indeed, this is an important area for research. However, to do the calculations, it is necessary to have a clear plan in mind for future management: for example, a 5-year rotation of 20% closures of the entire region. It should be quite feasible to develop more complicated yield models that allow the comparison of different management plans incorporating closures of different spatial extent and duration.

21) There remains the issue of how closed areas affect recruitment. Qualitatively, the biomass reservoir in the closed areas provides some buffer against recruitment overfishing, but the quantitative implications remain uncertain. Research on growth, fecundity, larval dispersion, and settlement might be useful in addressing this.

*Research Recommendations*

1) Further depletion studies should conducted in a variety of bottom type, so that results can be reliably applied to survey results in forming abundance estimates for an entire region. For this second step, it is important to inventory bottom types in areas where scallops are common. One way to carry out such an inventory would be to use precision bottom-scanning sonar similar to that currently in use off Newfoundland and the in the North Sea.

2) Depletion studies should include areas of smaller scallops, so that results can be size-stratified and used to check selectivity assumptions.

3) Lack of basic information on scallop growth continues to plague assessment and reference point calculation. The closed areas in particular provide an opportunity to remedy this, as "shock rings" caused by contact with fishing gear will be rare so that age might be reliably inferred from ring counts. Recovery of tagged animals from fisheries in newly-opened areas should also be informative. Large-scale aging of scallops via ring counts or isotope studies remains difficult, but other possibilities such as resilin measurements might still be investigated.

4) Closed areas provide an opportunity to refine estimates of natural mortality and to estimate non-yield mortality from fishing. Natural mortality estimates might be refined based on numbers of "clappers" in non-fished areas. Differences in numbers of clappers before and after an area is closed, or between closed and open areas, could be useful in inferring non-yield mortality.

5) Proper stock assessment for scallops will entail further development of assessment models. The most important need is to resolve the incompatibilities between current data and current assumptions discussed above. Simpler models and more complex models are both worthy of consideration.

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Table B1. Scallop landings (mt) by region, gear type, and year. Data from 1964-1988 were taken from Serchuck and Wigley (1988). Data from 1989-1993 were taken from the NEFSC commercial weighout database; canvass data not included. Data from April, 1994-1998 were estimated from Vessel Trip Reports and Dealer Logs.

| | Gulf of Maine | | | | Georges Bank | | | | S.New England | | | | Mid Atlantic | | | | 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 | 6241 | 6241 | | 52 | 3 | 55 | | | | | 137 | | 52 | 6436 | 6626 |
| 1965 | | 0 | 115 | 115 | | 3 | 1480 | 1483 | | 2 | 24 | 26 | | | | | 3974 | | 5 | 1619 | 5598 |
| 1966 | | 0 | 93 | 93 | | 0 | 883 | 884 | | 0 | 8 | 8 | | | | | 4071 | | 1 | 984 | 5056 |
| 1967 | | 0 | 80 | 80 | | 4 | 1217 | 1221 | | 0 | 8 | 8 | | | | | 1873 | | 4 | 1305 | 3182 |
| 1968 | | 0 | 113 | 113 | | 0 | 993 | 994 | | 0 | 56 | 56 | | 0 | 2437 | 2437 | | | 0 | 3599 | 3599 |
| 1969 | | 1 | 122 | 123 | | 8 | 1316 | 1324 | | 0 | 18 | 19 | | 5 | 846 | 851 | | | 14 | 2302 | 2317 |
| 1970 | | 0 | 132 | 132 | | 5 | 1410 | 1415 | | 0 | 6 | 6 | | 14 | 459 | 473 | | | 19 | 2006 | 2026 |
| 1971 | | 4 | 358 | 362 | | 18 | 1311 | 1329 | | 0 | 7 | 7 | | 0 | 274 | 274 | | | 22 | 1949 | 1971 |
| 1972 | | 1 | 524 | 525 | | 5 | 816 | 821 | | 0 | 2 | 2 | | 5 | 653 | 658 | | | 11 | 1995 | 2006 |
| 1973 | | 0 | 460 | 460 | | 15 | 1065 | 1080 | | 0 | 3 | 3 | | 4 | 245 | 249 | | | 19 | 1773 | 1792 |
| 1974 | | 0 | 223 | 223 | | 15 | 911 | 926 | | 0 | 4 | 5 | | 0 | 937 | 938 | | | 16 | 2076 | 2091 |
| 1975 | | 6 | 741 | 746 | | 13 | 844 | 857 | | 8 | 42 | 50 | | 52 | 1506 | 1558 | | | 80 | 3132 | 3212 |
| 1976 | | 3 | 364 | 366 | | 38 | 1723 | 1761 | | 4 | 3 | 7 | | 317 | 2972 | 3288 | | | 361 | 5061 | 5422 |
| 1977 | | 4 | 254 | 258 | | 27 | 4709 | 4736 | | 1 | 10 | 11 | | 27 | 2564 | 2591 | | | 58 | 7536 | 7595 |
| 1978 | 242 | 1 | 0 | 243 | 5532 | 37 | 0 | 5569 | 25 | 2 | 0 | 27 | 4175 | 21 | 0 | 4196 | | 9974 | 61 | 0 | 10035 |
| 1979 | 401 | 5 | 1 | 407 | 6253 | 25 | 7 | 6285 | 61 | 5 | 0 | 66 | 2857 | 29 | 1 | 2888 | | 9572 | 64 | 9 | 9645 |
| 1980 | 1489 | 122 | 3 | 1614 | 5382 | 34 | 2 | 5419 | 130 | 3 | 0 | 133 | 1966 | 9 | 0 | 1975 | < 0.01 | 8968 | 169 | 4 | 9142 |
| 1981 | 1225 | 73 | 7 | 1305 | 7787 | 56 | 0 | 7843 | 68 | 1 | 0 | 69 | 726 | 5 | 0 | 731 | | 9806 | 135 | 7 | 9948 |
| 1982 | 631 | 28 | 5 | 664 | 6204 | 119 | 0 | 6322 | 126 | 0 | 0 | 126 | 1602 | 6 | 2 | 1610 | | 8562 | 153 | 7 | 8723 |
| 1983 | 815 | 72 | 7 | 895 | 4247 | 32 | 4 | 4284 | 243 | 1 | 0 | 243 | 3081 | 18 | 10 | 3109 | | 8386 | 124 | 21 | 8530 |
| 1984 | 651 | 18 | 10 | 678 | 3011 | 29 | 3 | 3043 | 161 | 3 | 0 | 164 | 3647 | 26 | 2 | 3675 | | 7470 | 76 | 14 | 7560 |
| 1985 | 408 | 3 | 10 | 421 | 2860 | 34 | 0 | 2894 | 77 | 4 | 0 | 82 | 3227 | 47 | 1 | 3276 | | 6572 | 88 | 11 | 6672 |
| 1986 | 308 | 2 | 6 | 316 | 4428 | 10 | 0 | 4438 | 76 | 2 | 0 | 78 | 3257 | 101 | 0 | 3359 | | 8068 | 115 | 7 | 8190 |
| 1987 | 373 | 0 | 9 | 382 | 4821 | 30 | 0 | 4851 | 67 | 1 | 0 | 68 | 7488 | 315 | 1 | 7803 | | 12749 | 346 | 10 | 13104 |
| 1988 | 506 | 7 | 13 | 526 | 6036 | 18 | 0 | 6054 | 65 | 4 | 0 | 68 | 5774 | 402 | 2 | 6178 | | 12381 | 430 | 16 | 12826 |
| 1989 | 600 | 0 | 44 | 644 | 5637 | 25 | 0 | 5661 | 127 | 11 | 0 | 138 | 7549 | 422 | 2 | 7973 | | 13913 | 458 | 45 | 14416 |
| 1990 | 545 | 0 | 28 | 574 | 9972 | 10 | 0 | 9982 | 110 | 6 | 0 | 116 | 5954 | 476 | 4 | 6435 | | 16581 | 493 | 32 | 17107 |
| 1991 | 527 | 3 | 75 | 605 | 9235 | 77 | 0 | 9311 | 55 | 16 | 0 | 71 | 6195 | 808 | 9 | 7011 | | 16012 | 903 | 84 | 16999 |
| 1992 | 676 | 2 | 45 | 722 | 8230 | 7 | 0 | 8238 | 119 | 5 | 0 | 124 | 4386 | 563 | 5 | 4955 | | 13411 | 577 | 50 | 14039 |
| 1993 | 763 | 2 | 32 | 797 | 3637 | 18 | 0 | 3655 | 65 | 1 | 0 | 66 | 2382 | 392 | 3 | 2778 | | 6848 | 413 | 36 | 7296 |
| 1994 | 519 | 3 | 3 | 525 | 1133 | 3 | 1 | 1137 | 0 | 1 | 0 | 1 | 5176 | 688 | 9 | 5872 | | 6827 | 693 | 13 | 7534 |
| 1995 | 424 | 4 | 238 | 665 | 967 | 15 | 0 | 982 | 35 | 1 | 0 | 36 | 5408 | 744 | 166 | 6318 | | 6799 | 762 | 404 | 7965 |
| 1996 | 632 | 20 | 121 | 773 | 2040 | 6 | 0 | 2045 | 74 | 0 | 0 | 74 | 4335 | 656 | 9 | 4999 | | 7006 | 682 | 130 | 7818 |
| 1997 | 581 | 21 | 98 | 699 | 2317 | 10 | 0 | 2326 | 69 | 0 | 0 | 69 | 2442 | 357 | 111 | 2910 | | 5339 | 387 | 209 | 5936 |
| 1998 | 1122 | 10 | 1 | 1133 | 2036 | 28 | 0 | 2064 | 120 | 7 | 0 | 126 | 2199 | 573 | 6 | 2778 | | 5356 | 610 | 8 | 5974 |
| 1982-98 | | | | | | | | | | | | | | | | | | | | | |
| Mean | 593 | 11 | 44 | 648 | 4518 | 28 | 0 | 4546 | 93 | 4 | 0 | 97 | 4359 | 388 | 20 | 4767 | | 9546 | 430 | 64 | 10041 |
| Min | 308 | 0 | 1 | 316 | 967 | 3 | 0 | 982 | 0 | 0 | 0 | 1 | 1602 | 6 | 0 | 1610 | | 5339 | 76 | 7 | 5936 |
| Max | 1122 | 72 | 238 | 1133 | 9972 | 119 | 4 | 9982 | 243 | 16 | 0 | 243 | 7549 | 808 | 166 | 7973 | | 16581 | 903 | 404 | 17107 |

* Previous to 1978, dredge trips are included in the "other" gear type.

Table B2. Summary of trips and scallop shells sampled by NEFSC port agents from the commercial vessels using scallop dredges in Georges Bank and Mid-Atlantic regions 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 |

* Based on preliminary text files.

Table B3. Summary of trips, tows, and shells by NEFSC Sea Sampling Program for commercial vessels using scallop dredges in Georges Bank and Mid-Atlantic regions during 1992-1998.

| Calender | Number of sampled tows | | | Number of sampled trips | | | Number of discarded shells sampled | | | Number of kept shells sampled | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | an.-Jun. | Jul.-Dec | Sum | Jan.-Jun. | Jul.-Dec | Sum | Jan.-Jun. | Jul.-Dec | Sum | Jan.-Jun. | Jul.-Dec | Sum |
| Georges Bank | | | | | | | | | | | | |
| 1992 | 144 | 191 | 335 | 4 | 5 | 9 | 352 | 1,700 | 2,052 | 15,761 | 41,456 | 57,217 |
| 1993 | 253 | 168 | 421 | 7 | 4 | 11 | 4,372 | 260 | 4,632 | 49,227 | 22,105 | 71,332 |
| 1994 | 129 | 143 | 272 | 2 | 4 | 6 | 0 | 378 | 378 | 18,763 | 27,200 | 45,963 |
| 1995 | 32 | 190 | 222 | 1 | 5 | 6 | 0 | 2,018 | 2,018 | 4,683 | 20,002 | 24,685 |
| 1996 | 301 | 303 | 604 | 6 | 7 | 13 | 4,805 | 3,242 | 8,047 | 46,960 | 47,598 | 94,558 |
| 1997 | 262 | 335 | 597 | 6 | 5 | 11 | 1,700 | 4,280 | 5,980 | 29,479 | 27,154 | 56,633 |
| 1998 | 69 | 30 | 99 | 2 | 2 | 4 | 132 | 0 | 132 | 22,296 | 9,397 | 31,693 |
| Mid-Atlantic | | | | | | | | | | | | |
| 1992 | 118 | 142 | 260 | 3 | 3 | 6 | 372 | 0 | 372 | 10,916 | 17,109 | 28,025 |
| 1993 | 385 | 119 | 504 | 7 | 3 | 10 | 0 | 0 | 0 | 42,496 | 12,802 | 55,298 |
| 1994 | 484 | 293 | 777 | 9 | 6 | 15 | 1,226 | 3,473 | 4,699 | 80,474 | 39,704 | 120,178 |
| 1995 | 606 | 166 | 772 | 13 | 5 | 18 | 11,924 | 30 | 11,954 | 91,264 | 26,042 | 117,306 |
| 1996 | 500 | 417 | 917 | 15 | 9 | 24 | 8,229 | 975 | 9,204 | 61,693 | 41,172 | 102,865 |
| 1997 | 422 | 220 | 642 | 13 | 5 | 18 | 44 | 144 | 188 | 42,993 | 19,512 | 62,505 |
| 1998 | 178 | 131 | 309 | 6 | 8 | 14 | 2,746 | 0 | 2,746 | 19,833 | 13,760 | 33,593 |

Table B5. Definition of original (Serchuck and Wigley 1989a) and revised strata sets for the NEFSC sea scallop research surveys.

A. Original

| REGION | STRATA SET |
|---|---|
| **Mid-Atlantic** | |
| Virginia - No. Carolina | Strata 6-7 |
| Delmarva | Strata 10-11, 14-15, 18-19 |
| New York Bight | Strata 22-31, 33-35 |
| **Georges Bank** | |
| South Channel | Strata 46-47, 49-55 |
| Southeast Part | Strata 58-60 |
| USA No. Edge & Peak | Strata 61, 621, 631, 651, 661, 71, 72, 74 |
| CAN No. Edge & Peak | Strata 622, 632, 64, 652, 662 |

B. Revised

| REGION | STRATA SET |
|---|---|
| **Mid-Atlantic** | |
| Virginia Beach Closure | Strata 6-7, 10C, 11C |
| Delmarva Open Area | Strata 10O, 11O, 14-15, 18O, 19O |
| Hudson Canyon S. Closure | Strata 22C (include 18C, 25C, 26C), 23 (include 19C), 24C, 27C, 28C |
| New York Bight Open Area | Strata 22O, 24O, 25O, 26O, 27O (include 28O), 29-31, 33-35 |
| **Georges Bank** | |
| South Channel Open Area | Strata 47O (include 46O), 49, 50, 51O, 52O, 53O, 54O, 55O |
| South Channel Closed Area I | Strata 52C (include 51C), 53C, 54C, 55C (include NE corner of 47C) |
| South Channel Nantucket Lightship Closure | Strata 46C, 47C |
| Southeast Part Open Area | Strata 58, 59O, 60 |
| USA No. Edge & Peak Open Area | Strata 61O, 621O (include 61O), 651O, 661O, 71O, 72O (include 74O) |
| USA No. Edge & Peak Closed Area II | Strata 61C (include 59C), 621C, 631, 651C, 661C, 71C (include 72C), 74C |
| CAN No. Edge & Peak Open Area | Strata 622, 632, 64, 652, 662 |

Table B4. Estimated ratio between discarded and kept sea scallops by survey year in Georges Bank and Mid-Atlantic regions. Data sources: NEFSC Sea Sampling Program.

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 B6. Stratified mean number and weight (g) per tow with the corresponding swept area estimates of population (millions) and biomass (mt) by resource areas in Georges Bank region

| | | Mean Number per Tow | | | Swept Area population (10^6) | | | Mean Weight (g) per Tow | | | Swept Area Biomass (mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Tows | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total |
| South Channel Closed Area I | | | | | 636.30 sq. mile | | | | | | 636.30 sq. mile | | |
| 1982 | 14 | 53.90 | 35.35 | 89.26 | 22.48 | 14.74 | 37.22 | 145.03 | 909.41 | 1054.43 | 60.47 | 379.20 | 439.67 |
| 1983 | 18 | 11.53 | 39.05 | 50.59 | 4.81 | 16.28 | 21.09 | 45.31 | 809.48 | 854.78 | 18.89 | 337.53 | 356.42 |
| 1984 | 9 | 15.00 | 35.28 | 50.28 | 6.25 | 14.71 | 20.96 | 59.60 | 830.81 | 890.41 | 24.85 | 346.42 | 371.28 |
| 1985 | 18 | 42.31 | 115.95 | 158.26 | 17.64 | 48.35 | 65.99 | 218.18 | 1906.96 | 2125.14 | 90.98 | 795.15 | 886.12 |
| 1986 | 15 | 180.35 | 94.45 | 274.80 | 75.20 | 39.38 | 114.58 | 848.33 | 1424.58 | 2272.91 | 353.73 | 594.01 | 947.74 |
| 1987 | 18 | 43.91 | 34.27 | 78.18 | 18.31 | 14.29 | 32.60 | 130.34 | 609.80 | 740.14 | 54.35 | 254.27 | 308.62 |
| 1988 | 16 | 112.64 | 49.34 | 161.98 | 46.97 | 20.57 | 67.54 | 441.36 | 828.92 | 1270.27 | 184.03 | 345.64 | 529.67 |
| 1989 | 16 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 16 | 166.12 | 114.00 | 280.12 | 69.27 | 47.53 | 116.80 | 761.40 | 1590.04 | 2351.44 | 317.48 | 663.00 | 980.49 |
| 1991 | 18 | 119.17 | 71.41 | 190.57 | 49.69 | 29.77 | 79.46 | 527.41 | 980.27 | 1507.69 | 219.92 | 408.75 | 628.66 |
| 1992 | 16 | 670.10 | 142.13 | 812.22 | 279.41 | 59.26 | 338.67 | 2316.63 | 1482.32 | 3798.95 | 965.97 | 618.09 | 1584.06 |
| 1993 | 13 | 388.39 | 61.41 | 449.79 | 161.95 | 25.60 | 187.55 | 1679.44 | 550.38 | 2229.83 | 700.28 | 229.50 | 929.78 |
| 1994 | 18 | 61.02 | 102.19 | 163.21 | 25.44 | 42.61 | 68.06 | 347.91 | 1124.28 | 1472.19 | 145.07 | 468.79 | 613.86 |
| 1995 | 19 | 49.78 | 39.67 | 89.45 | 20.76 | 16.54 | 37.30 | 149.24 | 733.09 | 882.33 | 62.23 | 305.68 | 367.91 |
| 1996 | 20 | 68.30 | 111.04 | 179.34 | 28.48 | 46.30 | 74.78 | 263.11 | 2142.19 | 2405.29 | 109.71 | 893.23 | 1002.94 |
| 1997 | 21 | 12.62 | 169.66 | 182.28 | 5.26 | 70.74 | 76.01 | 42.56 | 4224.30 | 4266.86 | 17.75 | 1761.42 | 1779.16 |
| 1998 | 19 | 494.48 | 1124.33 | 1618.81 | 206.18 | 468.81 | 675.00 | 2225.66 | 24466.23 | 26691.89 | 928.04 | 10201.74 | 11129.78 |
| Nantucket Lightship Closure | | | | | 1009.87 | | | | | | 1009.87 | | |
| 1982 | 11 | 4.11 | 14.11 | 18.21 | 2.72 | 9.34 | 12.05 | 15.03 | 405.58 | 420.62 | 9.95 | 268.40 | 278.35 |
| 1983 | 11 | 2.54 | 7.34 | 9.88 | 1.68 | 4.86 | 6.54 | 11.22 | 309.96 | 321.18 | 7.42 | 205.12 | 212.55 |
| 1984 | 12 | 8.72 | 15.74 | 24.46 | 5.77 | 10.41 | 16.18 | 30.55 | 454.12 | 484.67 | 20.22 | 300.52 | 320.74 |
| 1985 | 10 | 61.50 | 19.43 | 80.93 | 40.70 | 12.86 | 53.56 | 237.61 | 283.48 | 521.09 | 157.24 | 187.60 | 344.84 |
| 1986 | 5 | 0.39 | 1.01 | 1.40 | 0.26 | 0.67 | 0.92 | 2.19 | 31.35 | 33.54 | 1.45 | 20.74 | 22.19 |
| 1987 | 14 | 16.00 | 16.58 | 32.58 | 10.59 | 10.97 | 21.56 | 54.35 | 395.26 | 449.61 | 35.97 | 261.57 | 297.54 |
| 1988 | 14 | 15.48 | 6.51 | 21.99 | 10.24 | 4.31 | 14.55 | 30.37 | 183.56 | 213.93 | 20.10 | 121.48 | 141.57 |
| 1989 | 16 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 13 | 120.64 | 20.75 | 141.39 | 79.84 | 13.73 | 93.57 | 278.45 | 324.10 | 602.55 | 184.27 | 214.48 | 398.75 |
| 1991 | 13 | 245.35 | 48.09 | 293.44 | 162.36 | 31.83 | 194.19 | 847.38 | 722.72 | 1570.10 | 560.78 | 478.28 | 1039.05 |
| 1992 | 15 | 6.70 | 19.38 | 26.08 | 4.43 | 12.83 | 17.26 | 35.75 | 274.74 | 310.49 | 23.66 | 181.82 | 205.48 |
| 1993 | 12 | 2.07 | 5.81 | 7.88 | 1.37 | 3.84 | 5.21 | 9.79 | 134.13 | 143.91 | 6.48 | 88.76 | 95.24 |
| 1994 | 16 | 15.39 | 14.48 | 29.87 | 10.19 | 9.58 | 19.77 | 40.90 | 245.94 | 286.83 | 27.06 | 162.76 | 189.82 |
| 1995 | 11 | 73.53 | 32.43 | 105.96 | 48.66 | 21.46 | 70.12 | 334.87 | 483.32 | 818.18 | 221.61 | 319.85 | 541.45 |
| 1996 | 13 | 103.29 | 91.77 | 195.06 | 68.36 | 60.73 | 129.09 | 438.65 | 1950.73 | 2389.38 | 290.29 | 1290.95 | 1581.24 |
| 1997 | 12 | 38.76 | 59.52 | 98.28 | 25.65 | 39.39 | 65.04 | 169.18 | 2107.12 | 2276.30 | 111.96 | 1394.44 | 1506.40 |
| 1998 | 29 | 127.35 | 120.42 | 247.76 | 84.27 | 79.69 | 163.96 | 403.62 | 3916.44 | 4320.05 | 267.10 | 2591.81 | 2858.91 |

Table B6. Continued

| Year | Number of Tows | Mean Number per Tow: Partial Recruits | Mean Number per Tow: Full Recruits | Mean Number per Tow: Total | Swept Area population (10^6): Partial Recruits | Swept Area population (10^6): Full Recruits | Swept Area population (10^6): Total | Mean Weight (g) per Tow: Partial Recruits | Mean Weight (g) per Tow: Full Recruits | Mean Weight (g) per Tow: Total | Swept Area Biomass (mt): Partial Recruits | Swept Area Biomass (mt): Full Recruits | Swept Area Biomass (mt): Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N. Edge & Peak Closed Area II | | | | | 1832.64 sq. mile | | | | | | 1832.64 sq. mile | | |
| 1982 | 22 | 6.40 | 28.82 | 35.23 | 7.69 | 34.61 | 42.30 | 33.34 | 611.67 | 645.01 | 40.04 | 734.58 | 774.62 |
| 1983 | 27 | 12.95 | 16.25 | 29.20 | 15.56 | 19.51 | 35.07 | 34.36 | 405.55 | 439.91 | 41.26 | 487.04 | 528.30 |
| 1984 | 26 | 23.58 | 23.22 | 46.80 | 28.32 | 27.88 | 56.20 | 80.80 | 545.85 | 626.65 | 97.04 | 655.53 | 752.57 |
| 1985 | 39 | 23.41 | 24.87 | 48.28 | 28.12 | 29.87 | 57.99 | 100.82 | 483.66 | 584.48 | 121.08 | 580.85 | 701.93 |
| 1986 | 28 | 69.47 | 34.96 | 104.43 | 83.44 | 41.98 | 125.42 | 253.72 | 705.90 | 959.61 | 304.70 | 847.74 | 1152.44 |
| 1987 | 40 | 74.80 | 56.22 | 131.02 | 89.83 | 67.51 | 157.35 | 267.40 | 791.85 | 1059.25 | 321.13 | 950.97 | 1272.10 |
| 1988 | 39 | 81.59 | 75.97 | 157.55 | 97.98 | 91.23 | 189.21 | 346.24 | 1076.48 | 1422.72 | 415.82 | 1292.79 | 1708.61 |
| 1989 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 40 | 152.84 | 168.12 | 320.96 | 183.55 | 201.90 | 385.45 | 840.68 | 1708.42 | 2549.10 | 1009.61 | 2051.72 | 3061.33 |
| 1991 | 41 | 199.08 | 96.39 | 295.48 | 239.09 | 115.76 | 354.85 | 731.81 | 1339.24 | 2071.05 | 878.86 | 1608.35 | 2487.22 |
| 1992 | 39 | 45.01 | 53.12 | 98.13 | 54.06 | 63.80 | 117.85 | 198.64 | 798.24 | 996.88 | 238.56 | 958.64 | 1197.20 |
| 1993 | 40 | 6.13 | 19.84 | 25.97 | 7.36 | 23.83 | 31.19 | 33.48 | 330.69 | 364.17 | 40.21 | 397.14 | 437.35 |
| 1994 | 41 | 19.82 | 15.86 | 35.69 | 23.80 | 19.05 | 42.86 | 45.03 | 354.74 | 399.77 | 54.08 | 426.03 | 480.10 |
| 1995 | 38 | 95.35 | 21.69 | 117.03 | 114.50 | 26.04 | 140.55 | 304.27 | 412.13 | 716.40 | 365.41 | 494.94 | 860.35 |
| 1996 | 42 | 105.93 | 99.42 | 205.35 | 127.21 | 119.40 | 246.61 | 348.67 | 1658.15 | 2006.82 | 418.74 | 1991.34 | 2410.08 |
| 1997 | 46 | 28.56 | 116.20 | 144.76 | 34.30 | 139.55 | 173.85 | 99.50 | 2552.21 | 2651.71 | 119.50 | 3065.06 | 3184.56 |
| 1998 | 39 | 123.95 | 120.93 | 244.88 | 148.86 | 145.23 | 294.08 | 314.56 | 3042.61 | 3357.17 | 377.77 | 3654.00 | 4031.77 |
| South Channel Open Area | | | | | 1390.83 sq. mile | | | | | | 1390.83 sq. mile | | |
| 1982 | 36 | 519.09 | 78.01 | 597.09 | 473.11 | 71.10 | 544.20 | 1568.01 | 906.18 | 2474.19 | 1429.12 | 825.91 | 2255.03 |
| 1983 | 39 | 85.16 | 118.63 | 203.79 | 77.62 | 108.12 | 185.74 | 441.90 | 1462.04 | 1903.95 | 402.76 | 1332.54 | 1735.30 |
| 1984 | 47 | 19.38 | 25.41 | 44.78 | 17.66 | 23.16 | 40.82 | 78.28 | 448.56 | 526.85 | 71.35 | 408.83 | 480.18 |
| 1985 | 48 | 50.70 | 37.46 | 88.16 | 46.21 | 34.14 | 80.35 | 172.94 | 789.49 | 962.43 | 157.62 | 719.56 | 877.18 |
| 1986 | 47 | 192.19 | 47.11 | 239.30 | 175.16 | 42.94 | 218.10 | 553.46 | 777.61 | 1331.07 | 504.44 | 708.73 | 1213.17 |
| 1987 | 56 | 148.79 | 97.59 | 246.38 | 135.61 | 88.95 | 224.56 | 587.69 | 1282.02 | 1869.71 | 535.63 | 1168.46 | 1704.09 |
| 1988 | 61 | 45.13 | 54.43 | 99.56 | 41.13 | 49.61 | 90.74 | 232.30 | 697.53 | 929.83 | 211.72 | 635.75 | 847.46 |
| 1989 | 56 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 62 | 297.28 | 39.51 | 336.78 | 270.94 | 36.01 | 306.95 | 746.22 | 530.50 | 1276.72 | 680.12 | 483.51 | 1163.63 |
| 1991 | 60 | 635.91 | 50.68 | 686.60 | 579.59 | 46.19 | 625.78 | 1319.82 | 628.24 | 1948.06 | 1202.91 | 572.59 | 1775.51 |
| 1992 | 58 | 583.84 | 194.88 | 778.72 | 532.12 | 177.62 | 709.74 | 2852.26 | 1669.75 | 4522.02 | 2599.62 | 1521.85 | 4121.47 |
| 1993 | 58 | 35.83 | 26.53 | 62.36 | 32.65 | 24.18 | 56.83 | 171.07 | 360.45 | 531.51 | 155.91 | 328.52 | 484.43 |
| 1994 | 57 | 15.32 | 28.20 | 43.52 | 13.96 | 25.71 | 39.67 | 69.45 | 416.01 | 485.46 | 63.30 | 379.16 | 442.46 |
| 1995 | 60 | 259.80 | 51.86 | 311.66 | 236.79 | 47.27 | 284.06 | 764.52 | 766.78 | 1531.30 | 696.80 | 698.86 | 1395.66 |
| 1996 | 53 | 100.10 | 93.16 | 193.26 | 91.23 | 84.91 | 176.14 | 480.38 | 1044.84 | 1525.22 | 437.83 | 952.29 | 1390.12 |
| 1997 | 64 | 44.83 | 56.00 | 100.82 | 40.86 | 51.04 | 91.89 | 167.35 | 927.43 | 1094.79 | 152.53 | 845.28 | 997.81 |
| 1998 | 61 | 79.50 | 58.05 | 137.55 | 72.46 | 52.91 | 125.36 | 303.60 | 786.98 | 1090.58 | 276.71 | 717.27 | 993.98 |

Table B6. Continued

| | | Mean Number per Tow | | | Swept Area population (10^6) | | | Mean Weight (g) per Tow | | | Swept Area Biomass (mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Tows | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total |
| Southeast Part Open Area | | | | | 1592.96 sq. mile | | | | | | 1592.96 sq. mile | | |
| 1982 | 21 | 0.62 | 11.93 | 12.56 | 0.65 | 12.46 | 13.11 | 2.18 | 395.07 | 397.25 | 2.28 | 412.41 | 414.69 |
| 1983 | 18 | 13.75 | 13.09 | 26.84 | 14.36 | 13.66 | 28.02 | 41.22 | 353.83 | 395.05 | 43.02 | 369.36 | 412.38 |
| 1984 | 18 | 7.06 | 18.21 | 25.27 | 7.37 | 19.01 | 26.38 | 29.09 | 333.40 | 362.49 | 30.37 | 348.03 | 378.40 |
| 1985 | 26 | 10.35 | 14.67 | 25.02 | 10.80 | 15.31 | 26.11 | 43.22 | 290.19 | 333.42 | 45.12 | 302.93 | 348.05 |
| 1986 | 31 | 28.90 | 25.17 | 54.07 | 30.17 | 26.28 | 56.44 | 103.60 | 541.85 | 645.45 | 108.15 | 565.63 | 673.77 |
| 1987 | 30 | 33.59 | 51.77 | 85.36 | 35.07 | 54.04 | 89.11 | 124.69 | 838.65 | 963.33 | 130.16 | 875.45 | 1005.60 |
| 1988 | 31 | 2.88 | 16.98 | 19.87 | 3.01 | 17.73 | 20.74 | 15.96 | 382.07 | 398.04 | 16.66 | 398.84 | 415.50 |
| 1989 | 32 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 29 | 2.72 | 9.19 | 11.91 | 2.84 | 9.60 | 12.43 | 14.74 | 180.38 | 195.13 | 15.39 | 188.30 | 203.69 |
| 1991 | 30 | 18.53 | 12.26 | 30.79 | 19.34 | 12.80 | 32.14 | 81.06 | 215.13 | 296.19 | 84.61 | 224.57 | 309.18 |
| 1992 | 30 | 16.75 | 26.56 | 43.30 | 17.48 | 27.72 | 45.20 | 71.86 | 467.29 | 539.15 | 75.01 | 487.80 | 562.81 |
| 1993 | 30 | 3.73 | 11.72 | 15.45 | 3.89 | 12.23 | 16.13 | 14.16 | 291.90 | 306.06 | 14.78 | 304.71 | 319.49 |
| 1994 | 30 | 12.53 | 10.56 | 23.08 | 13.08 | 11.02 | 24.10 | 24.17 | 322.30 | 346.47 | 25.23 | 336.44 | 361.67 |
| 1995 | 31 | 18.24 | 17.64 | 35.88 | 19.04 | 18.42 | 37.45 | 66.11 | 382.51 | 448.61 | 69.01 | 399.29 | 468.30 |
| 1996 | 31 | 23.31 | 13.51 | 36.81 | 24.33 | 14.10 | 38.43 | 66.09 | 272.32 | 338.40 | 68.99 | 284.27 | 353.25 |
| 1997 | 31 | 14.30 | 14.88 | 29.18 | 14.93 | 15.53 | 30.46 | 39.58 | 271.94 | 311.52 | 41.32 | 283.87 | 325.19 |
| 1998 | 29 | 77.59 | 24.69 | 102.28 | 80.99 | 25.78 | 106.77 | 258.47 | 306.15 | 564.62 | 269.81 | 319.58 | 589.39 |
| N. Edge & Peak Open Area | | | | | 993.40 sq. mile | | | | | | 993.40 sq. mile | | |
| 1982 | 25 | 15.12 | 26.24 | 41.37 | 9.84 | 17.08 | 26.93 | 56.48 | 524.35 | 580.83 | 36.77 | 341.34 | 378.11 |
| 1983 | 25 | 19.03 | 30.88 | 49.91 | 12.39 | 20.11 | 32.49 | 54.41 | 643.61 | 698.02 | 35.42 | 418.98 | 454.40 |
| 1984 | 24 | 13.46 | 24.48 | 37.94 | 8.77 | 15.93 | 24.70 | 44.97 | 596.79 | 641.76 | 29.27 | 388.50 | 417.77 |
| 1985 | 29 | 43.29 | 29.74 | 73.03 | 28.18 | 19.36 | 47.54 | 208.29 | 451.49 | 659.78 | 135.59 | 293.91 | 429.51 |
| 1986 | 30 | 37.79 | 44.27 | 82.06 | 24.60 | 28.82 | 53.42 | 134.61 | 881.96 | 1016.57 | 87.63 | 574.14 | 661.77 |
| 1987 | 32 | 50.68 | 52.59 | 103.26 | 32.99 | 34.23 | 67.22 | 195.70 | 895.61 | 1091.31 | 127.40 | 583.02 | 710.42 |
| 1988 | 31 | 70.40 | 58.53 | 128.92 | 45.83 | 38.10 | 83.93 | 276.18 | 831.22 | 1107.40 | 179.79 | 541.11 | 720.90 |
| 1989 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 28 | 30.37 | 61.49 | 91.87 | 19.77 | 40.03 | 59.80 | 205.57 | 683.67 | 889.24 | 133.82 | 445.06 | 578.88 |
| 1991 | 32 | 21.87 | 22.85 | 44.72 | 14.23 | 14.88 | 29.11 | 78.06 | 433.23 | 511.29 | 50.81 | 282.03 | 332.84 |
| 1992 | 33 | 20.45 | 39.79 | 60.24 | 13.31 | 25.90 | 39.22 | 104.42 | 605.22 | 709.65 | 67.98 | 393.99 | 461.97 |
| 1993 | 29 | 4.94 | 18.10 | 23.03 | 3.21 | 11.78 | 14.99 | 18.80 | 373.99 | 392.79 | 12.24 | 243.46 | 255.70 |
| 1994 | 32 | 14.13 | 11.06 | 25.19 | 9.20 | 7.20 | 16.40 | 38.19 | 205.61 | 243.79 | 24.86 | 133.85 | 158.71 |
| 1995 | 34 | 37.42 | 7.57 | 44.99 | 24.36 | 4.93 | 29.29 | 78.47 | 175.24 | 253.71 | 51.08 | 114.08 | 165.16 |
| 1996 | 30 | 28.34 | 27.86 | 56.20 | 18.45 | 18.14 | 36.59 | 112.11 | 423.84 | 535.95 | 72.98 | 275.91 | 348.89 |
| 1997 | 32 | 33.01 | 31.16 | 64.17 | 21.49 | 20.28 | 41.78 | 130.85 | 468.92 | 599.77 | 85.18 | 305.26 | 390.44 |
| 1998 | 29 | 110.01 | 43.04 | 153.04 | 71.61 | 28.02 | 99.63 | 357.98 | 586.68 | 944.67 | 233.04 | 381.92 | 614.96 |

Table B6. Continued

| | | Mean Number per Tow | | | Swept Area population (10^6) | | | Mean Weight (g) per Tow | | | Swept Area Biomass (mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Tows | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total |
| US Georges Bank Open Areas | | | | | 3977.19 sq. mile | | | | | | 3977.19 sq. mile | | |
| 1982 | 82 | 185.55 | 38.61 | 224.17 | 483.60 | 100.64 | 584.24 | 563.32 | 606.10 | 1169.42 | 1468.16 | 1579.66 | 3047.83 |
| 1983 | 82 | 40.04 | 54.44 | 94.48 | 104.36 | 141.89 | 246.25 | 184.63 | 813.76 | 998.39 | 481.21 | 2120.88 | 2602.09 |
| 1984 | 89 | 12.97 | 22.29 | 35.26 | 33.80 | 58.10 | 91.90 | 50.26 | 439.46 | 489.72 | 131.00 | 1145.36 | 1276.35 |
| 1985 | 103 | 32.69 | 26.40 | 59.09 | 85.19 | 68.81 | 154.01 | 129.82 | 505.09 | 634.90 | 338.34 | 1316.40 | 1654.73 |
| 1986 | 108 | 88.22 | 37.61 | 125.84 | 229.93 | 98.03 | 327.96 | 268.66 | 709.25 | 977.91 | 700.21 | 1848.50 | 2548.71 |
| 1987 | 118 | 78.14 | 68.00 | 146.14 | 203.66 | 177.22 | 380.89 | 304.33 | 1007.92 | 1312.26 | 793.18 | 2626.93 | 3420.12 |
| 1988 | 123 | 34.52 | 40.45 | 74.97 | 89.97 | 105.44 | 195.40 | 156.61 | 604.58 | 761.19 | 408.17 | 1575.70 | 1983.87 |
| 1989 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 119 | 112.63 | 32.86 | 145.49 | 293.55 | 85.63 | 379.19 | 318.20 | 428.53 | 746.73 | 829.33 | 1116.87 | 1946.20 |
| 1991 | 122 | 235.26 | 28.34 | 263.61 | 613.16 | 73.87 | 687.03 | 513.51 | 414.07 | 927.58 | 1338.34 | 1079.19 | 2417.53 |
| 1992 | 121 | 215.98 | 88.73 | 304.71 | 562.91 | 231.25 | 794.16 | 1052.31 | 922.25 | 1974.55 | 2742.61 | 2403.64 | 5146.24 |
| 1993 | 117 | 15.25 | 18.49 | 33.75 | 39.76 | 48.20 | 87.95 | 70.19 | 336.37 | 406.56 | 182.94 | 876.69 | 1059.62 |
| 1994 | 119 | 13.90 | 16.85 | 30.76 | 36.24 | 43.92 | 80.16 | 43.51 | 325.92 | 369.43 | 113.39 | 849.44 | 962.84 |
| 1995 | 125 | 107.50 | 27.09 | 134.60 | 280.19 | 70.61 | 350.80 | 313.43 | 465.12 | 778.55 | 816.88 | 1212.23 | 2029.12 |
| 1996 | 114 | 51.42 | 44.95 | 96.37 | 134.01 | 117.15 | 251.16 | 222.46 | 580.31 | 802.78 | 579.80 | 1512.46 | 2092.26 |
| 1997 | 127 | 29.65 | 33.32 | 62.97 | 77.28 | 86.85 | 164.13 | 107.06 | 550.37 | 657.43 | 279.02 | 1434.42 | 1713.44 |
| 1998 | 119 | 86.35 | 40.94 | 127.29 | 225.06 | 106.70 | 331.76 | 299.11 | 544.36 | 843.47 | 779.56 | 1418.77 | 2198.33 |
| US Georges Bank Closed Areas | | | | | 3478.81 sq. mile | | | | | | 3478.81 sq. mile | | |
| 1982 | 47 | 14.42 | 25.75 | 40.17 | 32.88 | 58.69 | 91.58 | 48.45 | 606.30 | 654.76 | 110.46 | 1382.18 | 1492.64 |
| 1983 | 56 | 9.67 | 17.83 | 27.50 | 22.05 | 40.65 | 62.70 | 29.64 | 451.68 | 481.32 | 67.58 | 1029.69 | 1097.27 |
| 1984 | 47 | 17.70 | 23.25 | 40.95 | 40.35 | 53.01 | 93.35 | 62.34 | 571.34 | 633.67 | 142.11 | 1302.48 | 1444.58 |
| 1985 | 67 | 37.92 | 39.95 | 77.88 | 86.46 | 91.08 | 177.53 | 161.99 | 685.88 | 847.88 | 369.30 | 1563.60 | 1932.90 |
| 1986 | 48 | 69.70 | 35.99 | 105.68 | 158.89 | 82.03 | 240.93 | 289.46 | 641.53 | 930.99 | 659.88 | 1462.50 | 2122.38 |
| 1987 | 72 | 52.08 | 40.70 | 92.78 | 118.73 | 92.78 | 211.51 | 180.48 | 643.42 | 823.91 | 411.45 | 1466.81 | 1878.26 |
| 1988 | 69 | 68.07 | 50.94 | 119.01 | 155.19 | 116.12 | 271.31 | 271.94 | 771.99 | 1043.94 | 619.95 | 1759.91 | 2379.85 |
| 1989 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 69 | 145.92 | 115.44 | 261.36 | 332.66 | 263.17 | 595.83 | 662.97 | 1284.91 | 1947.88 | 1511.36 | 2929.21 | 4440.57 |
| 1991 | 72 | 197.90 | 77.80 | 275.70 | 451.14 | 177.36 | 628.51 | 727.97 | 1094.61 | 1822.59 | 1659.56 | 2495.38 | 4154.94 |
| 1992 | 70 | 148.22 | 59.61 | 207.83 | 337.90 | 135.89 | 473.79 | 538.75 | 771.39 | 1310.15 | 1228.19 | 1758.54 | 2986.73 |
| 1993 | 65 | 74.87 | 23.37 | 98.24 | 170.68 | 53.28 | 223.96 | 327.66 | 313.81 | 641.48 | 746.97 | 715.40 | 1462.37 |
| 1994 | 75 | 26.07 | 31.25 | 57.32 | 59.43 | 71.25 | 130.68 | 99.23 | 463.91 | 563.14 | 226.21 | 1057.58 | 1283.79 |
| 1995 | 68 | 80.68 | 28.10 | 108.77 | 183.92 | 64.05 | 247.97 | 284.80 | 491.50 | 776.30 | 649.25 | 1120.47 | 1769.72 |
| 1996 | 75 | 98.28 | 99.32 | 197.61 | 224.05 | 226.43 | 450.48 | 359.14 | 1831.62 | 2190.76 | 818.73 | 4175.52 | 4994.25 |
| 1997 | 79 | 28.61 | 109.53 | 138.13 | 65.21 | 249.68 | 314.90 | 109.32 | 2728.84 | 2838.16 | 249.21 | 6220.92 | 6470.12 |
| 1998 | 87 | 192.71 | 304.31 | 497.02 | 439.32 | 693.73 | 1133.05 | 689.97 | 7214.81 | 7904.78 | 1572.91 | 16447.55 | 18020.47 |

Table B6. Continued

| Year | Number of Tows | Mean Number per Tow: Partial Recruits | Full Recruits | Total | Swept Area population (10^6): Partial Recruits | Full Recruits | Total | Mean Weight (g) per Tow: Partial Recruits | Full Recruits | Total | Swept Area Biomass (mt): Partial Recruits | Full Recruits | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| US Georges Bank Total | | | | | 7456.00 sq. mile | | | | | | 7456.00 sq. mile | | |
| 1982 | 129 | 105.7 | 32.6 | 138.3 | 516.48 | 159.33 | 675.82 | 323.1 | 606.2 | 929.3 | 1578.62 | 2961.85 | 4540.47 |
| 1983 | 138 | 25.9 | 37.4 | 63.2 | 126.41 | 182.54 | 308.95 | 112.3 | 644.8 | 757.1 | 548.78 | 3150.57 | 3699.36 |
| 1984 | 136 | 15.2 | 22.7 | 37.9 | 74.15 | 111.10 | 185.25 | 55.9 | 501.0 | 556.9 | 273.10 | 2447.83 | 2720.94 |
| 1985 | 170 | 35.1 | 32.7 | 67.9 | 171.65 | 159.89 | 331.54 | 144.8 | 589.4 | 734.3 | 707.64 | 2880.00 | 3587.63 |
| 1986 | 156 | 79.6 | 36.9 | 116.4 | 388.82 | 180.07 | 568.89 | 278.4 | 677.7 | 956.0 | 1360.09 | 3311.00 | 4671.09 |
| 1987 | 190 | 66.0 | 55.3 | 121.2 | 322.39 | 270.00 | 592.39 | 246.5 | 837.9 | 1084.4 | 1204.63 | 4093.74 | 5298.37 |
| 1988 | 192 | 50.2 | 45.3 | 95.5 | 245.16 | 221.55 | 466.71 | 210.4 | 682.7 | 893.1 | 1028.11 | 3335.60 | 4363.72 |
| 1989 | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C | N/C |
| 1990 | 188 | 128.2 | 71.4 | 199.6 | 626.21 | 348.80 | 975.01 | 479.1 | 828.1 | 1307.2 | 2340.69 | 4046.07 | 6386.76 |
| 1991 | 194 | 217.8 | 51.4 | 269.2 | 1064.30 | 251.24 | 1315.54 | 613.6 | 731.6 | 1345.2 | 2997.90 | 3574.56 | 6572.46 |
| 1992 | 191 | 184.4 | 75.1 | 259.5 | 900.81 | 367.13 | 1267.95 | 812.7 | 851.9 | 1664.6 | 3970.80 | 4162.18 | 8132.97 |
| 1993 | 182 | 43.1 | 20.8 | 63.8 | 210.44 | 101.47 | 311.91 | 190.3 | 325.8 | 516.2 | 929.90 | 1592.09 | 2521.99 |
| 1994 | 194 | 19.6 | 23.6 | 43.2 | 95.67 | 115.17 | 210.84 | 69.5 | 390.3 | 459.8 | 339.61 | 1907.02 | 2246.63 |
| 1995 | 193 | 95.0 | 27.6 | 122.5 | 464.11 | 134.66 | 598.77 | 300.1 | 477.4 | 777.5 | 1466.13 | 2332.70 | 3798.83 |
| 1996 | 189 | 73.3 | 70.3 | 143.6 | 358.06 | 343.58 | 701.64 | 286.2 | 1164.1 | 1450.4 | 1398.53 | 5687.98 | 7086.52 |
| 1997 | 206 | 29.2 | 68.3 | 98.0 | 142.49 | 336.54 | 479.03 | 108.1 | 1566.8 | 1674.9 | 528.23 | 7655.34 | 8183.57 |
| 1998 | 206 | 136.0 | 163.8 | 299.8 | 664.38 | 800.43 | 1464.81 | 481.5 | 3656.7 | 4138.1 | 2352.47 | 17866.32 | 20218.80 |

Table B7. Stratified mean number and weight (g) per tow with the corresponding swept area estimates of population (millions) and biomass (mt) by resource areas in Mid-Atlantic region

| | | Mean Number per Tow | | | Swept Area population (10^6) | | | Mean Weight (g) per Tow | | | Swept Area Meat Biomass (mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Tows | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total |
| New York Bight Open Area | | | | | 5365.64 sq. mile | | | | | | 5365.64 sq. mile | | |
| 1982 | 98 | 12.43 | 24.99 | 37.42 | 43.69 | 87.88 | 131.57 | 61.76 | 427.61 | 489.37 | 217.16 | 1503.54 | 1720.70 |
| 1983 | 101 | 15.67 | 19.90 | 35.58 | 55.10 | 69.99 | 125.09 | 48.91 | 419.84 | 468.75 | 171.96 | 1476.23 | 1648.19 |
| 1984 | 108 | 14.19 | 24.84 | 39.03 | 49.91 | 87.33 | 137.24 | 51.95 | 403.71 | 455.66 | 182.66 | 1419.49 | 1602.15 |
| 1985 | 101 | 46.58 | 35.50 | 82.08 | 163.80 | 124.81 | 288.61 | 149.33 | 548.06 | 697.39 | 525.07 | 1927.06 | 2452.13 |
| 1986 | 108 | 64.29 | 52.02 | 116.31 | 226.06 | 182.92 | 408.98 | 222.54 | 817.34 | 1039.88 | 782.48 | 2873.89 | 3656.37 |
| 1987 | 118 | 99.65 | 48.67 | 148.33 | 350.39 | 171.14 | 521.53 | 271.79 | 683.64 | 955.43 | 955.64 | 2403.79 | 3359.43 |
| 1988 | 114 | 75.51 | 91.62 | 167.13 | 265.49 | 322.16 | 587.65 | 321.61 | 1333.53 | 1655.14 | 1130.82 | 4688.90 | 5819.72 |
| 1989 | 136 | 93.79 | 70.36 | 164.14 | 329.76 | 247.39 | 577.15 | 371.56 | 949.64 | 1321.20 | 1306.46 | 3339.08 | 4645.54 |
| 1990 | 112 | 98.15 | 45.37 | 143.53 | 345.12 | 159.54 | 504.66 | 367.19 | 624.30 | 991.49 | 1291.10 | 2195.14 | 3486.24 |
| 1991 | 115 | 33.39 | 52.13 | 85.52 | 117.40 | 183.29 | 300.69 | 163.19 | 779.42 | 942.62 | 573.81 | 2740.56 | 3314.37 |
| 1992 | 121 | 23.88 | 28.39 | 52.27 | 83.95 | 99.83 | 183.78 | 81.97 | 481.88 | 563.85 | 288.23 | 1694.36 | 1982.59 |
| 1993 | 109 | 46.78 | 23.04 | 69.82 | 164.49 | 81.03 | 245.51 | 154.54 | 352.75 | 507.29 | 543.39 | 1240.31 | 1783.70 |
| 1994 | 114 | 30.58 | 34.61 | 65.19 | 107.52 | 121.70 | 229.22 | 115.87 | 456.85 | 572.72 | 407.41 | 1606.37 | 2013.77 |
| 1995 | 113 | 59.77 | 54.51 | 114.29 | 210.17 | 191.67 | 401.85 | 284.51 | 648.58 | 933.09 | 1000.40 | 2280.50 | 3280.89 |
| 1996 | 105 | 11.57 | 29.44 | 41.01 | 40.68 | 103.50 | 144.19 | 60.08 | 413.62 | 473.70 | 211.26 | 1454.34 | 1665.60 |
| 1997 | 117 | 8.20 | 21.43 | 29.63 | 28.83 | 75.37 | 104.19 | 26.54 | 416.92 | 443.46 | 93.32 | 1465.95 | 1559.28 |
| 1998 | 106 | 72.09 | 25.69 | 97.78 | 253.50 | 90.32 | 343.81 | 245.12 | 403.90 | 649.02 | 861.87 | 1420.17 | 2282.04 |
| Delmarva Open Area | | | | | 1402.96 sq. mile | | | | | | 1402.96 sq. mile | | |
| 1982 | 40 | 16.71 | 22.28 | 38.99 | 58.77 | 78.34 | 137.11 | 70.98 | 579.74 | 650.72 | 65.26 | 533.00 | 598.25 |
| 1983 | 43 | 40.36 | 19.60 | 59.96 | 141.90 | 68.92 | 210.82 | 153.29 | 509.12 | 662.41 | 140.93 | 468.07 | 609.00 |
| 1984 | 47 | 16.53 | 25.72 | 42.24 | 58.11 | 90.42 | 148.53 | 57.64 | 513.51 | 571.15 | 52.99 | 472.11 | 525.10 |
| 1985 | 50 | 68.47 | 33.17 | 101.64 | 240.75 | 116.63 | 357.38 | 316.79 | 499.32 | 816.11 | 291.25 | 459.06 | 750.31 |
| 1986 | 60 | 182.48 | 89.97 | 272.45 | 641.64 | 316.34 | 957.98 | 723.24 | 1128.09 | 1851.33 | 664.93 | 1037.13 | 1702.06 |
| 1987 | 54 | 79.04 | 71.78 | 150.82 | 277.91 | 252.38 | 530.29 | 307.53 | 956.17 | 1263.70 | 282.73 | 879.08 | 1161.81 |
| 1988 | 56 | 81.20 | 51.04 | 132.24 | 285.51 | 179.48 | 464.99 | 220.70 | 840.85 | 1061.55 | 202.91 | 773.05 | 975.96 |
| 1989 | 56 | 154.31 | 109.30 | 263.61 | 542.56 | 384.32 | 926.88 | 530.85 | 1348.07 | 1878.93 | 488.05 | 1239.38 | 1727.43 |
| 1990 | 54 | 54.16 | 86.18 | 140.34 | 190.44 | 303.03 | 493.47 | 268.43 | 1012.66 | 1281.09 | 246.79 | 931.01 | 1177.80 |
| 1991 | 57 | 57.91 | 34.43 | 92.34 | 203.61 | 121.07 | 324.67 | 199.04 | 609.95 | 808.99 | 182.99 | 560.77 | 743.76 |
| 1992 | 57 | 24.59 | 21.49 | 46.08 | 86.46 | 75.58 | 162.04 | 71.38 | 423.38 | 494.76 | 65.63 | 389.24 | 454.87 |
| 1993 | 52 | 419.41 | 22.06 | 441.47 | 1474.70 | 77.56 | 1552.26 | 1138.31 | 350.42 | 1488.73 | 1046.53 | 322.16 | 1368.70 |
| 1994 | 58 | 137.18 | 139.65 | 276.82 | 482.33 | 491.02 | 973.35 | 729.18 | 1329.80 | 2058.99 | 670.39 | 1222.58 | 1892.97 |
| 1995 | 56 | 169.94 | 97.08 | 267.02 | 597.53 | 341.35 | 938.88 | 679.67 | 1160.33 | 1839.99 | 624.87 | 1066.77 | 1691.64 |
| 1996 | 54 | 27.20 | 49.64 | 76.84 | 95.64 | 174.54 | 270.18 | 91.79 | 752.08 | 843.87 | 84.39 | 691.44 | 775.83 |
| 1997 | 55 | 32.77 | 28.39 | 61.16 | 115.22 | 99.84 | 215.06 | 77.30 | 554.12 | 631.42 | 71.06 | 509.44 | 580.51 |
| 1998 | 56 | 163.55 | 37.39 | 200.94 | 575.08 | 131.47 | 706.54 | 597.38 | 432.01 | 1029.39 | 549.21 | 397.18 | 946.39 |

Table B7. Continued

| Year | Number of Tows | Mean Number per Tow: Partial Recruits | Mean Number per Tow: Full Recruits | Mean Number per Tow: Total | Swept Area population (10^6): Partial Recruits | Swept Area population (10^6): Full Recruits | Swept Area population (10^6): Total | Mean Weight (g) per Tow: Partial Recruits | Mean Weight (g) per Tow: Full Recruits | Mean Weight (g) per Tow: Total | Swept Area Biomass (mt): Partial Recruits | Swept Area Biomass (mt): Full Recruits | Swept Area Biomass (mt): Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Virginia Beach Closed Area | | | | | 192.67 sq. mile | | | | | | 192.67 sq. mile | | |
| 1982 | 11 | 3.75 | 14.29 | 18.05 | 13.20 | 50.26 | 63.46 | 11.29 | 353.03 | 364.31 | 39.68 | 1241.30 | 1280.98 |
| 1983 | 13 | 38.18 | 14.84 | 53.03 | 134.25 | 52.19 | 186.45 | 134.41 | 454.91 | 589.32 | 472.60 | 1599.55 | 2072.15 |
| 1984 | 14 | 2.40 | 16.66 | 19.06 | 8.43 | 58.59 | 67.02 | 9.38 | 371.17 | 380.55 | 32.99 | 1305.08 | 1338.07 |
| 1985 | 14 | 4.45 | 10.85 | 15.31 | 15.66 | 38.16 | 53.82 | 17.42 | 294.52 | 311.94 | 61.26 | 1035.57 | 1096.84 |
| 1986 | 13 | 80.40 | 21.14 | 101.54 | 282.71 | 74.32 | 357.03 | 250.76 | 362.60 | 613.36 | 881.73 | 1274.95 | 2156.67 |
| 1987 | 15 | 12.51 | 28.27 | 40.77 | 43.98 | 99.39 | 143.37 | 63.09 | 381.16 | 444.25 | 221.83 | 1340.20 | 1562.03 |
| 1988 | 16 | 17.76 | 27.38 | 45.14 | 62.44 | 96.28 | 158.73 | 71.03 | 561.25 | 632.28 | 249.75 | 1973.45 | 2223.19 |
| 1989 | 13 | 79.76 | 32.27 | 112.03 | 280.44 | 113.48 | 393.92 | 227.92 | 442.32 | 670.24 | 801.39 | 1555.27 | 2356.66 |
| 1990 | 11 | 71.34 | 78.92 | 150.26 | 250.83 | 277.49 | 528.32 | 311.18 | 899.63 | 1210.82 | 1094.17 | 3163.24 | 4257.40 |
| 1991 | 14 | 145.97 | 49.50 | 195.47 | 513.24 | 174.06 | 687.30 | 525.41 | 673.53 | 1198.94 | 1847.41 | 2368.23 | 4215.64 |
| 1992 | 15 | 27.57 | 40.53 | 68.11 | 96.95 | 142.52 | 239.47 | 129.25 | 523.51 | 652.76 | 454.47 | 1840.74 | 2295.20 |
| 1993 | 15 | 673.87 | 47.66 | 721.53 | 2369.42 | 167.57 | 2536.99 | 2228.73 | 460.27 | 2689.00 | 7836.54 | 1618.36 | 9454.90 |
| 1994 | 14 | 164.58 | 192.56 | 357.14 | 578.70 | 677.07 | 1255.76 | 1015.71 | 1689.78 | 2705.49 | 3571.39 | 5941.52 | 9512.91 |
| 1995 | 16 | 120.74 | 48.70 | 169.43 | 424.53 | 171.23 | 595.75 | 386.55 | 548.34 | 934.89 | 1359.18 | 1928.05 | 3287.22 |
| 1996 | 14 | 94.43 | 31.81 | 126.23 | 332.03 | 111.83 | 443.86 | 239.61 | 408.80 | 648.41 | 842.51 | 1437.39 | 2279.89 |
| 1997 | 14 | 290.31 | 31.35 | 321.66 | 1020.76 | 110.24 | 1130.99 | 850.35 | 410.20 | 1260.55 | 2989.95 | 1442.34 | 4432.29 |
| 1998 | 14 | 123.45 | 225.29 | 348.74 | 434.06 | 792.16 | 1226.22 | 556.50 | 2831.61 | 3388.10 | 1956.72 | 9956.35 | 11913.07 |
| Hudson Canyon S. Closed Area | | | | | 1465.77 sq. mile | | | | | | 1465.77 sq. mile | | |
| 1982 | 36 | 28.25 | 21.66 | 49.91 | 27.13 | 20.80 | 47.94 | 91.11 | 405.56 | 496.68 | 87.52 | 389.56 | 477.07 |
| 1983 | 36 | 11.65 | 10.50 | 22.15 | 11.19 | 10.09 | 21.27 | 38.25 | 291.09 | 329.34 | 36.74 | 279.60 | 316.34 |
| 1984 | 34 | 19.42 | 15.60 | 35.01 | 18.65 | 14.98 | 33.63 | 49.88 | 356.43 | 406.31 | 47.91 | 342.36 | 390.27 |
| 1985 | 36 | 85.87 | 29.73 | 115.59 | 82.48 | 28.55 | 111.03 | 326.32 | 484.39 | 810.71 | 313.44 | 465.28 | 778.71 |
| 1986 | 38 | 88.94 | 78.31 | 167.26 | 85.43 | 75.22 | 160.66 | 383.33 | 907.50 | 1290.83 | 368.20 | 871.68 | 1239.88 |
| 1987 | 39 | 97.02 | 68.25 | 165.27 | 93.19 | 65.56 | 158.75 | 341.77 | 889.06 | 1230.83 | 328.28 | 853.97 | 1182.25 |
| 1988 | 41 | 92.71 | 181.54 | 274.25 | 89.05 | 174.37 | 263.42 | 431.51 | 2242.29 | 2673.80 | 414.47 | 2153.79 | 2568.26 |
| 1989 | 39 | 253.06 | 119.63 | 372.70 | 243.07 | 114.91 | 357.99 | 906.64 | 1320.36 | 2226.99 | 870.85 | 1268.24 | 2139.10 |
| 1990 | 39 | 599.06 | 249.36 | 848.43 | 575.42 | 239.52 | 814.94 | 2626.61 | 2242.73 | 4869.34 | 2522.94 | 2154.21 | 4677.15 |
| 1991 | 42 | 76.76 | 77.45 | 154.21 | 73.73 | 74.39 | 148.12 | 306.29 | 917.34 | 1223.63 | 294.20 | 881.13 | 1175.33 |
| 1992 | 36 | 25.62 | 32.58 | 58.20 | 24.61 | 31.29 | 55.90 | 107.86 | 463.57 | 571.43 | 103.60 | 445.27 | 548.87 |
| 1993 | 38 | 109.89 | 33.53 | 143.42 | 105.55 | 32.21 | 137.76 | 299.63 | 427.88 | 727.51 | 287.81 | 410.99 | 698.79 |
| 1994 | 41 | 297.09 | 83.63 | 380.72 | 285.36 | 80.33 | 365.70 | 723.72 | 897.99 | 1621.70 | 695.15 | 862.55 | 1557.70 |
| 1995 | 42 | 354.96 | 233.60 | 588.56 | 340.95 | 224.38 | 565.33 | 1803.25 | 2165.21 | 3968.47 | 1732.08 | 2079.75 | 3811.83 |
| 1996 | 38 | 57.18 | 140.66 | 197.84 | 54.92 | 135.11 | 190.03 | 390.85 | 1493.69 | 1884.54 | 375.42 | 1434.74 | 1810.16 |
| 1997 | 39 | 82.86 | 41.16 | 124.02 | 79.59 | 39.54 | 119.12 | 165.11 | 625.28 | 790.39 | 158.60 | 600.60 | 759.19 |
| 1998 | 39 | 461.92 | 140.74 | 602.65 | 443.68 | 135.18 | 578.86 | 1486.31 | 1538.09 | 3024.40 | 1427.65 | 1477.38 | 2905.03 |

Table B7. Continued

| Year | Number of Tows | Mean Number per Tow: Partial Recruits | Mean Number per Tow: Full Recruits | Mean Number per Tow: Total | Swept Area population (10^6): Partial Recruits | Swept Area population (10^6): Full Recruits | Swept Area population (10^6): Total | Mean Weight (g) per Tow: Partial Recruits | Mean Weight (g) per Tow: Full Recruits | Mean Weight (g) per Tow: Total | Swept Area Biomass (mt): Partial Recruits | Swept Area Biomass (mt): Full Recruits | Swept Area Biomass (mt): Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mid-Atlantic Open Areas | | | | | 6768.60 sq. mile | | | | | | 6768.60 sq. mile | | |
| 1982 | 138 | 13.3 | 24.4 | 37.7 | 59.06 | 108.37 | 167.42 | 63.7 | 459.1 | 522.8 | 282.42 | 2036.54 | 2318.96 |
| 1983 | 144 | 20.8 | 19.8 | 40.6 | 92.20 | 88.01 | 180.21 | 70.5 | 438.3 | 508.9 | 312.89 | 1944.30 | 2257.19 |
| 1984 | 155 | 14.7 | 25.0 | 39.7 | 65.10 | 110.97 | 176.07 | 53.1 | 426.5 | 479.6 | 235.65 | 1891.60 | 2127.25 |
| 1985 | 151 | 51.1 | 35.0 | 86.1 | 226.75 | 155.30 | 382.05 | 184.0 | 538.0 | 722.0 | 816.32 | 2386.13 | 3202.44 |
| 1986 | 168 | 88.8 | 59.9 | 148.7 | 393.83 | 265.63 | 659.46 | 326.3 | 881.8 | 1208.1 | 1447.40 | 3911.03 | 5358.43 |
| 1987 | 172 | 95.4 | 53.5 | 148.8 | 423.06 | 237.13 | 660.19 | 279.2 | 740.1 | 1019.3 | 1238.37 | 3282.87 | 4521.24 |
| 1988 | 170 | 76.7 | 83.2 | 159.9 | 340.14 | 369.09 | 709.23 | 300.7 | 1231.4 | 1532.1 | 1333.73 | 5461.95 | 6795.68 |
| 1989 | 192 | 106.3 | 78.4 | 184.8 | 471.63 | 347.88 | 819.51 | 404.6 | 1032.2 | 1436.8 | 1794.51 | 4578.46 | 6372.97 |
| 1990 | 166 | 89.0 | 53.8 | 142.9 | 394.91 | 238.77 | 633.68 | 346.7 | 704.8 | 1051.5 | 1537.89 | 3126.15 | 4664.04 |
| 1991 | 172 | 38.5 | 48.5 | 86.9 | 170.64 | 214.94 | 385.58 | 170.6 | 744.3 | 914.9 | 756.80 | 3301.33 | 4058.14 |
| 1992 | 178 | 24.0 | 27.0 | 51.0 | 106.56 | 119.60 | 226.15 | 79.8 | 469.8 | 549.5 | 353.86 | 2083.60 | 2437.46 |
| 1993 | 161 | 124.0 | 22.8 | 146.9 | 550.08 | 101.31 | 651.39 | 358.5 | 352.3 | 710.7 | 1589.92 | 1562.47 | 3152.39 |
| 1994 | 172 | 52.7 | 56.4 | 109.1 | 233.63 | 250.09 | 483.72 | 243.0 | 637.8 | 880.8 | 1077.80 | 2828.95 | 3906.75 |
| 1995 | 169 | 82.6 | 63.3 | 145.9 | 366.41 | 280.93 | 647.34 | 366.4 | 754.7 | 1121.1 | 1625.26 | 3347.27 | 4972.53 |
| 1996 | 159 | 14.8 | 33.6 | 48.4 | 65.69 | 149.14 | 214.83 | 66.7 | 483.8 | 550.4 | 295.65 | 2145.78 | 2441.43 |
| 1997 | 172 | 13.3 | 22.9 | 36.2 | 58.96 | 101.47 | 160.43 | 37.1 | 445.4 | 482.4 | 164.39 | 1975.40 | 2139.78 |
| 1998 | 162 | 91.1 | 28.1 | 119.2 | 403.86 | 124.69 | 528.55 | 318.1 | 409.7 | 727.9 | 1411.08 | 1817.34 | 3228.43 |
| Mid-Atlantic Closed Areas | | | | | 1658.44 sq. mile | | | | | | 1658.44 sq. mile | | |
| 1982 | 47 | 25.4 | 20.8 | 46.2 | 27.61 | 22.61 | 50.22 | 81.8 | 399.5 | 481.3 | 88.94 | 434.13 | 523.07 |
| 1983 | 49 | 14.7 | 11.0 | 25.7 | 16.01 | 11.96 | 27.97 | 49.4 | 310.1 | 359.5 | 53.71 | 337.04 | 390.75 |
| 1984 | 48 | 17.4 | 15.7 | 33.2 | 18.95 | 17.08 | 36.04 | 45.2 | 358.1 | 403.3 | 49.09 | 389.22 | 438.32 |
| 1985 | 50 | 76.4 | 27.5 | 103.9 | 83.04 | 29.92 | 112.96 | 290.4 | 462.3 | 752.8 | 315.64 | 502.46 | 818.10 |
| 1986 | 51 | 88.0 | 71.7 | 159.6 | 95.59 | 77.89 | 173.48 | 367.9 | 844.2 | 1212.1 | 399.86 | 917.46 | 1317.32 |
| 1987 | 54 | 87.2 | 63.6 | 150.8 | 94.77 | 69.13 | 163.89 | 309.4 | 830.1 | 1139.4 | 336.24 | 902.09 | 1238.34 |
| 1988 | 57 | 84.0 | 163.6 | 247.6 | 91.29 | 177.83 | 269.12 | 389.6 | 2047.0 | 2436.6 | 423.44 | 2224.65 | 2648.09 |
| 1989 | 52 | 232.9 | 109.5 | 342.4 | 253.14 | 118.99 | 372.13 | 827.8 | 1218.4 | 2046.1 | 899.63 | 1324.09 | 2223.72 |
| 1990 | 50 | 537.8 | 229.6 | 767.3 | 584.43 | 249.49 | 833.91 | 2357.6 | 2086.7 | 4444.3 | 2562.23 | 2267.80 | 4830.02 |
| 1991 | 56 | 84.8 | 74.2 | 159.0 | 92.16 | 80.64 | 172.80 | 331.7 | 889.0 | 1220.8 | 360.54 | 966.17 | 1326.71 |
| 1992 | 51 | 25.8 | 33.5 | 59.3 | 28.09 | 36.41 | 64.50 | 110.3 | 470.5 | 580.9 | 119.92 | 511.37 | 631.29 |
| 1993 | 53 | 175.4 | 35.2 | 210.6 | 190.64 | 38.23 | 228.86 | 523.7 | 431.6 | 955.4 | 569.20 | 469.10 | 1038.30 |
| 1994 | 55 | 281.7 | 96.3 | 378.0 | 306.14 | 104.64 | 410.79 | 757.6 | 990.0 | 1747.6 | 823.39 | 1075.90 | 1899.29 |
| 1995 | 58 | 327.7 | 212.1 | 539.9 | 356.19 | 230.53 | 586.72 | 1638.7 | 1977.4 | 3616.0 | 1780.89 | 2148.99 | 3929.87 |
| 1996 | 52 | 61.5 | 128.0 | 189.5 | 66.84 | 139.13 | 205.97 | 373.3 | 1367.7 | 1740.9 | 405.68 | 1486.35 | 1892.03 |
| 1997 | 53 | 107.0 | 40.0 | 147.0 | 116.24 | 43.49 | 159.74 | 244.7 | 600.3 | 845.0 | 265.96 | 652.39 | 918.35 |
| 1998 | 53 | 422.6 | 150.6 | 573.2 | 459.27 | 163.63 | 622.90 | 1378.3 | 1688.4 | 3066.7 | 1497.91 | 1834.89 | 3332.81 |

Table B7. Continued

| | | Mean Number per Tow | | | Swept Area population (10^6) | | | Mean Weight (g) per Tow | | | Swept Area Biomass (mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Tows | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total | Partial Recruits | Full Recruits | Total |
| Mid-Atlantic Total | | | | | 8427.04 sq. mile | | | | | | 8427.04 sq. mile | | |
| 1982 | 185 | 15.7 | 23.7 | 39.4 | 86.66 | 130.97 | 217.64 | 67.2 | 447.4 | 514.6 | 371.36 | 2470.67 | 2842.03 |
| 1983 | 193 | 19.6 | 18.1 | 37.7 | 108.21 | 99.97 | 208.18 | 66.4 | 413.1 | 479.5 | 366.60 | 2281.34 | 2647.94 |
| 1984 | 203 | 15.2 | 23.2 | 38.4 | 84.05 | 128.06 | 212.11 | 51.6 | 413.0 | 464.6 | 284.74 | 2280.83 | 2565.57 |
| 1985 | 201 | 56.1 | 33.5 | 89.6 | 309.79 | 185.23 | 495.01 | 205.0 | 523.1 | 728.1 | 1131.95 | 2888.59 | 4020.54 |
| 1986 | 219 | 88.6 | 62.2 | 150.8 | 489.42 | 343.52 | 832.94 | 334.5 | 874.4 | 1208.9 | 1847.26 | 4828.49 | 6675.75 |
| 1987 | 226 | 93.8 | 55.5 | 149.2 | 517.82 | 306.26 | 824.08 | 285.1 | 757.8 | 1043.0 | 1574.62 | 4184.96 | 5759.58 |
| 1988 | 227 | 78.1 | 99.0 | 177.2 | 431.43 | 546.92 | 978.35 | 318.2 | 1391.9 | 1710.1 | 1757.17 | 7686.61 | 9443.78 |
| 1989 | 244 | 131.2 | 84.5 | 215.8 | 724.77 | 466.87 | 1191.64 | 487.9 | 1068.9 | 1556.7 | 2694.14 | 5902.55 | 8596.69 |
| 1990 | 216 | 177.3 | 88.4 | 265.8 | 979.34 | 488.26 | 1467.60 | 742.5 | 976.8 | 1719.2 | 4100.11 | 5393.95 | 9494.06 |
| 1991 | 228 | 47.6 | 53.5 | 101.1 | 262.80 | 295.59 | 558.39 | 202.3 | 772.8 | 975.1 | 1117.34 | 4267.50 | 5384.84 |
| 1992 | 229 | 24.4 | 28.2 | 52.6 | 134.65 | 156.00 | 290.65 | 85.8 | 469.9 | 555.7 | 473.78 | 2594.97 | 3068.75 |
| 1993 | 214 | 134.1 | 25.3 | 159.4 | 740.72 | 139.53 | 880.25 | 391.0 | 367.9 | 758.9 | 2159.12 | 2031.58 | 4190.70 |
| 1994 | 227 | 97.7 | 64.2 | 162.0 | 539.78 | 354.73 | 894.51 | 344.3 | 707.1 | 1051.4 | 1901.19 | 3904.84 | 5806.04 |
| 1995 | 227 | 130.9 | 92.6 | 223.5 | 722.60 | 511.46 | 1234.06 | 616.8 | 995.3 | 1612.1 | 3406.15 | 5496.25 | 8902.40 |
| 1996 | 211 | 24.0 | 52.2 | 76.2 | 132.53 | 288.27 | 420.80 | 127.0 | 657.7 | 784.7 | 701.33 | 3632.13 | 4333.46 |
| 1997 | 225 | 31.7 | 26.3 | 58.0 | 175.20 | 144.96 | 320.16 | 77.9 | 475.8 | 553.8 | 430.35 | 2627.79 | 3058.13 |
| 1998 | 215 | 156.3 | 52.2 | 208.5 | 863.13 | 288.32 | 1151.45 | 526.8 | 661.4 | 1188.1 | 2909.00 | 3652.24 | 6561.23 |

Table B8. Commercial landings and CPUE for sea scallops in Georges Bank and Mid-Atlantic regions.

| | Commercial Landings | | | | | | | Catch | CPUE |
|---|---|---|---|---|---|---|---|---|---|
| Calendar | Meat Weight (mt) | | Mean Weight (g) | | Catch Number (x10^6) | | Survey | Number 10^4 / Days | |
| YEAR | Jan-Jun | Jul-Dec | Jan-Jun | Jul-Dec | Jan-Jun | Jul-Dec | YEAR | (x10^6) | Fished) |
| Georges Bank | | | | | | | | | |
| 1982 | 3012 | 3309 | 22.117 | 21.496 | 136.185 | 153.938 | 1982 | 243.445 | 2.401 |
| 1983 | 2119 | 2164 | 23.674 | 27.264 | 89.507 | 79.372 | 1983 | 126.677 | 1.356 |
| 1984 | 1308 | 1734 | 27.650 | 27.200 | 47.305 | 63.750 | 1984 | 99.797 | 1.160 |
| 1985 | 825 | 2070 | 22.887 | 25.811 | 36.047 | 80.198 | 1985 | 186.390 | 1.748 |
| 1986 | 1995 | 2440 | 18.787 | 21.109 | 106.192 | 115.589 | 1986 | 234.701 | 2.268 |
| 1987 | 1916 | 2934 | 16.086 | 20.826 | 119.113 | 140.878 | 1987 | 272.249 | 2.445 |
| 1988 | 2743 | 3312 | 20.880 | 21.049 | 131.371 | 157.351 | 1988 | 257.806 | 1.984 |
| 1989 | 2388 | 3276 | 23.772 | 23.056 | 100.455 | 142.092 | 1989 | 355.636 | 2.418 |
| 1990 | 3633 | 6352 | 17.013 | 17.437 | 213.544 | 364.287 | 1990 | 684.604 | 3.064 |
| 1991 | 5348 | 3963 | 16.696 | 20.852 | 320.318 | 190.058 | 1991 | 455.402 | 2.099 |
| 1992 | 4388 | 3849 | 16.537 | 16.802 | 265.344 | 229.080 | 1992 | 345.134 | 1.757 |
| 1993 | 2275 | 1380 | 19.603 | 24.033 | 116.054 | 57.421 | 1993 | 91.068 | 0.653 |
| 1994 | 628 | 508 | 18.679 | 19.749 | 33.647 | 25.746 | 1994 | 32.282 | 1.849 |
| 1995 | 124 | 858 | 19.001 | 21.231 | 6.536 | 40.401 | 1995 | 77.065 | 0.397 |
| 1996 | 626 | 1419 | 17.075 | 16.817 | 36.664 | 84.405 | 1996 | 159.716 | 1.388 |
| 1997 | 1329 | 997 | 17.649 | 23.451 | 75.311 | 42.518 | 1997 | 89.228 | 0.270 |
| 1998 | 1073 | 990 | 22.979 | | 46.710 | | 1998 | | |
| Mid-Atlantic | | | | | | | | | |
| 1982 | 775 | 836 | 23.127 | 29.793 | 33.506 | 28.068 | 1982 | 97.184 | 1.893 |
| 1983 | 1697 | 1411 | 24.549 | 27.385 | 69.116 | 51.543 | 1983 | 152.041 | 1.689 |
| 1984 | 2291 | 1382 | 22.800 | 24.129 | 100.498 | 57.262 | 1984 | 151.849 | 1.445 |
| 1985 | 2157 | 1119 | 22.803 | 26.975 | 94.587 | 41.499 | 1985 | 126.465 | 1.674 |
| 1986 | 1807 | 1551 | 21.267 | 21.084 | 84.966 | 73.564 | 1986 | 310.430 | 3.138 |
| 1987 | 4376 | 3429 | 18.474 | 19.932 | 236.867 | 172.011 | 1987 | 351.326 | 2.429 |
| 1988 | 3648 | 2529 | 20.344 | 26.041 | 179.315 | 97.122 | 1988 | 372.655 | 2.284 |
| 1989 | 5815 | 2159 | 21.104 | 20.837 | 275.532 | 103.639 | 1989 | 377.877 | 2.455 |
| 1990 | 4789 | 1646 | 17.462 | 16.182 | 274.238 | 101.715 | 1990 | 301.331 | 2.097 |
| 1991 | 4601 | 2408 | 23.050 | 27.994 | 199.616 | 86.027 | 1991 | 214.049 | 1.225 |
| 1992 | 2659 | 2296 | 20.772 | 21.178 | 128.022 | 108.415 | 1992 | 167.554 | 0.908 |
| 1993 | 1451 | 1327 | 24.539 | 24.770 | 59.139 | 53.563 | 1993 | 230.408 | 0.714 |
| 1994 | 2959 | 2914 | 16.730 | 14.097 | 176.845 | 206.699 | 1994 | 471.414 | 1.148 |
| 1995 | 4346 | 1971 | 16.419 | 22.301 | 264.715 | 88.396 | 1995 | 274.166 | 0.884 |
| 1996 | 3075 | 1924 | 16.554 | 24.549 | 185.770 | 78.385 | 1996 | 146.890 | 0.654 |
| 1997 | 1642 | 1268 | 23.975 | 27.482 | 68.505 | 46.129 | 1997 | 108.953 | 0.527 |
| 1998 | 1512 | 1266 | 24.062 | | 62.824 | | 1998 | | |

Table B9. Input data for the two stage stock assessment model. PR: Partial recruits, FR: full recruits, Open: Open areas, Closed: Closed areas, Total: open and closed areas.

Georges Bank region

| | Swept Area Abundance Indices (10^8 scallops) | | | | | | Catch | CPUE |
|---|---|---|---|---|---|---|---|---|
| Year | PR total | PR open | R Closed | FR total | FR open | FR closed | 10^8 | (10^4/DF) |
| 1982 | 5.1648 | | | 1.5933 | | | 2.4345 | 2.4009 |
| 1983 | 1.2641 | | | 1.8254 | | | 1.2668 | 1.3564 |
| 1984 | 0.7415 | | | 1.1110 | | | 0.9980 | 1.1604 |
| 1985 | 1.7165 | | | 1.5989 | | | 1.8639 | 1.7478 |
| 1986 | 3.8882 | | | 1.8007 | | | 2.3470 | 2.2678 |
| 1987 | 3.2239 | | | 2.7000 | | | 2.7225 | 2.4449 |
| 1988 | 2.4516 | | | 2.2155 | | | 2.5781 | 1.9842 |
| 1989 | 0.0000 | | | 0.0000 | | | 3.5564 | 2.4182 |
| 1990 | 6.2621 | | | 3.4880 | | | 6.8460 | 3.0639 |
| 1991 | 10.6430 | | | 2.5124 | | | 4.5540 | 2.0994 |
| 1992 | 9.0081 | | | 3.6713 | | | 3.4513 | 1.7572 |
| 1993 | 2.1044 | | | 1.0147 | | | 0.9107 | 0.6529 |
| 1994 | 0.9567 | | | 1.1517 | | | 0.3228 | 1.8486 |
| 1995 | 4.6411 | 2.8019 | 1.8392 | 1.3466 | 0.7061 | 0.6405 | 0.7707 | 0.3971 |
| 1996 | 3.5806 | 1.3401 | 2.2405 | 3.4358 | 1.1715 | 2.2643 | 1.5972 | 1.3878 |
| 1997 | 1.4249 | 0.7728 | 0.6521 | 3.3654 | 0.8685 | 2.4968 | 0.8923 | 0.2699 |
| 1998 | 6.6438 | 2.2506 | 4.3932 | 8.0043 | 1.0670 | 6.9373 | | |

Mid-Atlantic

| | Swept Area Abundance Indices (10^8 scallops) | | | | | | Catch | CPUE |
|---|---|---|---|---|---|---|---|---|
| Year | PR total | PR open | R Closed | FR total | FR open | FR closed | 10^8 | (10^4/DF) |
| 1982 | 0.8666 | | | 1.3097 | | | 0.9718 | 1.8929 |
| 1983 | 1.0821 | | | 0.9997 | | | 1.5204 | 1.6889 |
| 1984 | 0.8405 | | | 1.2806 | | | 1.5185 | 1.4453 |
| 1985 | 3.0978 | | | 1.8523 | | | 1.2647 | 1.6739 |
| 1986 | 4.8941 | | | 3.4352 | | | 3.1043 | 3.1380 |
| 1987 | 5.1782 | | | 3.0626 | | | 3.5133 | 2.4293 |
| 1988 | 4.3143 | | | 5.4692 | | | 3.7265 | 2.2836 |
| 1989 | 7.2477 | | | 4.6686 | | | 3.7788 | 2.4546 |
| 1990 | 9.7934 | | | 4.8825 | | | 3.0133 | 2.0966 |
| 1991 | 2.6280 | | | 2.9559 | | | 2.1405 | 1.2247 |
| 1992 | 1.3464 | | | 1.5600 | | | 1.6755 | 0.9083 |
| 1993 | 7.4071 | | | 1.3953 | | | 2.3041 | 0.7137 |
| 1994 | 5.3978 | | | 3.5473 | | | 4.7141 | 1.1480 |
| 1995 | 7.2260 | | | 5.1145 | | | 2.7417 | 0.8839 |
| 1996 | 1.3253 | | | 2.8827 | | | 1.4689 | 0.6537 |
| 1997 | 1.7520 | | | 1.4498 | | | 1.0895 | 0.5270 |
| 1998 | 8.6313 | 4.0386 | 4.5927 | 2.8832 | 1.2469 | 1.6363 | | |

Table B10. Estimation of empirical fishing mortality ($F_E$) in Georges Bank and Mid-Atlantic regions.
($F_S$: abundance-based estimates of fishing mortality, $F_B$: biomass-based estimates of fishing mortality, Model Estimated F: F-estimates from two stage stock assessment model, $\alpha$: adjustment factor)

GEORGES BANK

| | Mean Number per Tow | | | | Swept Area Biomass (mt) | | | | | | Model |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Partial | Full | | | Partial | Full | | | $F_B$ | $F_E$ | Estimated |
| Year | Recruits | Recruits | Total | $F_S$ | Recruits | Recruits | Total | Catch, mt | q=0.6 | $=\alpha F_B$ | F |
| 1982 | 105.71 | 32.61 | 138.32 | 1.21 | 1578.62 | 2961.85 | 4540.47 | 6322.2 | 0.835 | 1.146 | 0.656 |
| 1983 | 25.87 | 37.36 | 63.23 | 0.92 | 548.78 | 3150.57 | 3699.36 | 4283.6 | 0.695 | 0.953 | 0.415 |
| 1984 | 15.18 | 22.74 | 37.91 | 0.05 | 273.10 | 2447.83 | 2720.94 | 3042.8 | 0.671 | 0.921 | 0.348 |
| 1985 | 35.13 | 32.72 | 67.86 | 0.51 | 707.64 | 2880.00 | 3587.63 | 2894.2 | 0.484 | 0.664 | 0.553 |
| 1986 | 79.58 | 36.85 | 116.43 | 0.65 | 1360.09 | 3311.00 | 4671.09 | 4438.1 | 0.570 | 0.782 | 0.480 |
| 1987 | 65.98 | 55.26 | 121.24 | 0.88 | 1204.63 | 4093.74 | 5298.37 | 4850.5 | 0.549 | 0.754 | 0.517 |
| 1988 | 50.18 | 45.34 | 95.52 | | 1028.11 | 3335.60 | 4363.72 | 6054.1 | 0.832 | 1.142 | 0.462 |
| 1989 | N/C | N/C | N/C | | N/C | N/C | N/C | 5661.1 | | | 0.634 |
| 1990 | 128.16 | 71.39 | 199.55 | 1.26 | 2340.69 | 4046.07 | 6386.76 | 9982.0 | 0.938 | 1.287 | 1.373 |
| 1991 | 217.83 | 51.42 | 269.25 | 1.18 | 2997.90 | 3574.56 | 6572.46 | 9311.4 | 0.850 | 1.166 | 1.091 |
| 1992 | 184.37 | 75.14 | 259.51 | 2.43 | 3970.80 | 4162.18 | 8132.97 | 8237.5 | 0.608 | 0.834 | 1.272 |
| 1993 | 43.07 | 20.77 | 63.84 | 0.90 | 929.90 | 1592.09 | 2521.99 | 3654.8 | 0.869 | 1.193 | 0.407 |
| 1994 | 19.58 | 23.57 | 43.15 | 0.35 | 339.61 | 1907.02 | 2246.63 | 1137.0 | 0.304 | 0.417 | 0.136 |
| 1995 | 94.99 | 27.56 | 122.55 | 0.46 | 1466.13 | 2332.70 | 3798.83 | 981.9 | 0.155 | 0.213 | 0.124 |
| 1996 | 73.28 | 70.32 | 143.60 | 0.63 | 1398.53 | 5687.98 | 7086.52 | 2045.5 | 0.173 | 0.238 | 0.181 |
| 1997 | 29.16 | 68.38 | 98.04 | -0.61 | 528.23 | 7655.34 | 8183.57 | 2326.3 | 0.171 | 0.234 | 0.099 |
| 1998 | 135.98 | 163.62 | 299.80 | | 2352.47 | 17866.32 | 20218.80 | 2063.6 | 0.061 | 0.084 | |
| | | | AVG. $F_S$(82-94) | 0.94 | | | | AVG. $F_B$(82-94) | 0.68 | | |
| | | | | | | | | $\alpha$ | 1.372 | | |

MID-ATLANTIC

| | Mean Number per Tow | | | | Swept Area Biomass (mt) | | | | | | Model |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Partial | Full | | | Partial | Full | | | $F_B$ | $F_E$ | Estimated |
| Year | Recruits | Recruits | Total | $F_S$ | Recruits | Recruits | Total | Catch, mt | q=0.6 | $=\alpha F_B$ | F |
| 1982 | 15.69 | 23.72 | 39.41 | 0.68 | 371.36 | 2470.67 | 2842.03 | 1610.3 | 0.340 | 0.399 | 0.418 |
| 1983 | 19.60 | 18.10 | 37.70 | 0.39 | 366.60 | 2281.34 | 2647.94 | 3108.8 | 0.704 | 0.826 | 0.547 |
| 1984 | 15.22 | 23.19 | 38.41 | 0.04 | 284.74 | 2280.83 | 2565.57 | 3674.9 | 0.859 | 1.008 | 0.604 |
| 1985 | 56.10 | 33.54 | 89.64 | 0.27 | 1131.95 | 2888.59 | 4020.54 | 3275.6 | 0.489 | 0.573 | 0.298 |
| 1986 | 88.63 | 62.21 | 150.83 | 0.90 | 1847.26 | 4828.49 | 6675.75 | 3358.5 | 0.302 | 0.354 | 0.537 |
| 1987 | 93.77 | 55.46 | 149.23 | 0.31 | 1574.62 | 4184.96 | 5759.58 | 7803.4 | 0.813 | 0.953 | 0.513 |
| 1988 | 78.13 | 99.04 | 177.16 | 0.64 | 1757.17 | 7686.61 | 9443.78 | 6177.6 | 0.392 | 0.460 | 0.635 |
| 1989 | 131.24 | 84.54 | 215.79 | 0.79 | 2694.14 | 5902.55 | 8596.69 | 7973.1 | 0.556 | 0.652 | 0.696 |
| 1990 | 177.34 | 88.42 | 265.76 | 1.50 | 4100.11 | 5393.95 | 9494.06 | 6434.7 | 0.407 | 0.477 | 0.573 |
| 1991 | 47.59 | 53.53 | 101.11 | 1.18 | 1117.34 | 4267.50 | 5384.84 | 7011.2 | 0.781 | 0.916 | 0.513 |
| 1992 | 24.38 | 28.25 | 52.63 | 0.63 | 473.78 | 2594.97 | 3068.75 | 4955.0 | 0.969 | 1.136 | 0.493 |
| 1993 | 134.13 | 25.27 | 159.40 | 0.81 | 2159.12 | 2031.58 | 4190.70 | 2777.9 | 0.398 | 0.466 | 0.350 |
| 1994 | 97.75 | 64.24 | 161.98 | 0.46 | 1901.19 | 3904.84 | 5806.04 | 5872.4 | 0.607 | 0.711 | 0.691 |
| 1995 | 130.85 | 92.62 | 223.47 | 1.35 | 3406.15 | 5496.25 | 8902.40 | 6317.7 | 0.426 | 0.499 | 0.410 |
| 1996 | 24.00 | 52.20 | 76.20 | 0.97 | 701.33 | 3632.13 | 4333.46 | 4999.5 | 0.692 | 0.812 | 0.264 |
| 1997 | 31.73 | 26.25 | 57.98 | 0.00 | 430.35 | 2627.79 | 3058.13 | 2910.2 | 0.571 | 0.669 | 0.167 |
| 1998 | 156.30 | 52.21 | 208.51 | | 2909.00 | 3652.24 | 6561.23 | 2777.8 | 0.254 | 0.298 | |
| | | | AVG. $F_S$ | 0.68 | | | | AVG. $F_B$ | 0.58 | | |
| | | | | | | | | $\alpha$ | 1.172 | | |

Table B11. Survey indices (stratified mean number per tow) for partial recruits used in SFA and SARC29. The estimates used in SFA were based on the original strata set (Table B5) and that in SARC29 were based on the revised strata set, in which post-stratification was applied to all years. (N/A: incomplete survey)

| | Georges Bank | | Mid-Atlantic | |
|---|---|---|---|---|
| Year | SFA | SARC29 | SFA | SARC29 |
| 1979 | 71.472 | | 11.308 | |
| 1980 | 328.260 | | 26.158 | |
| 1981 | 179.189 | | 17.289 | |
| 1982 | 114.960 | 105.708 | 15.333 | 15.694 |
| 1983 | 36.153 | 25.871 | 19.173 | 19.596 |
| 1984 | 72.639 | 15.175 | 15.263 | 15.220 |
| 1985 | 111.879 | 35.131 | 57.174 | 56.097 |
| 1986 | 156.789 | 79.579 | 87.775 | 88.625 |
| 1987 | 119.247 | 65.983 | 95.150 | 93.769 |
| 1988 | 80.850 | 50.176 | 76.909 | 78.125 |
| 1989 | N/A | N/A | 132.191 | 131.245 |
| 1990 | 203.160 | 128.165 | 159.864 | 177.343 |
| 1991 | 247.468 | 217.828 | 47.721 | 47.589 |
| 1992 | 178.957 | 184.367 | 24.221 | 24.382 |
| 1993 | 22.972 | 43.069 | 137.307 | 134.131 |
| 1994 | 20.730 | 19.581 | 99.513 | 97.745 |
| 1995 | 78.345 | 94.988 | 162.353 | 130.851 |
| 1996 | 87.968 | 73.284 | 24.109 | 24.000 |
| 1997 | 34.919 | 29.163 | 30.675 | 31.726 |
| 1998 | | 135.977 | | 156.299 |
| MEDIAN | | | | |
| 79-97 | 99.923 | | 47.721 | |
| 82-97 | 87.968 | 69.633 | 67.042 | 78.125 |

Table B12. Biological reference points for sea scallops in Georges Bank and Mid-Atlantic regions calculated from different growth curves, cohort age, and median recruits per tow from surveys. Survey indices in 1998, B(1998), and mean $F_E$ in 1997-98 were given to determine the state of stock.

| | Median Recruits | | | Cohort | | mean $F_E$ | max.B/R | max.Y/R | Bmax | ¼ Bmax | Ymax | B(1998) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #/tow | Years | Growth Curves | Age | Fmax | 1997-98 | g/tow | g/tow | kg/tow | kg/tow | kg/tow | kg/tow |
| **Georges Bank** | | | | | | | | | | | | |
| Original Strata Set | 99.92 | 1979-97 | Serchuk & Rak | t | 0.18 | 0.16 | 111.50 | 17.15 | 11.14 | 2.79 | 1.71 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 112.51 | 19.38 | 11.24 | 2.81 | 1.94 | 4.14 |
| | | | | t+0.75 | 0.22 | 0.16 | 112.50 | 20.56 | 11.24 | 2.81 | 2.05 | 4.14 |
| | | | Current | t | 0.18 | 0.16 | 95.62 | 14.94 | 9.56 | 2.39 | 1.49 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 96.31 | 16.88 | 9.62 | 2.41 | 1.69 | 4.14 |
| | | | | t+0.75 | 0.23 | 0.16 | 96.20 | 17.90 | 9.61 | 2.40 | 1.79 | 4.14 |
| | | | SFA (Robert | t | 0.19 | 0.16 | 82.19 | 13.27 | 8.21 | 2.05 | 1.33 | 4.14 |
| | | | & Butler) | t+0.5 | 0.22 | 0.16 | 82.19 | 14.81 | 8.21 | 2.05 | 1.48 | 4.14 |
| | | | | t+0.75 | 0.24 | 0.16 | 81.62 | 16.11 | 8.16 | 2.04 | 1.61 | 4.14 |
| | 87.97 | 1982-98 | Serchuk & Rak | t | 0.18 | 0.16 | 111.50 | 17.15 | 9.81 | 2.45 | 1.51 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 112.51 | 19.38 | 9.90 | 2.47 | 1.71 | 4.14 |
| | | | | t+0.75 | 0.22 | 0.16 | 112.50 | 20.56 | 9.90 | 2.47 | 1.81 | 4.14 |
| | | | Current | t | 0.18 | 0.16 | 95.62 | 14.94 | 8.41 | 2.10 | 1.31 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 96.31 | 16.88 | 8.47 | 2.12 | 1.48 | 4.14 |
| | | | | t+0.75 | 0.23 | 0.16 | 96.20 | 17.90 | 8.46 | 2.12 | 1.57 | 4.14 |
| | | | SFA (Robert | t | 0.19 | 0.16 | 82.19 | 13.27 | 7.23 | 1.81 | 1.17 | 4.14 |
| | | | & Butler) | t+0.5 | 0.22 | 0.16 | 82.19 | 14.81 | 7.23 | 1.81 | 1.30 | 4.14 |
| | | | | t+0.75 | 0.24 | 0.16 | 81.62 | 16.11 | 7.18 | 1.79 | 1.42 | 4.14 |
| Revise Strata Set | 69.63 | 1982-98 | Serchuk & Rak | t | 0.18 | 0.16 | 111.50 | 17.15 | 7.76 | 1.94 | 1.19 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 112.51 | 19.38 | 7.83 | 1.96 | 1.35 | 4.14 |
| | | | | t+0.75 | 0.22 | 0.16 | 112.50 | 20.56 | 7.83 | 1.96 | 1.43 | 4.14 |
| | | | Current | t | 0.18 | 0.16 | 95.62 | 14.94 | 6.66 | 1.66 | 1.04 | 4.14 |
| | | | | t+0.5 | 0.21 | 0.16 | 96.31 | 16.88 | 6.71 | 1.68 | 1.18 | 4.14 |
| | | | | t+0.75 | 0.23 | 0.16 | 96.20 | 17.90 | 6.70 | 1.67 | 1.25 | 4.14 |
| | | | SFA (Robert | t | 0.19 | 0.16 | 82.19 | 13.27 | 5.72 | 1.43 | 0.92 | 4.14 |
| | | | & Butler) | t+0.5 | 0.22 | 0.16 | 82.19 | 14.81 | 5.72 | 1.43 | 1.03 | 4.14 |
| | | | | t+0.75 | 0.24 | 0.16 | 81.62 | 16.11 | 5.68 | 1.42 | 1.12 | 4.14 |
| **Mid-Atlantic** | | | | | | | | | | | | |
| Original Strata Set | 47.72 | 1979-97 | Serchuk & Rak | t | 0.17 | 0.66 | 80.67 | 11.81 | 3.85 | 0.96 | 0.56 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 92.15 | 13.39 | 4.40 | 1.10 | 0.64 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 93.57 | 14.21 | 4.47 | 1.12 | 0.68 | 1.19 |
| | | | Current | t | 0.15 | 0.66 | 82.54 | 10.98 | 3.94 | 0.98 | 0.52 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 85.77 | 12.42 | 4.09 | 1.02 | 0.59 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 87.11 | 13.18 | 4.16 | 1.04 | 0.63 | 1.19 |
| | | | SFA (Robert | t | 0.19 | 0.66 | 82.19 | 13.27 | 3.92 | 0.98 | 0.63 | 1.19 |
| | | | & Butler) | t+0.5 | 0.22 | 0.66 | 82.19 | 14.81 | 3.92 | 0.98 | 0.71 | 1.19 |
| | | | | t+0.75 | 0.24 | 0.66 | 81.62 | 16.11 | 3.90 | 0.97 | 0.77 | 1.19 |
| | 67.04 | 1982-98 | Serchuk & Rak | t | 0.17 | 0.66 | 80.67 | 11.81 | 5.41 | 1.35 | 0.79 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 92.15 | 13.39 | 6.18 | 1.54 | 0.90 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 93.57 | 14.21 | 6.27 | 1.57 | 0.95 | 1.19 |
| | | | Current | t | 0.15 | 0.66 | 82.54 | 10.98 | 5.53 | 1.38 | 0.74 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 85.77 | 12.42 | 5.75 | 1.44 | 0.83 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 87.11 | 13.18 | 5.84 | 1.46 | 0.88 | 1.19 |
| | | | SFA (Robert | t | 0.19 | 0.66 | 82.19 | 13.27 | 5.51 | 1.38 | 0.89 | 1.19 |
| | | | & Butler) | t+0.5 | 0.22 | 0.66 | 82.19 | 14.81 | 5.51 | 1.38 | 0.99 | 1.19 |
| | | | | t+0.75 | 0.24 | 0.66 | 81.62 | 16.11 | 5.47 | 1.37 | 1.08 | 1.19 |
| Revise Strata Set | 78.13 | 1982-98 | Serchuk & Rak | t | 0.17 | 0.66 | 80.67 | 11.81 | 6.30 | 1.58 | 0.92 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 92.15 | 13.39 | 7.20 | 1.80 | 1.05 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 93.57 | 14.21 | 7.31 | 1.83 | 1.11 | 1.19 |
| | | | Current | t | 0.15 | 0.66 | 82.54 | 10.98 | 6.45 | 1.61 | 0.86 | 1.19 |
| | | | | t+0.5 | 0.17 | 0.66 | 85.77 | 12.42 | 6.70 | 1.68 | 0.97 | 1.19 |
| | | | | t+0.75 | 0.18 | 0.66 | 87.11 | 13.18 | 6.81 | 1.70 | 1.03 | 1.19 |
| | | | SFA (Robert | t | 0.19 | 0.66 | 82.19 | 13.27 | 6.42 | 1.61 | 1.04 | 1.19 |
| | | | & Butler) | t+0.5 | 0.22 | 0.66 | 82.19 | 14.81 | 6.42 | 1.61 | 1.16 | 1.19 |
| | | | | t+0.75 | 0.24 | 0.66 | 81.62 | 16.11 | 6.38 | 1.59 | 1.26 | 1.19 |

Figure B1. Scallop management chronology of major regulations implemented since 1982 and planned through 2000. (mpp = meats per pound)

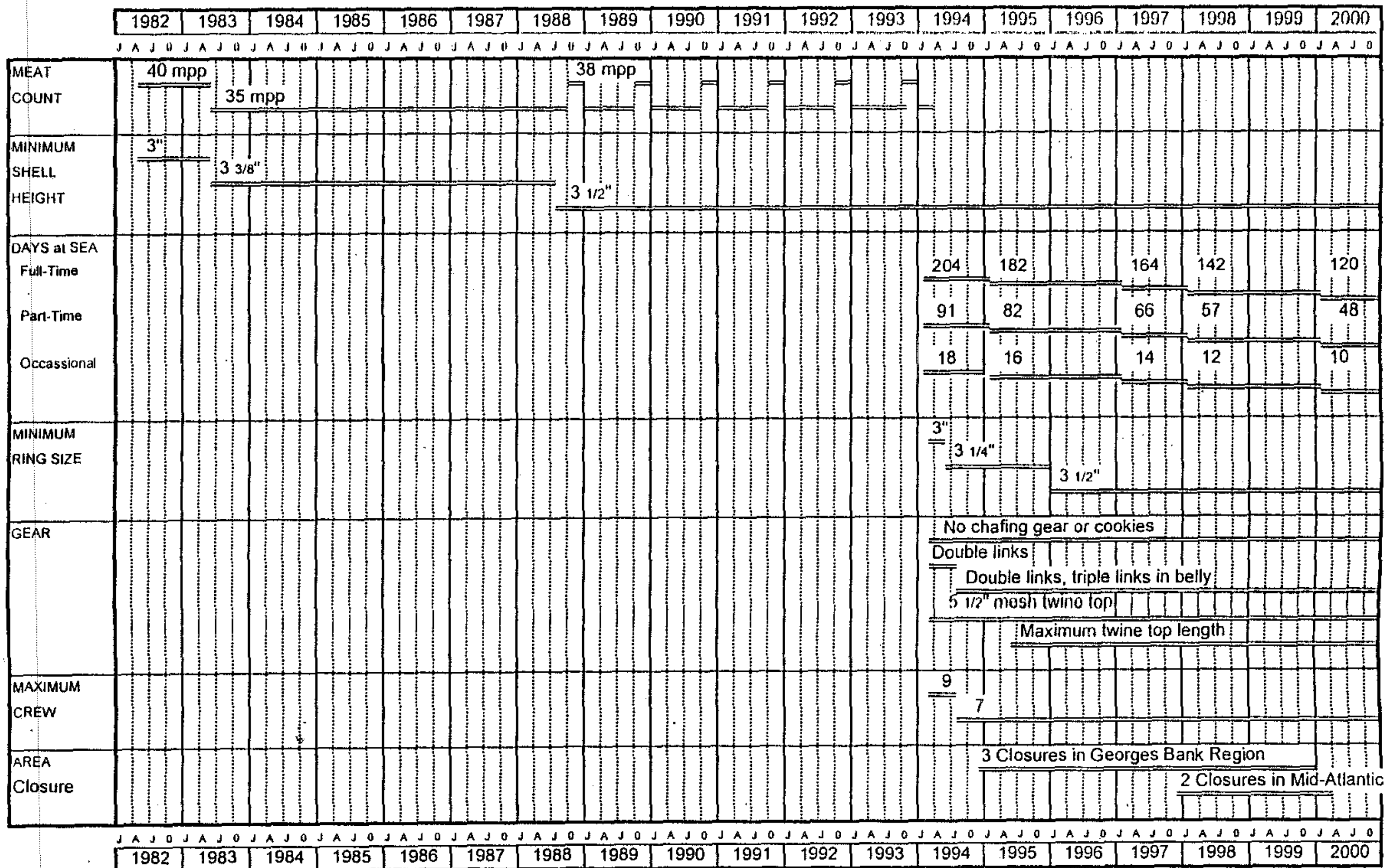


Figure B2. Survey strata in Georges Bank region. Dot lines indicate closed areas. Italic numbers indicate 3-digit statistical areas.

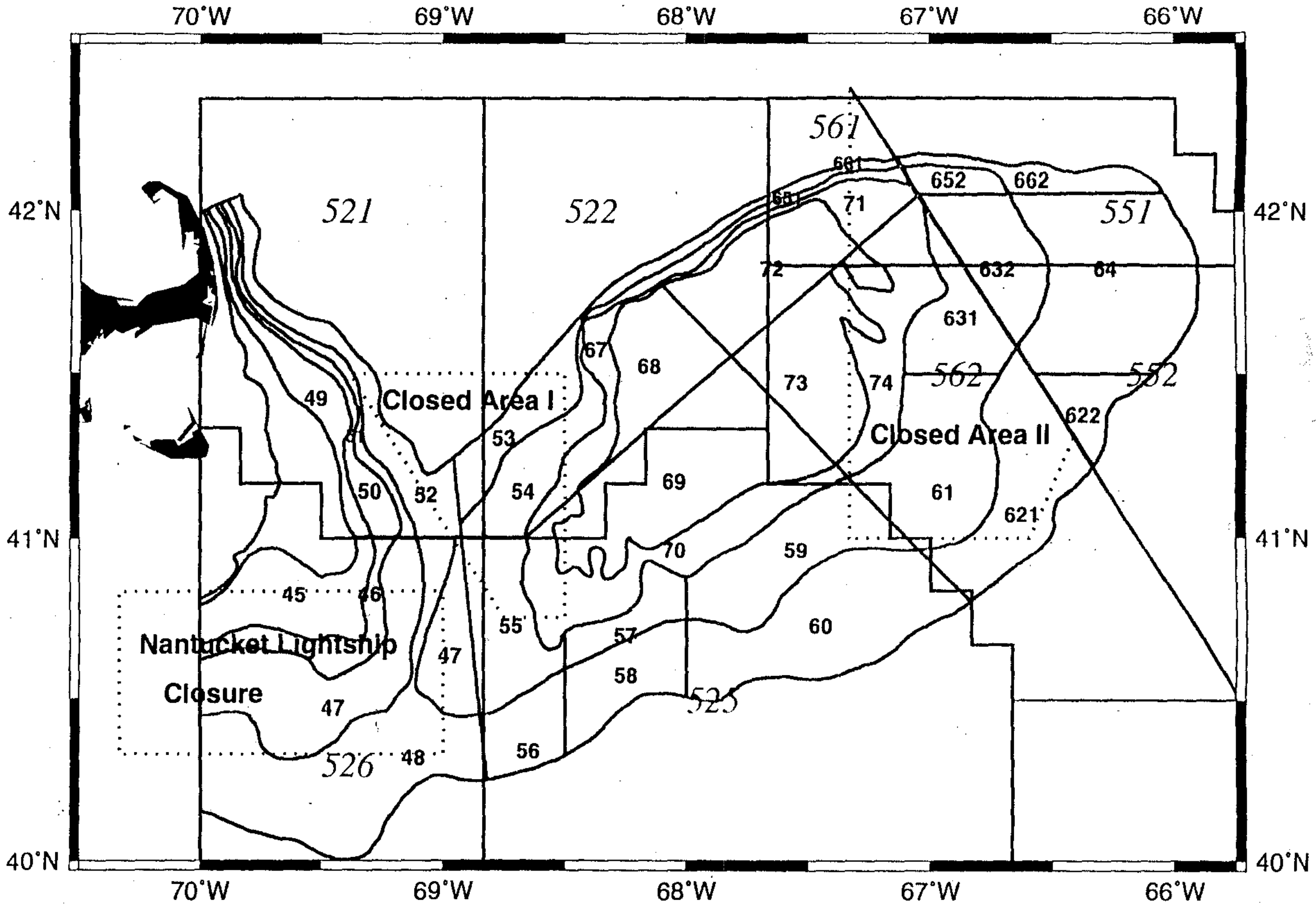
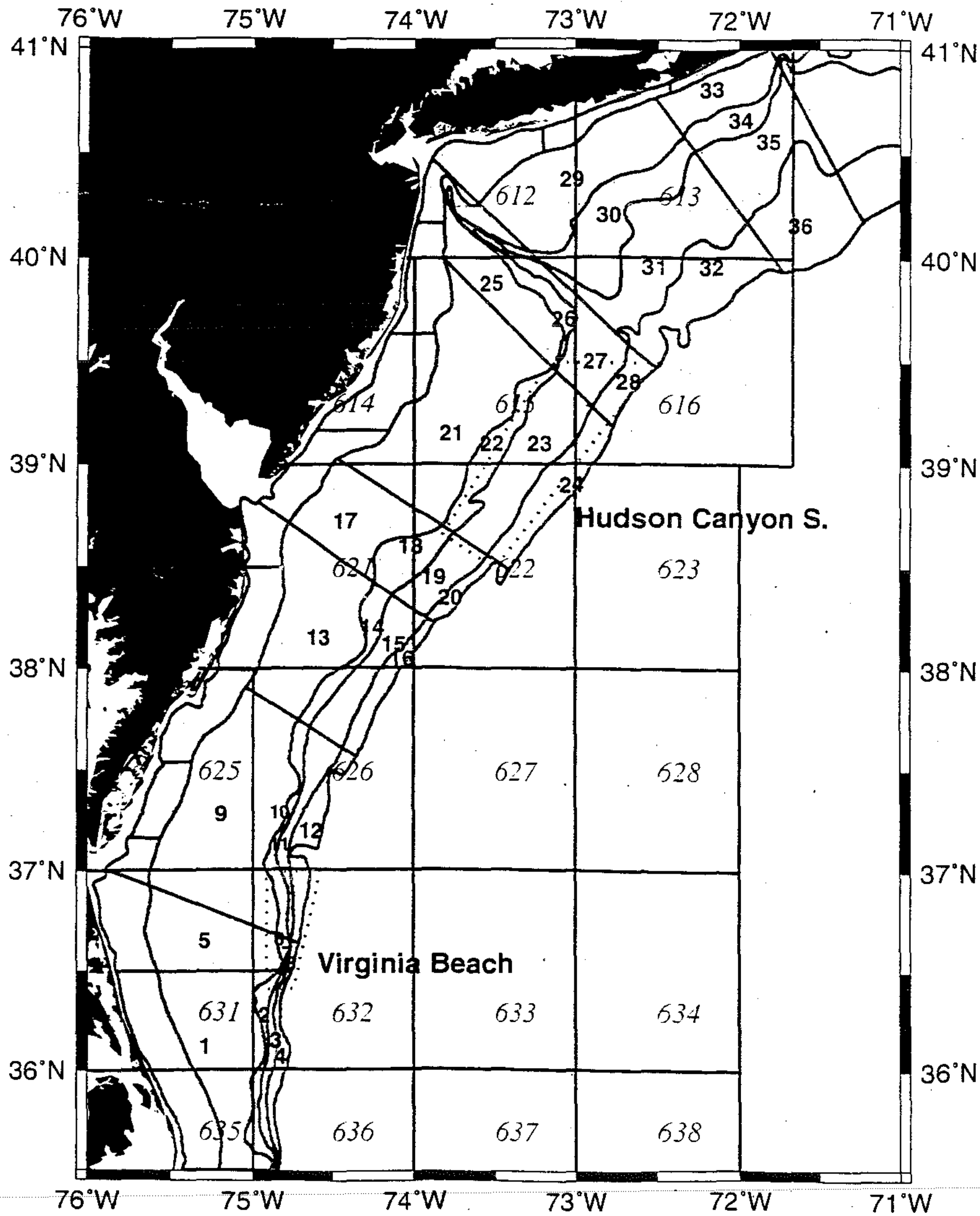


Figure B3. Survey strata in Mid-Atlantic region. Dot lines indicate closed areas. Italic numbers indicate 3-digit statistical areas.



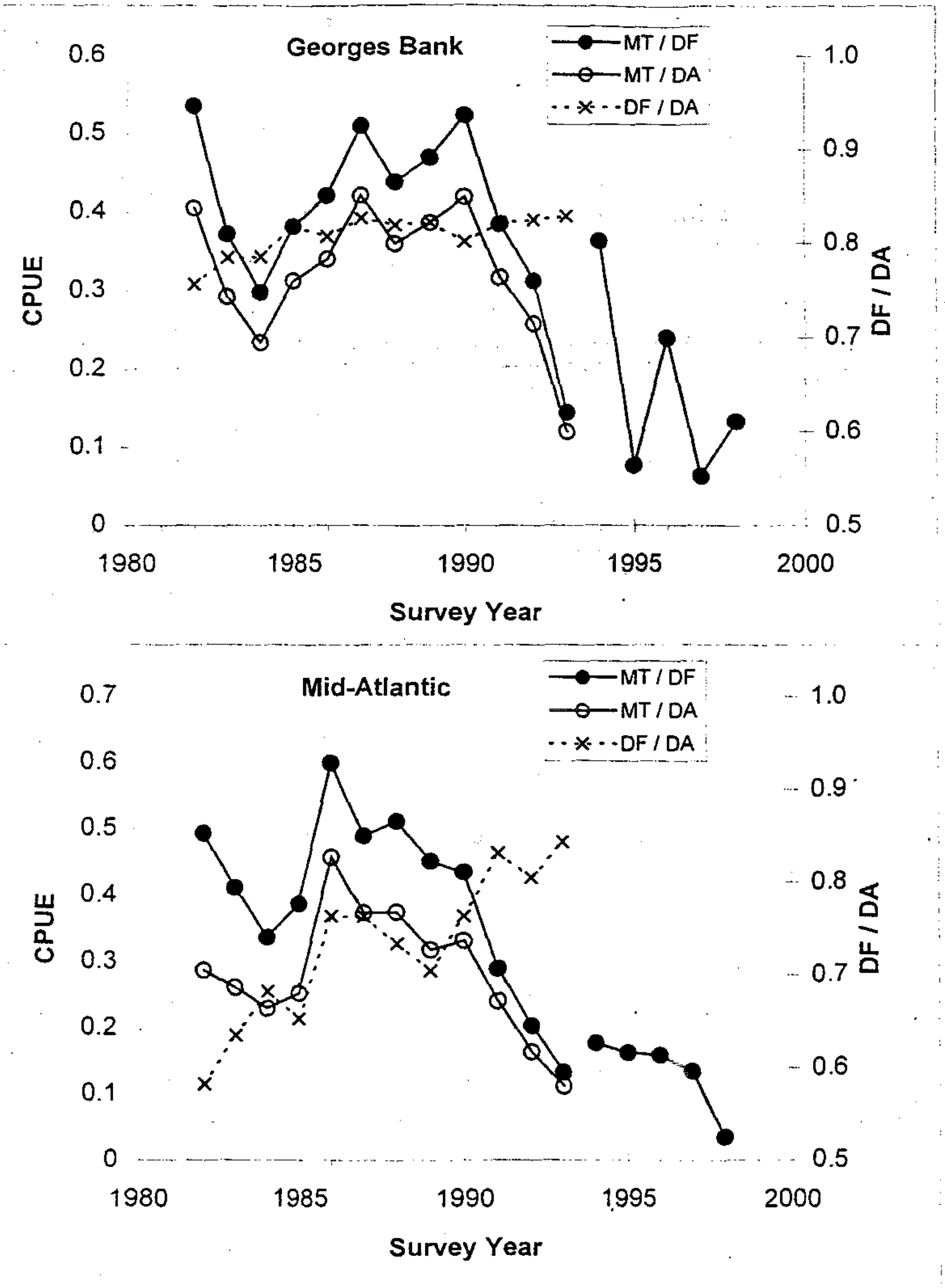



Fig. B4. US sea scallop landings (MT) per day fished (DF) and landings per day at sea (DA) for ton-classes 3 and 4 (50-500 tons) dredge vessels in Georges Bank and Mid-Atlantic regions. The break in 1993 and 1994 reflects implementation of vessel trip reports and dealer logs in 1994.

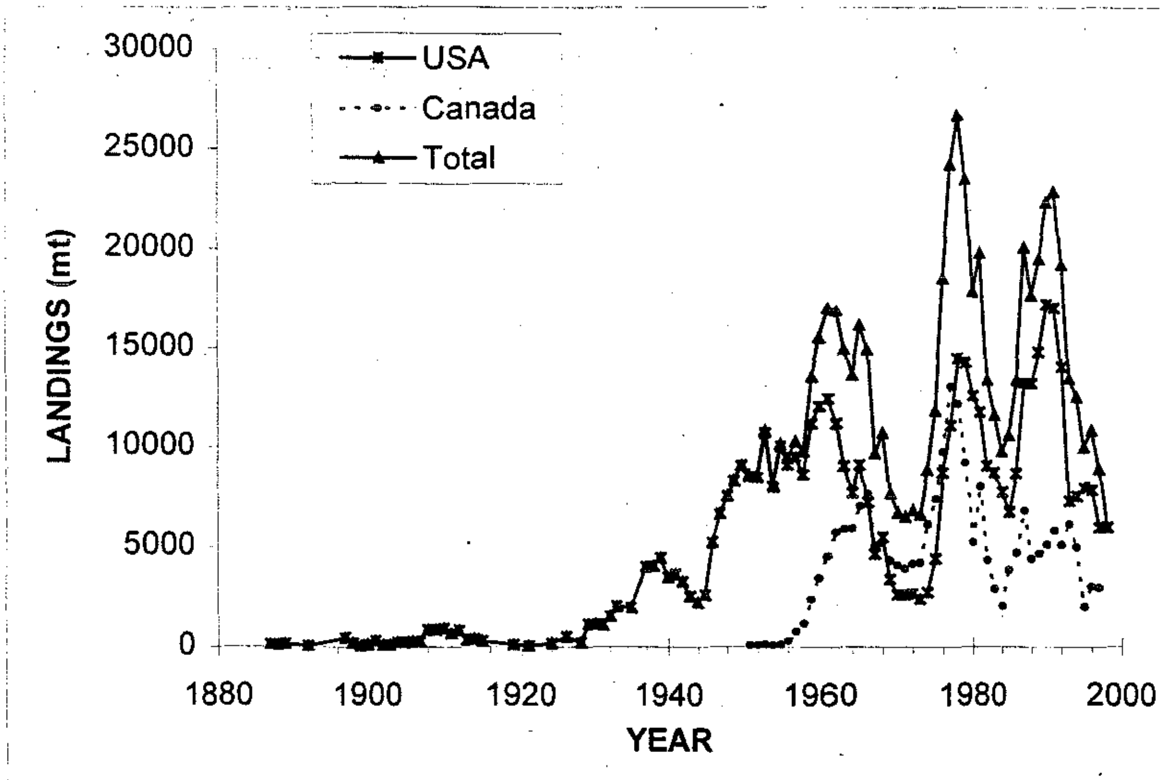



Fig. B5. US and Canadian sea scallop landings (mt of meats) from the Northwest Atlantic (NAFO Subareas 5 and 6), 1987-1998.

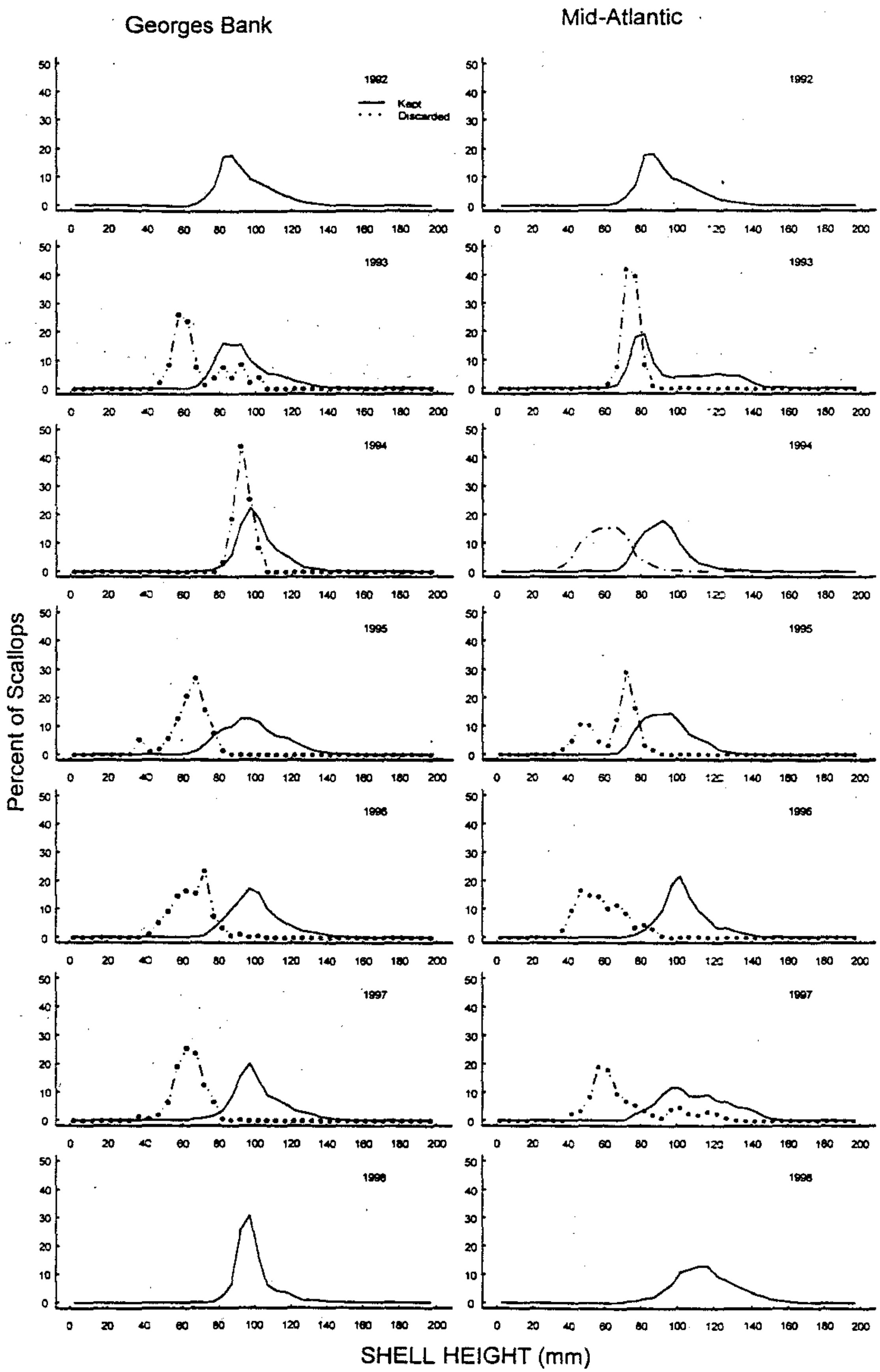



Figure B6. Kept and discarded Shell height distributions in Georges Bank and Mid-Atlantic, by survey year 1992-98.

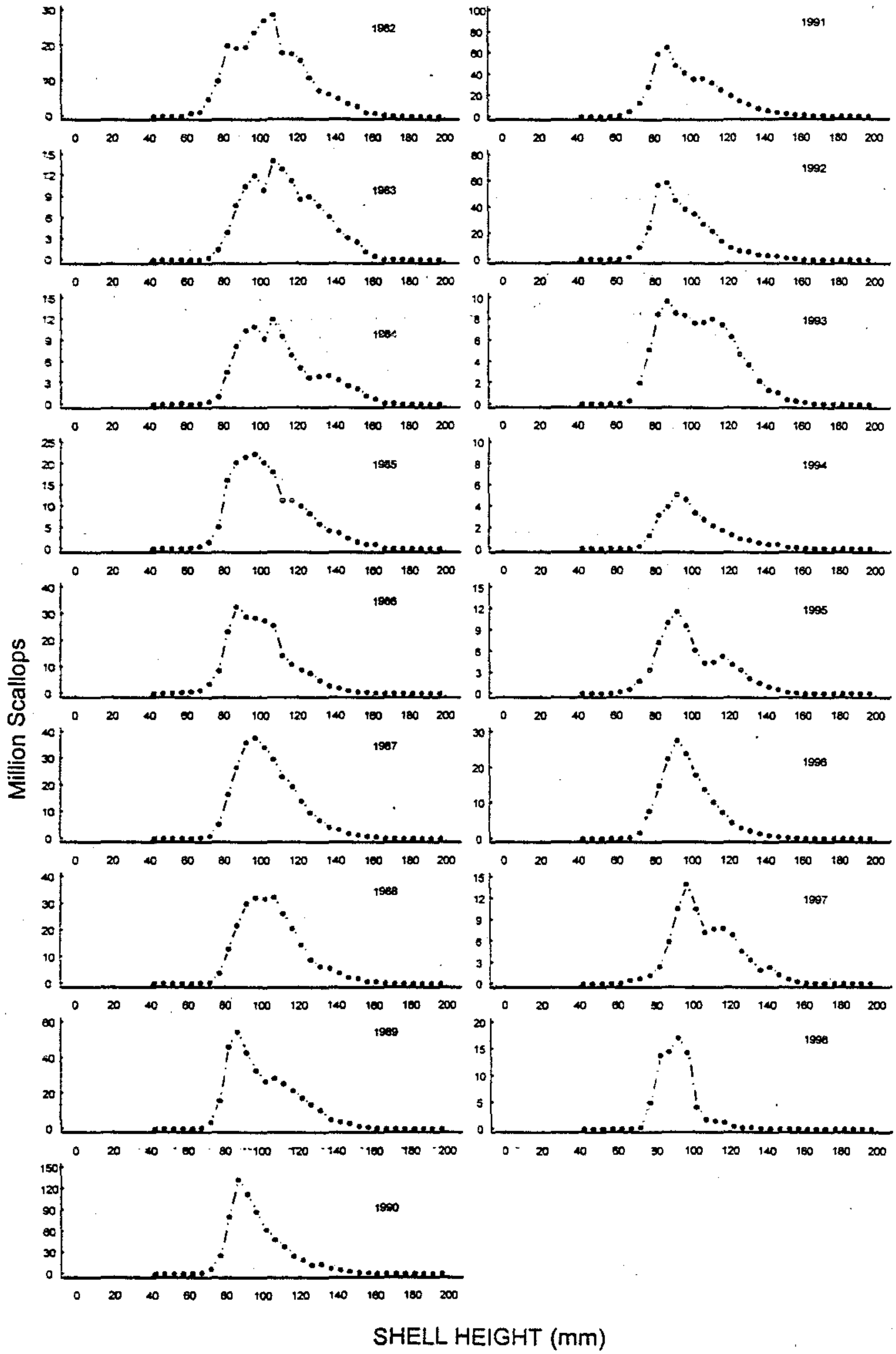



Figure B7. Shell height distributions of commercial catch in Georges Bank.

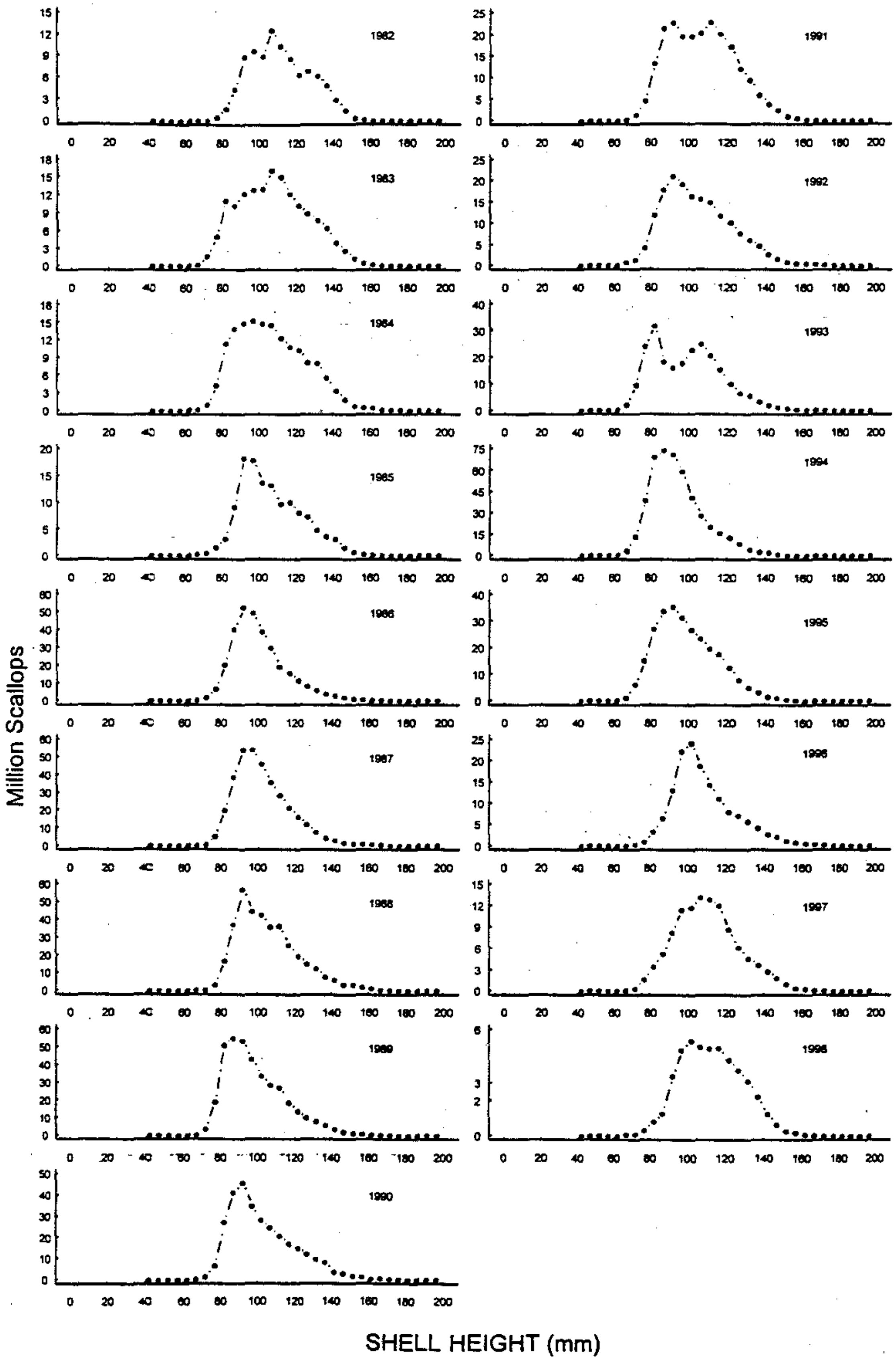



Figure B8. Shell height distributions of commercial catch in Mid-Atlantic.

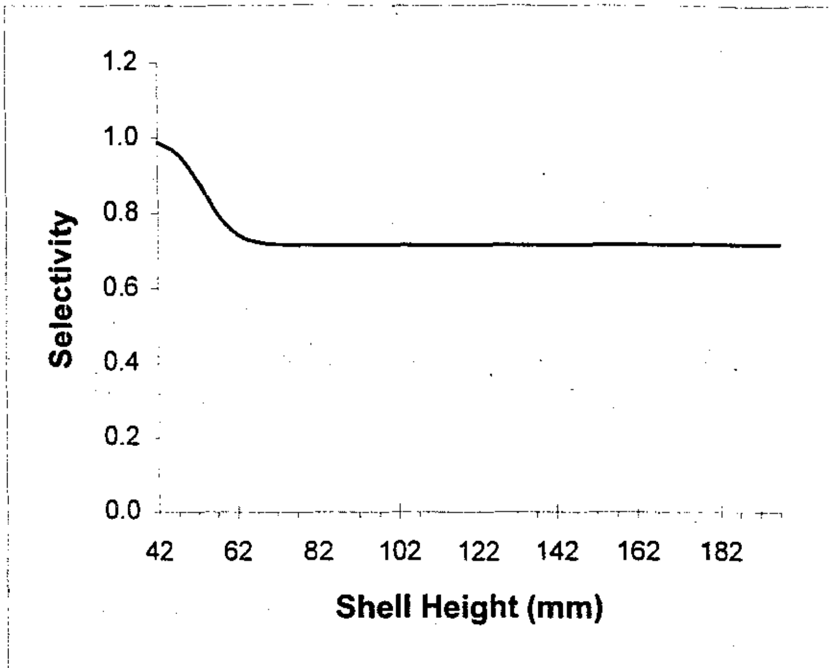



Figure B9. Selectivity of survey dredge with 3.8 cm (1.5 inch) polypropylene mesh liner.

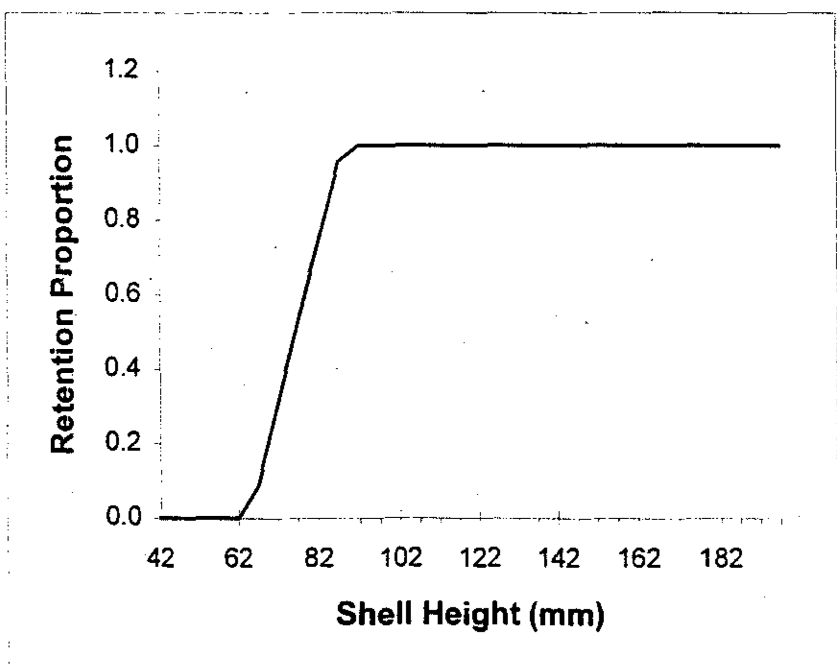



Figure B10. Proportion of sea scallops retained by commercial dredges.

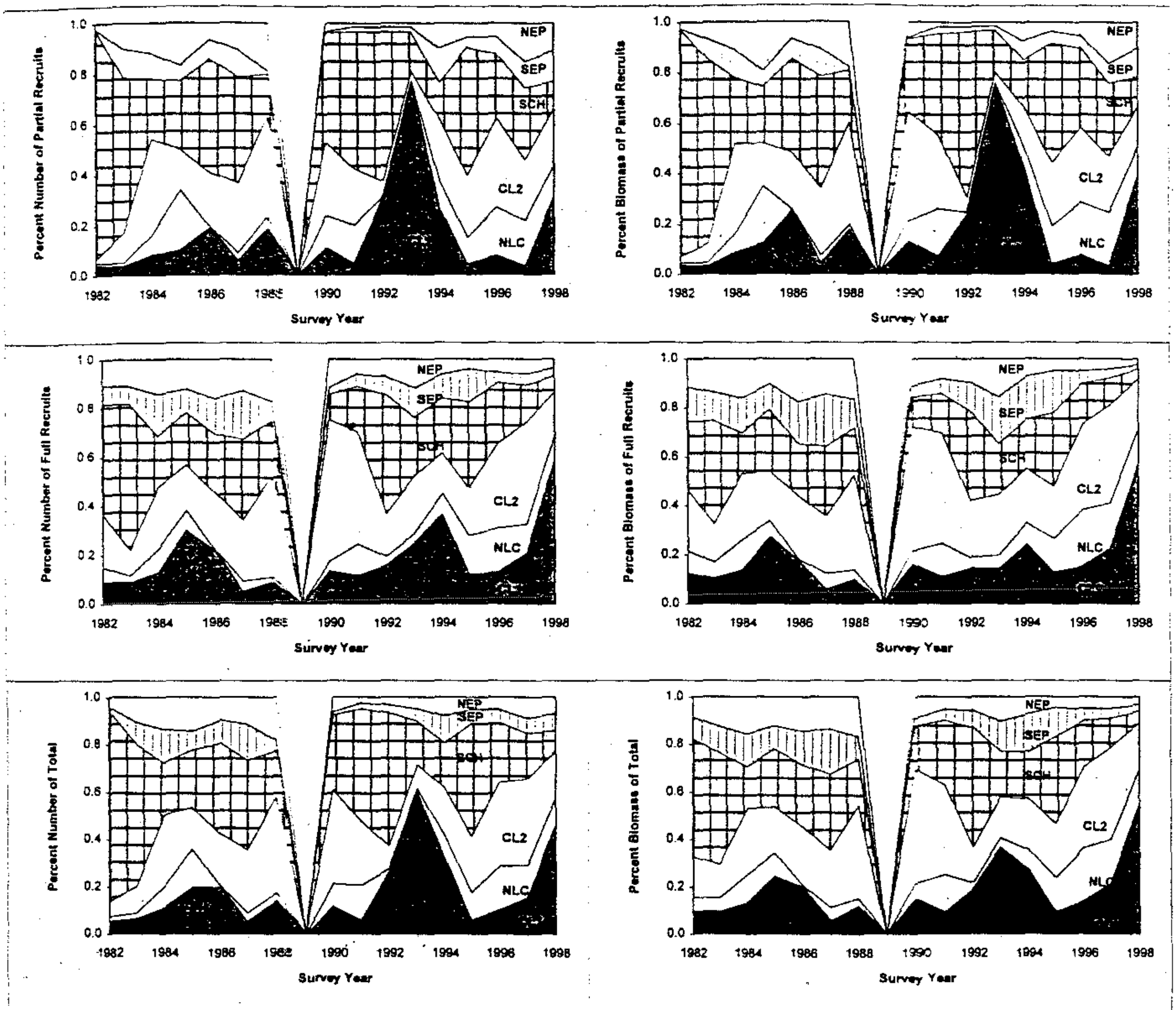



Figure B11. Percent distribution of population size and biomass for Partial recruits, and total for six resource areas in Georges Bank region. CL1: Closed Area 1; NLC: Nantucket Lightship Closure; CL2: Closed Area 2; SCH: South Channel Open area; SEP: Southeast Part Open area; NEP: Northern Edge and Peak Open Area

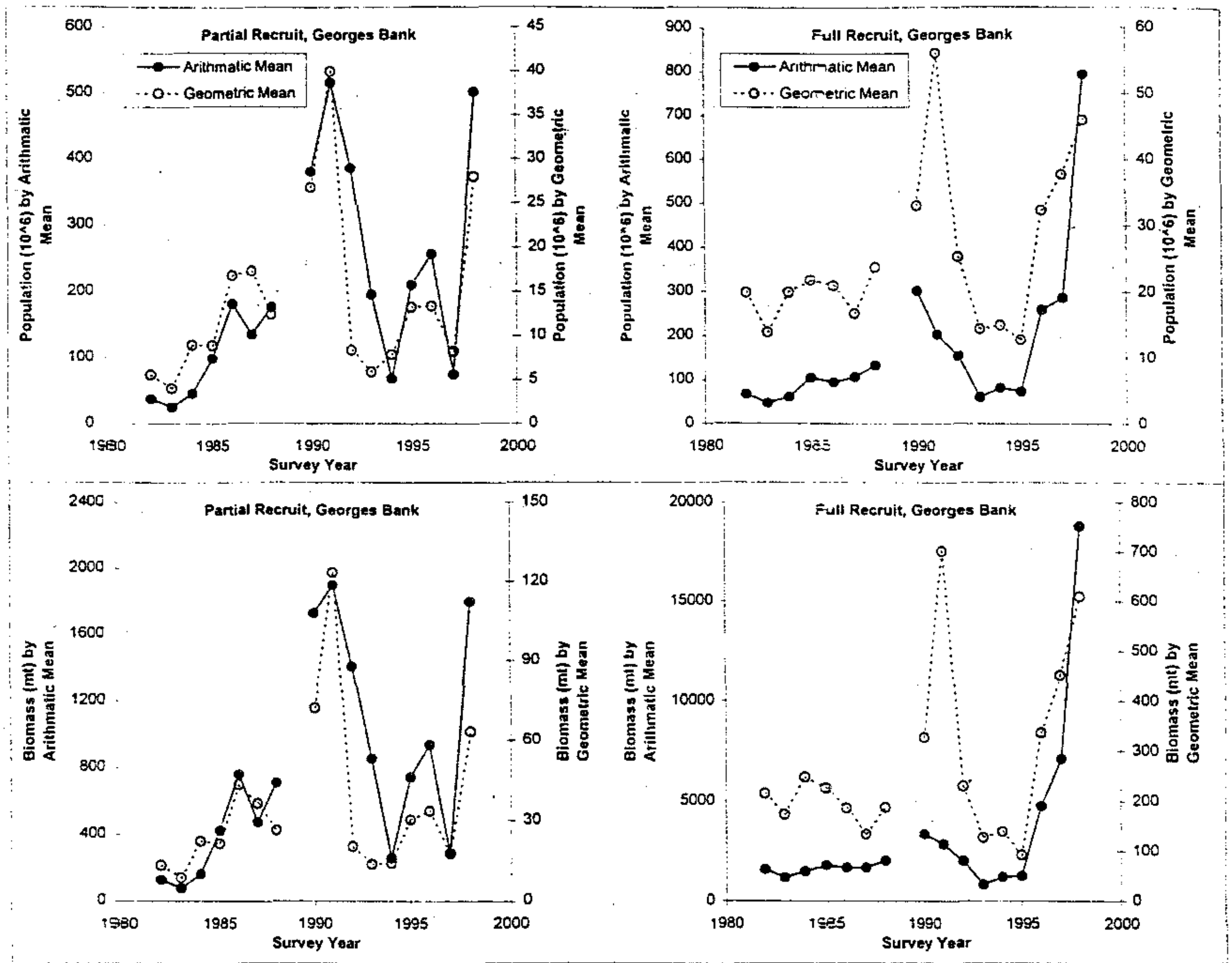



Figure B12. Comparison of swept area estimated population size and biomass for partial and full recruits from NEFSC surveys in Georges Bank

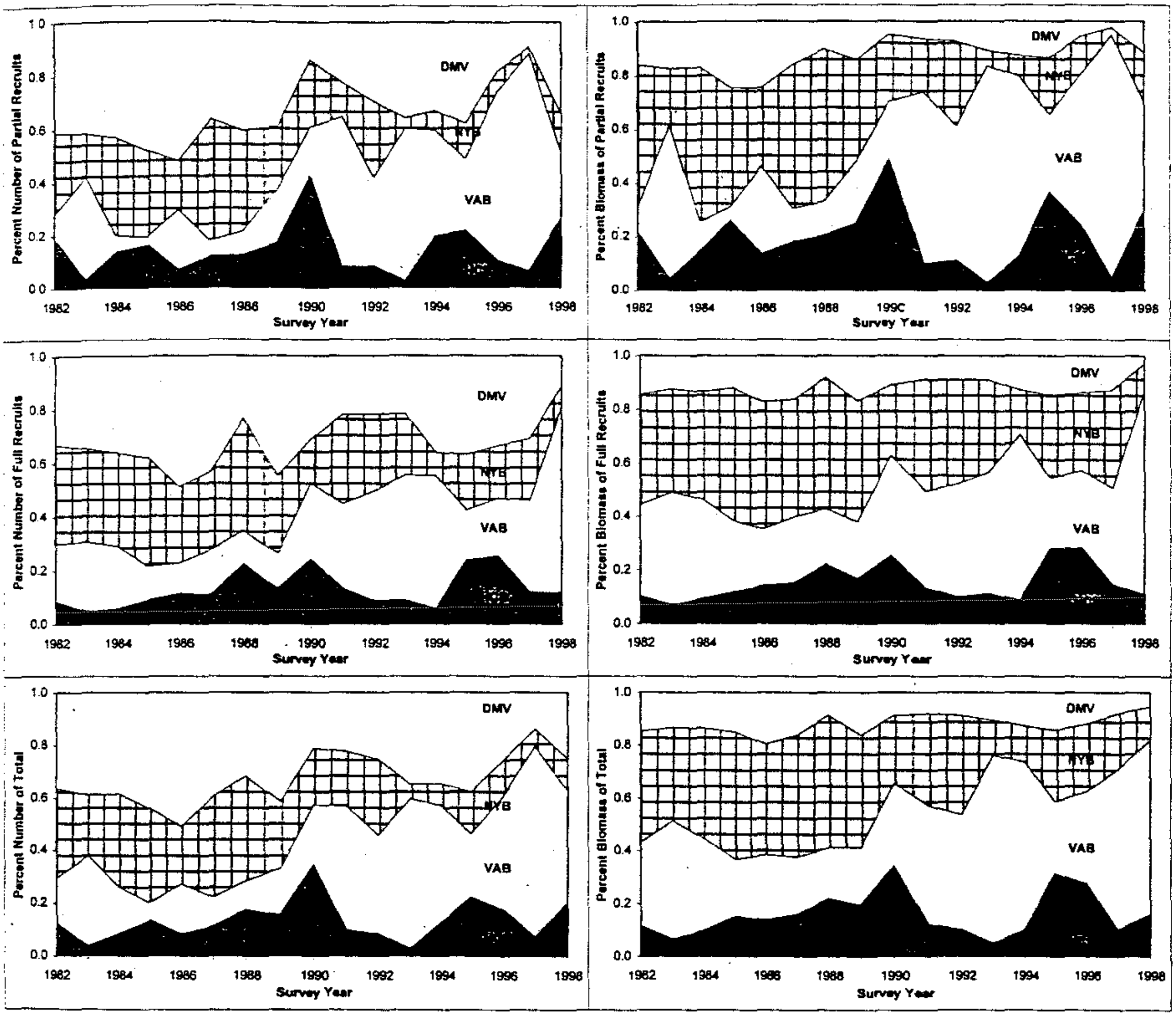



Figure B13. Percent distribution of population size and biomass for Partial recruits, and total for six resource areas in Mid-Atlantic Region. HCS: Hudson Canyon S. Closure; VAB: Virginia Beach Closure; NYB: New York Bight open Area; DMV: DELMARVA open area.

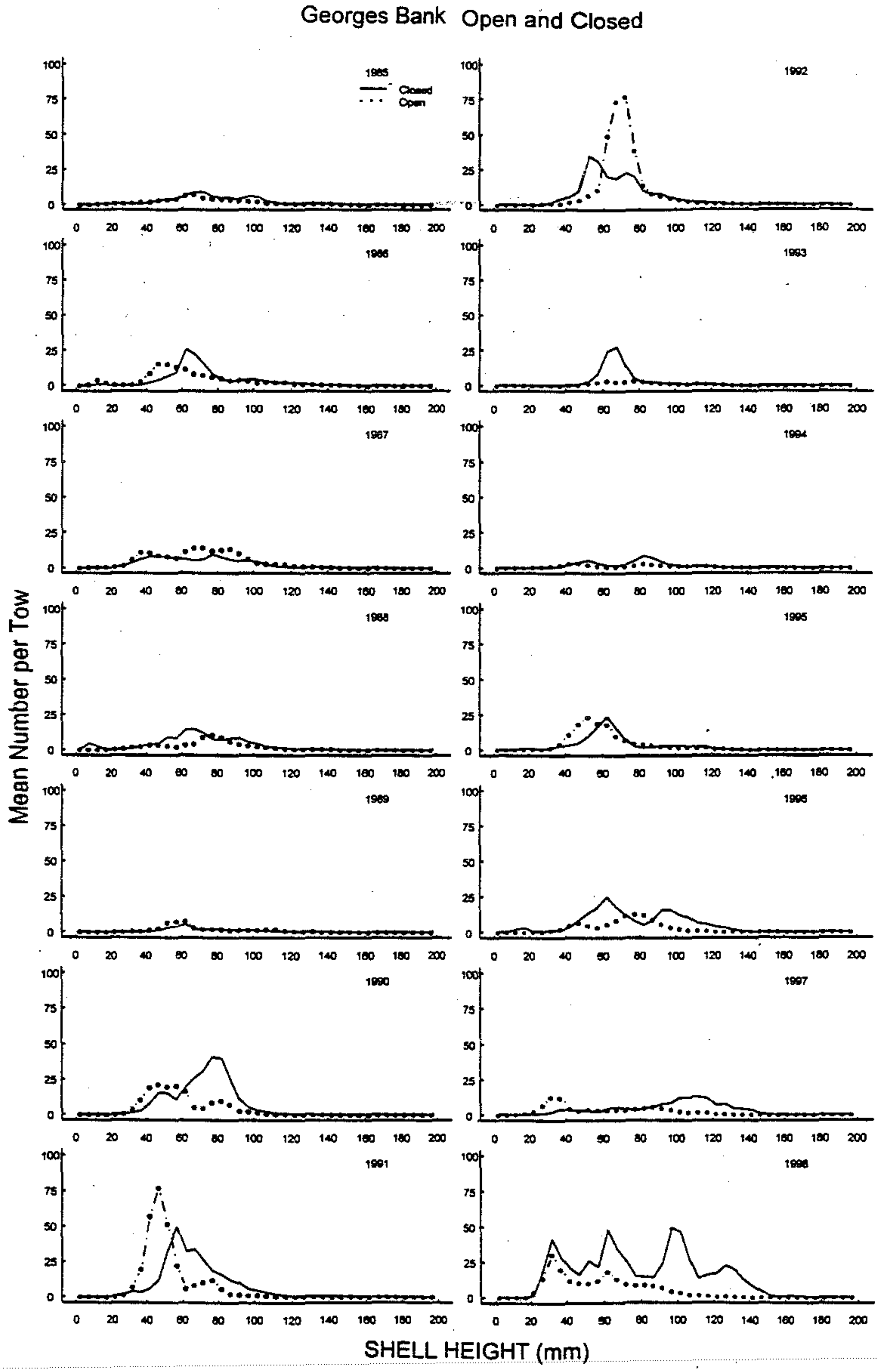



Figure B14. Shell height distributions in Georges Bank Open and Closed Areas, 1985-98. Selectivity of survey dredge was not applied to scallops < 42 mm.

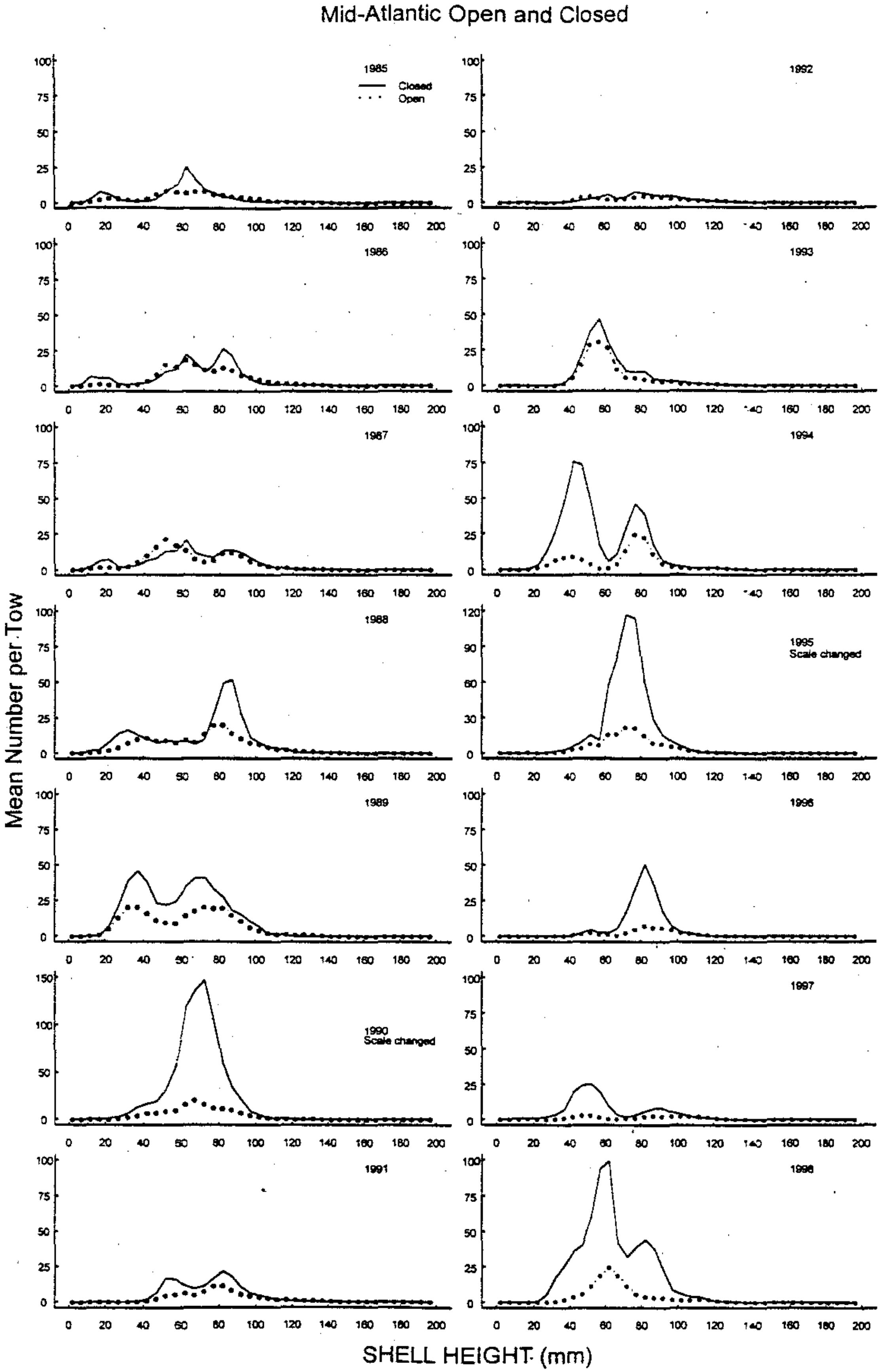



Figure B15. Shell height distributions in Mid-Atlantic Open and Closed Areas, 1985-98. Selectivity of survey dredge was not applied to scallops < 42 mm.

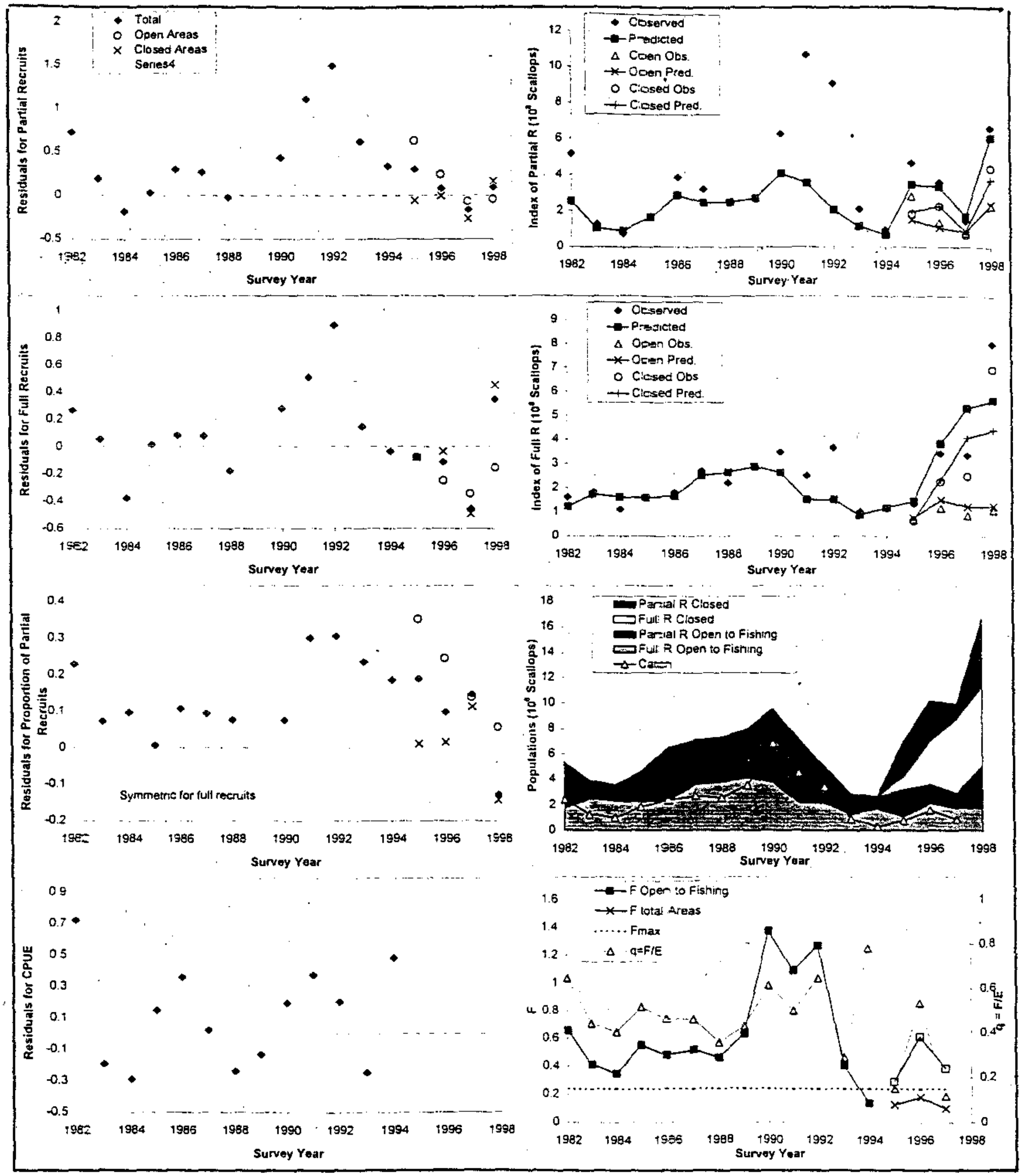



Figure B16. Results of basic run from the two stage stock assessment model in Georges Bank region.

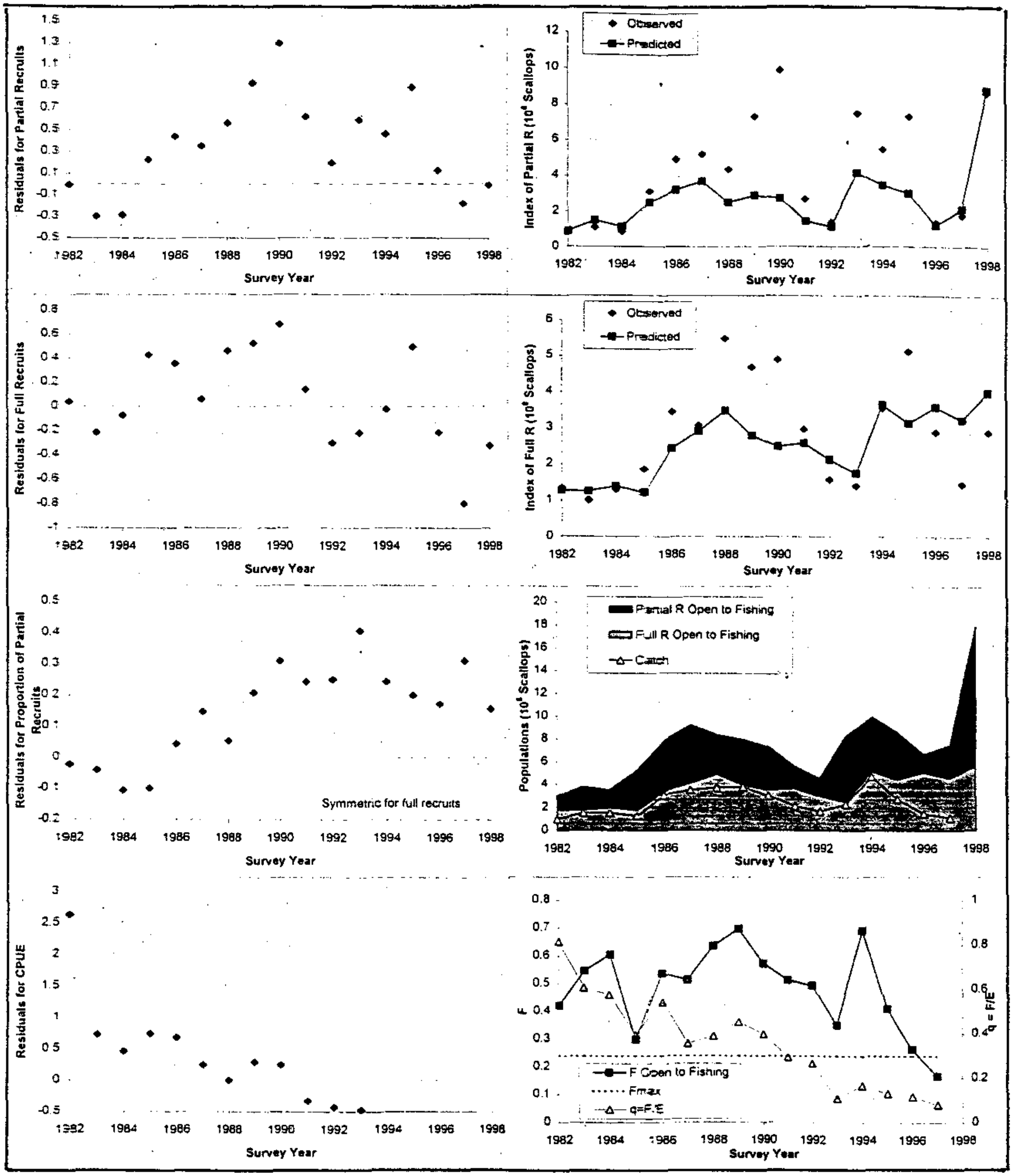



Figure B17. Results of basic run from the two stage stock assessment model in MID-ATLANTIC region.

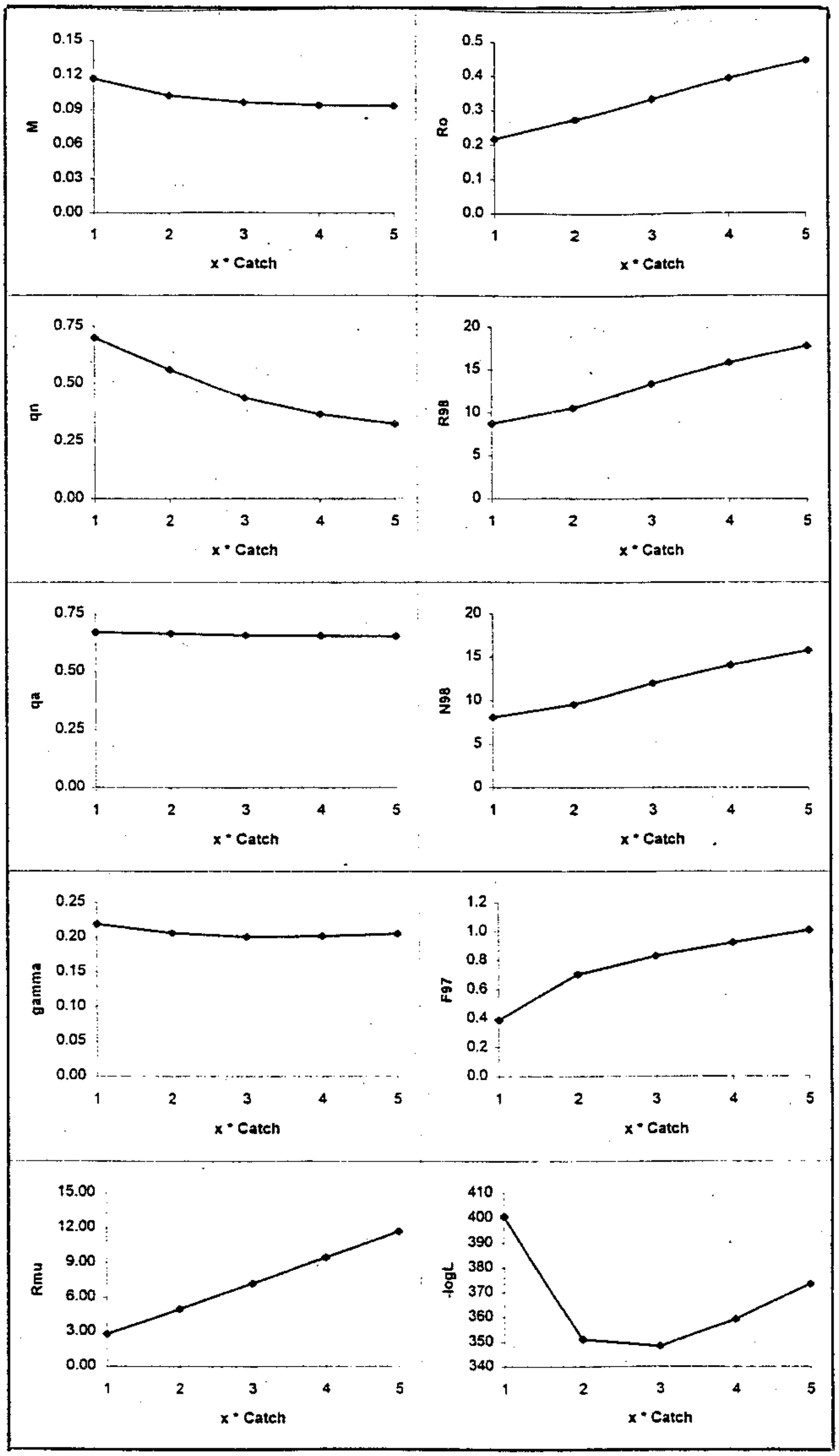



Figure B18. The estimated parameters for various hypothetic under-reporting catch levels in Georges Bank region.

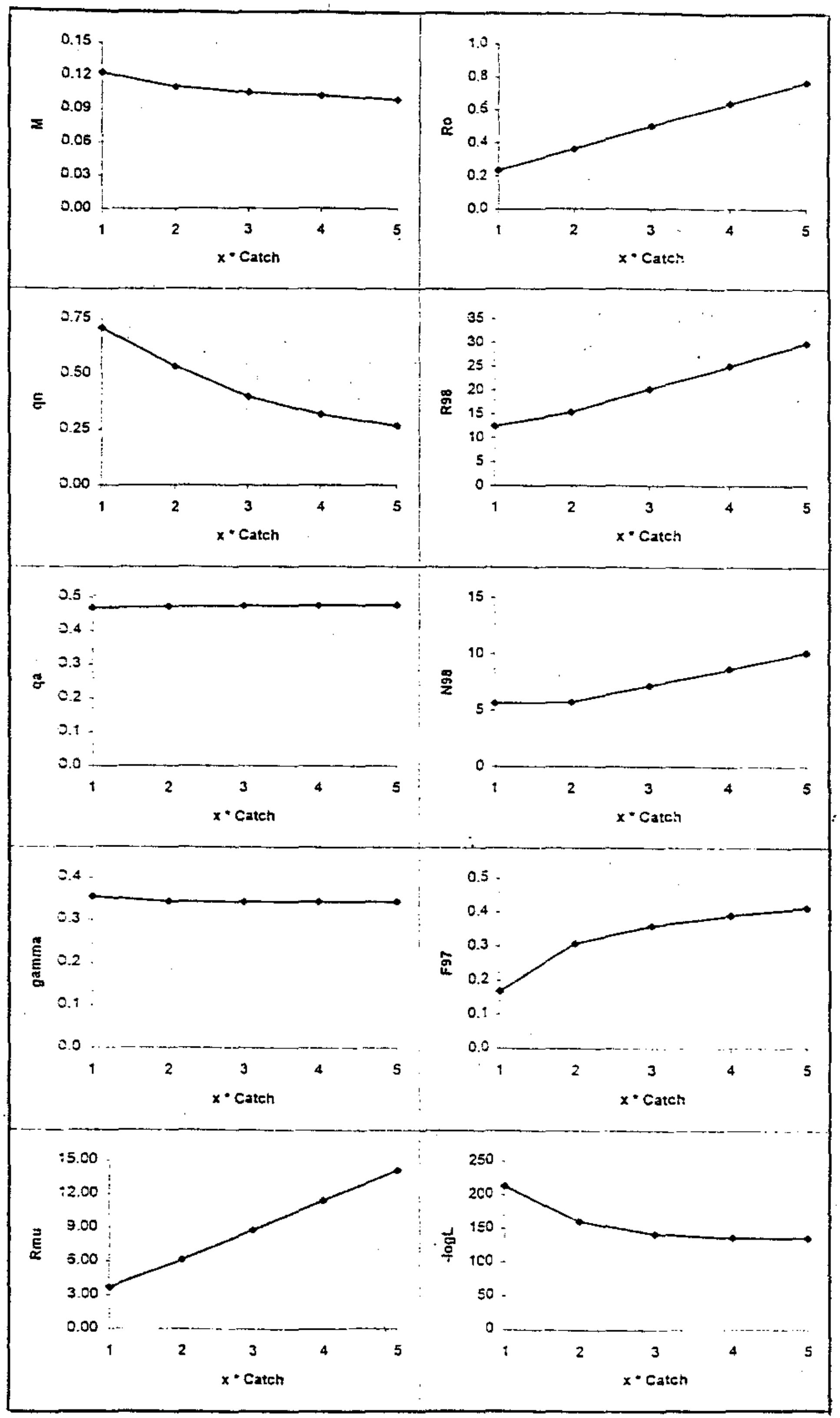



Figure B19. The estimated parameters for various hypothetic under-reporting catch levels in the Mid-Atlantic region.

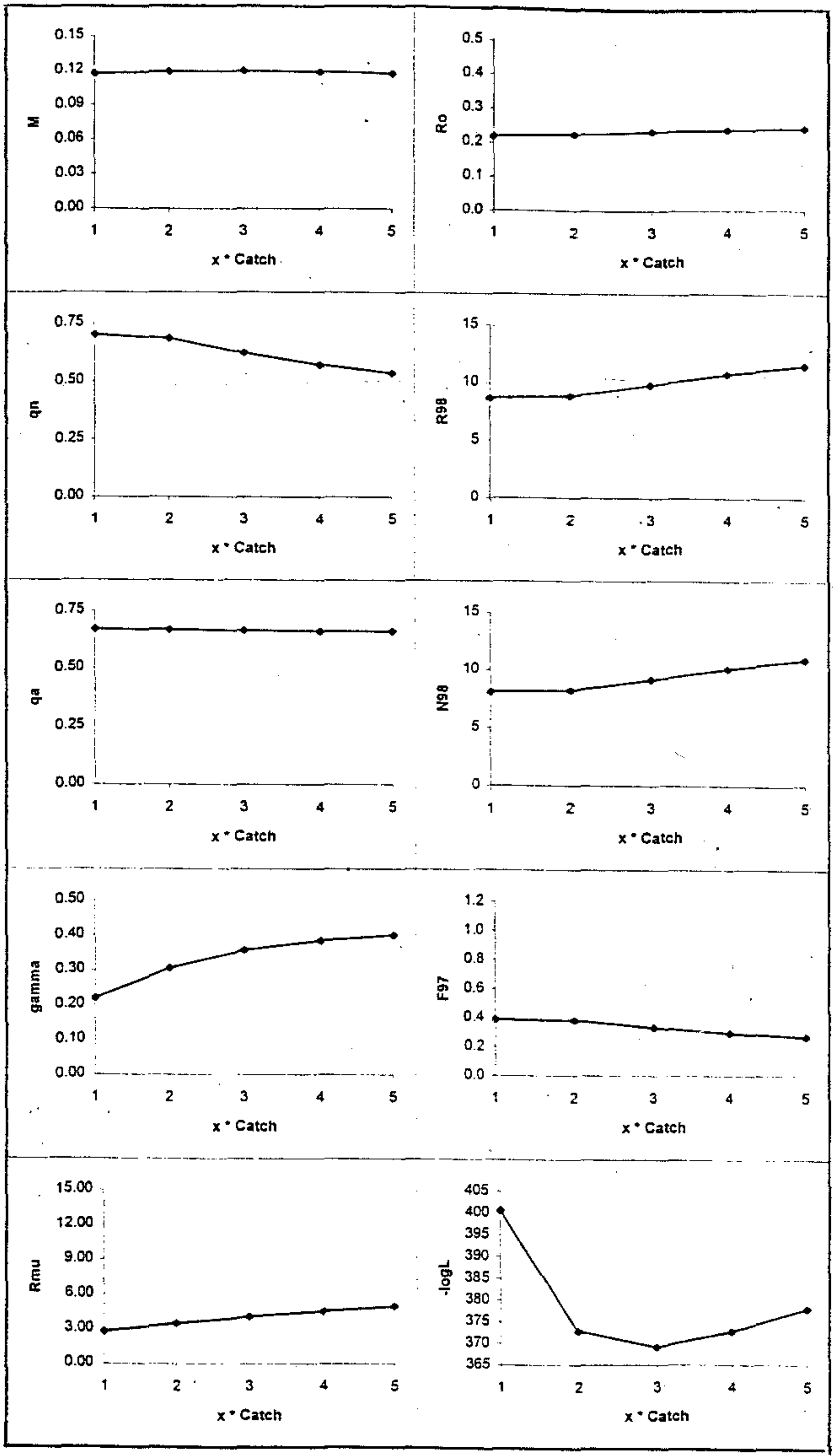
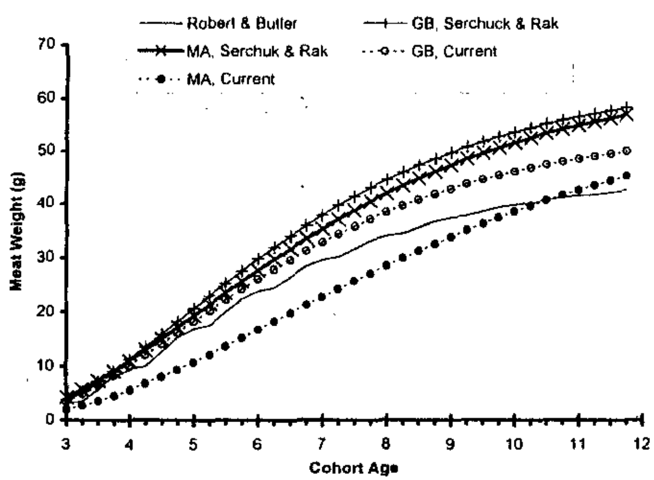
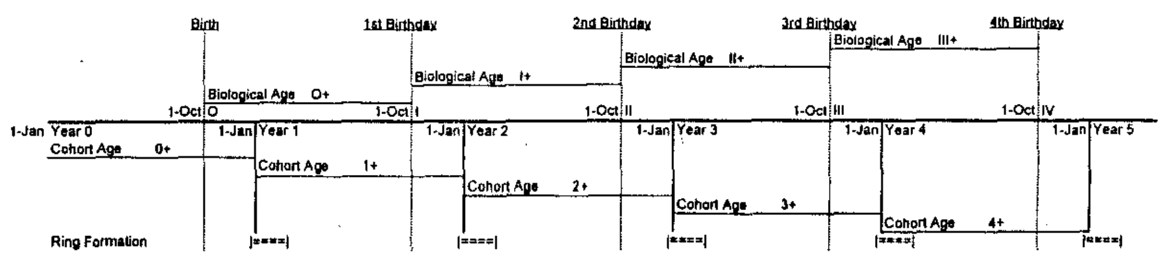



Figure B20. The estimated parameters for various hypothetic under-reporting catch levels in 1990-92, Georges Bank region.

Meat weight at cohort age




Cohort age and biological age, based on hypothetic birthday of Oct. 1.




Meat weight (g) at cohort age from three studies.

| Cohort Age | Robert Butler | Serchuk and Rak GB | Serchuk and Rak MA | Current GB | Current MA |
|---|---|---|---|---|---|
| 3 | 3.11 | 3.71 | 4.19 | 3.46 | 1.96 |
| 3.25 | 3.44 | 5.29 | 5.65 | 4.88 | 2.70 |
| 3.5 | 5.73 | 7.10 | 7.28 | 6.49 | 3.57 |
| 3.75 | 8.03 | 9.10 | 9.06 | 8.25 | 4.55 |
| 4 | 9.34 | 11.24 | 10.96 | 10.13 | 5.64 |
| 4.25 | 10.00 | 13.50 | 12.96 | 12.10 | 6.82 |
| 4.5 | 12.64 | 15.84 | 15.03 | 14.13 | 8.08 |
| 4.75 | 15.29 | 18.21 | 17.14 | 16.18 | 9.41 |
| 5 | 16.80 | 20.60 | 19.28 | 18.23 | 10.80 |
| 5.25 | 17.55 | 22.98 | 21.42 | 20.26 | 12.23 |
| 5.5 | 19.99 | 25.32 | 23.55 | 22.27 | 13.71 |
| 5.75 | 22.42 | 27.81 | 25.65 | 24.22 | 15.21 |
| 6 | 23.81 | 29.84 | 27.71 | 26.11 | 16.73 |
| 6.25 | 24.50 | 32.00 | 29.73 | 27.94 | 18.26 |
| 6.5 | 26.49 | 34.07 | 31.69 | 29.70 | 19.79 |
| 6.75 | 28.49 | 36.06 | 33.58 | 31.37 | 21.31 |
| 7 | 29.63 | 37.95 | 35.41 | 32.97 | 22.82 |
| 7.25 | 30.20 | 39.75 | 37.17 | 34.48 | 24.31 |
| 7.5 | 31.73 | 41.46 | 38.85 | 35.92 | 25.79 |
| 7.75 | 33.26 | 43.07 | 40.46 | 37.27 | 27.23 |
| 8 | 34.13 | 44.58 | 41.99 | 38.54 | 28.65 |
| 8.25 | 34.57 | 46.01 | 43.45 | 39.73 | 30.03 |
| 8.5 | 35.69 | 47.35 | 44.83 | 40.85 | 31.38 |
| 8.75 | 36.82 | 48.60 | 46.14 | 41.90 | 32.69 |
| 9 | 37.47 | 49.77 | 47.38 | 42.88 | 33.96 |
| 9.25 | 37.79 | 50.86 | 48.55 | 43.80 | 35.19 |
| 9.5 | 38.60 | 51.88 | 49.66 | 44.65 | 36.38 |
| 9.75 | 39.41 | 52.83 | 50.70 | 45.44 | 37.53 |
| 10 | 39.88 | 53.72 | 51.67 | 46.17 | 38.64 |
| 10.25 | 40.11 | 54.54 | 52.59 | 46.86 | 39.71 |
| 10.5 | 40.68 | 55.30 | 53.45 | 47.49 | 40.73 |
| 10.75 | 41.26 | 56.00 | 54.26 | 48.08 | 41.72 |
| 11 | 41.58 | 56.66 | 55.02 | 48.63 | 42.67 |
| 11.25 | 41.75 | 57.27 | 55.73 | 49.13 | 43.57 |
| 11.5 | 42.15 | 57.83 | 56.40 | 49.60 | 44.44 |
| 11.75 | 42.55 | 58.35 | 57.02 | 50.03 | 45.27 |
| Linf (mm) | | 152.46 | 151.84 | 152.46 | 151.84 |
| K | | 0.3374 | 0.2297 | 0.3374 | 0.2297 |
| to | | 1.4544 | 1.1266 | 1.4544 | 1.1256 |
| a | | -11.7656 | -12.1628 | -11.4403 | -12.3405 |
| b | | 3.1693 | 3.2539 | 3.0734 | 3.2754 |
| Winf (g) | | 64.47 | 65.43 | 55.11 | 61.02 |
| M | | 0.1 | 0.1 | 0.1 | 0.1 |

Figure B21. Meat weight at cohort age in Georges Bank and Mid-Atlantic regions from three studies and an illustration of differences between cohort and biological ages with hypothetic birthday of October 1.

## Appendix A. MODEL DESCRIPTION

A two-stage population model was constructed using Bayes' theorem to maximize likelihood of a posterior distribution of parameters given observations of data. The method included a joint sample distribution that was specified by the observed data and state moments given the unobservable true parameters, and a joint prior distribution of certain parameters for which some information were available through additional research and observations outside of the model. The catch data were treated as control variable (Schnute 1994) so that state-space model was implicitly implemented. The analysis also adapted the concepts of error-in-variable (EV) model. However, instead of treating observed data as parameters, they were set to the expected values of state moments. The ratio of variances of any component to a referenced component (abundance indices of partial recruits) was used as the weighting factor so that the weighting factors usually used in the stock assessment modeling have a better statistical basis.

Index

| | |
|---|---|
| $i$ | index for partial recruits (i=1) and full recruits (i=2) |
| $t$ | index for survey year |
| $T$ | number of survey years |
| $k$ | index for residual components |
| $K_k$ | number of items (observations) for the kth residual components |
| $j$ | index for iteration during optimization |
| $m$ | index for prior information |
| $P$ | number of priors |
| $y_c$ | beginning survey year of closures (1995 in Georges Bank region and 1998 in Mid-Atlantic region) |

Data

| | |
|---|---|
| $y$ | vector of data $(=\{n_{i,t}, C_t, u_{i,t}, I_t\})$ |
| $C_t$ | catch in number in survey year $t < T$ |
| $n_{i,t}$ | swept area estimated population for partial and full recruits in survey year t |
| $u_{i,t}$ | proportion of partial and full recruits in survey year t |
| $u_{i,t,o}$ | proportion of partial and full recruits in open areas, survey year t |
| $u_{i,t,c}$ | proportion of partial and full recruits in closed areas, survey year t |
| $I_t$ | cpue in number per day fished for tonclasses 3 and 4 dredge vessels in survey year t |
| ^ | predicted or fitted values from the model |

State moments

| | |
|---|---|
| $N_{i,t}$ | population totals for partial and full recruits in survey year t |
| $N_{i,t,o}$ | population totals for partial and full recruits in open areas, survey year t |
| $N_{i,t,c}$ | population totals for partial and full recruits in closed areas, survey year t |

Parameters

| | |
|---|---|
| $\Theta$ | vector of parameters |
| $F_t$ | instantaneous fishing mortality rate estimated from model |
| $F'_t$ | empirical $F_t$ estimated from swept area abundance indices |
| M | instantaneous natural mortality rate |
| $q_a$ | catchability of commercial fishery |
| $q_n$ | catchability of survey dredge |
| $\overline{R}$ | historical mean of partial recruits |
| $R_o$ | average partial recruit for t < 1 |
| $\gamma$ | coefficient of autoregressive recruitment |
| $\xi, \delta, \eta, \tau$ | deviations of observation from model prediction |
| $\sigma_k^2$ | variances of the kth residual component |
| $\sigma^2$ | $= \sum_k \sigma_k^2$ |
| $\alpha_k$ | $= \sigma_k^2 / \sigma_1^2$, ratio of variances |
| $SS_k$ | sum of squares for the kth residual component |
| $\mu_M, \sigma_M^2$ | mean and variance of M prior |
| $\mu_{qn}, \sigma_{qn}^2$ | mean and variance of $q_n$ prior |
| $\mu_{qa}, \sigma_{qa}^2$ | mean and variance of $q_a$ prior |
| $\mu_\gamma, \sigma_\gamma^2$ | mean and variance of $\gamma$ prior |
| $x_p$ | given values of the pth prior |

*Model Specifications*

The population of sea scallops was categorized into two segments, partal (i = 1) and full (i = 2) recruits, using the methods described in SURVEYS section. The basic equation for the model is (M.4), which specified the transition of population from current time step into the next, subject to natural (M) and fishing mortality ($F_t$) rates.

Partial recruits ($N_{1,t}$) was assumed to follow the first-order lognormal autoregressive process (Schnute and Richards 1995) as described in (M.3). The random errors derived from this process (E.1 and E.2) were normally distributed as in (F.7). The variance of logged partial recruits was

$$Var[\log(N_{1,t})] = \sigma_7^2 / (1 - \gamma^2).$$

Because of closure closures that interrupted the continuity of time series of recruitment, this autoregressive recruitment process was carried out up to 1995 for Georges Bank region and up to 1998 in Mid-Atlantic region. Although it is possible to apply a separate autoregressive recruitment in the open and closed areas after the year of $y_c$, however, the precision and accuracy might be low due to short history of time series after $y_c$.

An initial state (t = 1, survey year 1982) was required to start the population dynamics. It required an additional parameters $R_o$, the partial recruits in 1981 or t = 0 to initialize autoregressive recruitment. Following the conventional wisdom, the model assumed on a steady-state partial recruits prior to initial state (i.e., $N_{1,t} = R_o$, for t = 0, -1, ..., -z). the population of full recruits was assumed to be dependent. The full recruits at t = 1 were computed by (M.2), which was the approximation of

$$N_{2,1} = \sum_{i=1}^{z} R_o \exp(-iM) + N_{2,m}\exp(-zM), \text{ for } z \to \infty.$$

After specifying the recruitment process and initial states, the population of full recruits ($N_{2,t}$) of the subsequent states (t > 1) was calculated by the state transition equation (M.4). The equation (M.4) was processed to 1995, the year that closure took full effect, in Georges Bank region and to 1998 in Mid-Atlantic region.

In the year of $y_c$, the populations of partial and full recruits, respectively, were partitioned into closed and open areas according to the observed fractions of partial and full recruits obtained from survey indices (M.6 and M7). After the year of $y_c$, $N_{1,t,o}$ and $N_{1,t,c}$ were estimated parameters. The full recruits in open and closed areas, $N_{2,t,o}$ and $N_{2,t,c}$, were calculated by using (M.4). The populations of partial and full recruits ($N_{1,t}$ and $N_{2,t}$) were the sums of $N_{2,t,o}$ and $N_{2,t,c}$ and of $N_{1,t,o}$ and $N_{1,t,c}$.

Compositions of population (M.5, M.11, and M.12) were important characteristics of an exploited population. Incorporating composition into model would help to (i) constrain unexpected deviation of estimated population size, and (ii) related measurement error to sampling effort. However, traditional variance derived from sampling theory, which may be based on binomial distribution or large sample approximation, may not be realistic. A lognormal bivariate logistic distribution (Schnute and Richards 1995) was adopted (E.8, E.9, and E.10).

The observed data ($n_{i,t}$, $u_{i,t}$, and $I_t$) were related to the state moments, defined by Equations (M.13) to (M.20) with the error structures listed in (E.3) to (E.10) and (F.1) to (F.6). These equations specified the stochastic properties of measurement errors for the observations in terms of their expected population sizes.

$$E(n_{i,t} \mid N_{i,t}, \Theta) = q_n N_{i,t}$$
$$E(I_t \mid N_{i,t}, \Theta) = q_a N_{i,t}$$
$$E(u_{i,t} \mid N_{i,t}, \Theta) = N_{i,t} \Big/ \sum_i N_{i,t}$$

The measurement errors for survey indices and cpue were lognormally distributed (F.1) to (F.8) and that for $u_{i,t}$ were logistically bivariate distributed (F.9) to (F.11). Because swept area estimates were used in the model, $q_n$ was equivalent to gear efficient, proportion of animals within the dredge path would be caught and landed.

*Estimation*

With the error structures specified in (F.1) to (F.11), the joint likelihood function of all of the components was given in (L.2), on which usual maximum likelihood estimation (MLE) was based. Although errors within and between components were assumed to be independent in (L.2), correlated errors can be incorporated through covariance matrix. In addition to more complicated mathematics, parameter estimation would be more labor and uncertain, especially without some information *a priori*. The likelihood given in (L.2) represented the probability density function of data observed (sample distribution) from a stock whose underlying parameters were $\Theta$ (listed in M.1), that is, $p(y|\Theta)$.

It is well known that if all of the variances ($\sigma_k^2$) were unknown, unbiased estimates of parameters were unattainable. The general theory of EV was adopted to overcome this difficulty by specifying ratio of variances ($\alpha_k$) and redistributed total variance ($\sigma^2$) into $\sigma_k^2$ as described in (L.4) and (L.5). Substitute (L.5) into (L.3) to yield (L.6) by incorporating EV theory. The parameter $\sigma^2$ could be calculated by taking the first derivative of (L.6), setting the derivative equal to zero, and solving for $\sigma^2$ within each iteration of optimization (L.7). The quantity of $\alpha/\alpha_k$ has the same meaning as a weighting factor but with a better statistical interpretation.

Application of Bayes' theorem (L.12) is an effective way to incorporate the sample distribution (L.2) and prior information of the stock into parameter estimation. The prior information might come from other independent research or anecdotal information, especially for the domains of various parameters. With the specification of a prior density function $p(\Theta)$, some parameters (such as M), which was thought inestimable, will become estimable up to some degree of precision.

The lognormal prior density function (F.13) was assigned to the natural mortality rate. Merrill and Posgay (1964) estimated that M = 0.1 which has been applied to sea scallop resources in U.S. and Canada EEZ. The confidence of this estimate was unknown, therefore, 100% cv was assigned to its logged mean. The parameter $q_n$ described efficiency of the survey dredge. The prior information of $q_n$ was obtained by comparing the results of NEFSC research survey and the results of depletion experiments by commercial vessels using dredge operated in the Closed Area 2, 1998. The variance of expected $q_n$ reflected a 30% cv for the Georges Bank region. It was increased to 100% for the Mid-Atlantic region to reflect increased uncertainty with respect to efficiency in that area.

The prior information of $q_a$ was obtained from relationships between commercial cpue and a survey index of full recruits by using a regression line passes through origin. In the Georges Bank region, the deviations of observations from the relationship appeared to be random (Fig. 16). There was a time dependent trend in Mid-Atlantic region. Also, there was uncertainty in the calculation of cpue. Instead of trying to manipulate the variance of the prior, a large ratio of variance was assigned to this component. The prior information for $\gamma$ was derived from linear regression of $\log(n_{1,t+1})$ against $\log(n_{1,t})$ shown in Fig. 17. Similar to that of $q_n$, a large ratio of variances was assigned to this component instead of manipulating the variance of the prior.

Fishing mortality rates ($F_t$) were calculated by solving Baranov catch equation numerically with the observed catch and the current values of partial and full recruits within iteration of optimization. The observed catch is treated as a constant without associated random error. The fishing mortality rate $F_t$ is calculated by solving the catch equation. This iterative procedure prevented the population estimates from becoming non-positive. Nonetheless, size of full recruits might become a small positive number and a penalty was added to prevent it from occurring.

Catchability of commercial dredges was usually expressed by $F_t = q_a E_t$, where $q_a$ was a constant catchability of commercial dredges. Fishing effort ($E_t$) was derived from catch and cpue as $E_t = C_t / I_t$. There was tremendous variability in the computation of $C_t$ and $I_t$ that would affect the resultant $E_t$. Also, changes of fishery regulations implied that q could be time variant. Therefore, the effort component was not implemented into the model. Instead, catchability ($q_t$) was calculated outside of estimation.

Using Bayes theorem, the posterior density function $p(\Theta|y)$ is given in (L.13). The likelihood function from this posterior density function is given in (L.14). The maximum likelihood estimation from (L.14) is a maximum posterior likelihood estimation (MPLE). The likelihood profile method (Edward 1992, Venzon and Moolgavkor 1988, Fournier 1998) from the MPLE can be used to construct confidence intervals of the estimated parameters ($M$, $q_n$, $q_a$, $\gamma$, $\bar{R}$, $R_o$, $N_{1,T,o}$, $N_{1,T,c}$) and calculated variables ($N_{1,T}$, $N_{2,T,o}$, $N_{2,T,c}$, $N_{2,T}$, $F_{T-1}$) in the model.

The Markov Chain Monte Carlo (MCMC, Gelman et al. 1995, and Gilks et al. 1996) method is an alternative method for statistical inferences. Under ideal situations, the two methods would yield similar results, however, discrepancies may occur for some parameters (that is, $q_n$ in this model, see Results section). This may indicate that the inferences for this parameter may not be appropriate due to prior or accepted probability of Metropolis-Hastings algorithm for MCMC. Therefore, MPLE was employed.

*Results*

For the Georges Bank region, residuals for partial recruits were positively skewed and large residuals were associated with the large observed indices of partial and full recruits in the period of 1990-1992 but not in 1993. Coincidentally, the R/V Oregon was used in 1990-93 surveys. For the Mid-Atlantic region, residuals for partial recruits were greater than zero from 1985 to 1996, especially during 1988-1990 and 1993-1995 (Fig. B19) implying that the change in survey vessels might be a problem.

To address the uncertainties, extensive sensitivity analyses were presented to the SARC (see below).

(1) *Mixture prior for $q_n$*.-The basic model included the $q_n$-prior from Rago et al. (1999). A supplemental analysis was carried out (Appendix C) that blended prior estimates of $q_n$ from all three sources. Results using mixture priors were almost identical to results from the basic model.

(2) *Under-estimation of landings*.-Scallop catches might be under-estimated due to: (i) un-reported landings, (ii) biased samples (a tendency to sample large scallops in catches) for commercial size composition that resulted into biased estimates of mean meat weight and catch in number, (iii) decreasing average meat weight (lnW-lnH relationships of current study and Serchuk and Rak, 1983), (iv) discards and deck mortality, (v) dredge-encountered or non-landed mortality, and (vi) high discard rate in the years of strong partial recruits. For lack of other information, the entire time series of landings was increased by 2-, 3-, 4- and 5-fold for the two regions.

For the Georges Bank region, increasing catch by 3-fold gave the best model fit (highest log-likelihood, Fig. B20). The estimated $q_n$ was 0.44 for a three-fold increase in catch, which was similar to the estimate ($q_n$=0.41) from Rago et al. (1999). This result may have been due to the prior estimate ($q_n$=0.41) assumed in the model.

In the Mid-Atlantic region, goodness of fit increased as catches were increased but changes in goodness of fit were trivial when catches were increased beyond three-fold (Fig. B21). Once again, the model-estimated $q_n$ = 0.40 at a 3-fold increase of catch was almost identical to Rago et al.'s (1999) depletion study estimate. As described above, this may have been due to the prior estimate ($q_n$=0.41) used in the model.

Under-reporting and non-landing mortality might have been high during 1990-1992 in Georges Bank because partial recruits were very abundant. In another sensitivity analyses, landings for 1990-1992 from the Georges Bank region were increased as described above. Goodness of fit was maximum for a three-fold increase in catch (Fig. B22).

(3) *Assumptions about $q_n$ and $q_r$*.- In the basic model, the fit to indices of full recruits was generally better than that of partial recruits in Georges Bank and Mid-Atlantic regions. These results indicate that a different assumption about relative catchability for partial $q_r$ and full recruits $q_n$ might improve model fit. In 1990-1992, the R/V Oregon replaced the R/V Albatross in the research survey and residuals were large, suggesting that catchability assumptions might depend on vessels used in the surveys. Three different assumptions on $q_n$ and $q_r$ were carried out to address these possibilities. However, the questions about the magnitude of estimated catchability coefficients were not resolved because estimates of $q_r$ were always greater than one.

| State Dynamics | | Time domain | Georges Bank region | Mid-Atlantic region |
|---|---|---|---|---|
| M.1 | Parameters | | $\Theta = (M, \gamma, q_a, q_n, \bar{R}, R_o, \sigma^2, \{N_{1,t} \mid 1 \leq t < y_c\}, \{N_{1,t,o}, N_{1,t,c} \mid t \geq y_c\})$ | $\Theta = (M, \gamma, q_a, q_n, \bar{R}, R_o, \sigma^2, \{N_{1,t} \mid 1 \leq t < T\})$ |
| M.2 | Initial State | $t = 1$ | $N_{2,1} = R_o \exp(-M) / [1-\exp(-M)]$ | $N_{2,1} = R_o \exp(-M) / [1-\exp(-M)]$ |
| M.3 | Recruitment | $1 \leq t \leq y_c$ | $\log(N_{1,t}) = \log(\bar{R}) + \gamma[\log(N_{1,t-1}) - \log(\bar{R})]$ | $\log(N_{1,t}) = \log(\bar{R}) + \gamma[\log(N_{1,t-1}) - \log(\bar{R})]$ |
| M.4 | State (t>1) | $1 < t \leq y_c$ | $N_{2,t} = (N_{1,t-1} + N_{2,t-1})\exp(-M - F_{t-1})$ | $N_{2,t} = (N_{1,t-1} + N_{2,t-1})\exp(-M - F_{t-1})$ |
| M.5 | | $1 < t \leq y_c$ | $u_{i,t} = n_{i,t} / (n_{1,t} + n_{2,t})$ | $u_{i,t} = n_{i,t} / (n_{1,t} + n_{2,t})$ |
| M.6 | | $t = y_c$ | $N_{i,t,o} = N_{i,t}\, n_{i,t,o} / (n_{1,t,o} + n_{2,t,c})$ | None |
| M.7 | | $t = y_c$ | $N_{i,t,c} = N_{i,t}\, n_{i,t,c} / (n_{1,t,o} + n_{2,t,c})$ | None |
| M.8 | | $t > y_c$ | $N_{i,t} = N_{i,t,o} + N_{i,t,c}$ | None |
| M.9 | | $t > y_c$ | $N_{2,t,o} = (N_{1,t-1,o} + N_{2,t-1,o})\exp(-M - F_{t-1})$ | None |
| M.10 | | $t > y_c$ | $N_{2,t,c} = (N_{1,t-1,c} + N_{2,t-1,c})\exp(-M)$ | None |
| M.11 | | $t > y_c$ | $u_{i,t,o} = n_{i,t,o} / (n_{1,t,o} + n_{2,t,o})$ | None |
| M.12 | | $t > y_c$ | $u_{i,t,c} = n_{i,t,c} / (n_{1,t,c} + n_{2,t,c})$ | None |
| M.13 | Observations | $1 \leq t \leq y_c$, $t \leq 94$ | $\hat{I}_t = q_a N_{2,t}$ | $\hat{I}_t = q_a N_{2,t}$ |
| M.14 | | $t \geq y_c$, $t \leq 94$ | $\hat{I}_t = q_a N_{2,t,o}$, NOT USED | None |
| M.15 | | $1 \leq t < y_c$ | $\hat{n}_{i,t} = q_n N_{i,t}$ | $\hat{n}_{i,t} = q_n N_{i,t}$ |
| M.16 | | $t \geq y_c$ | $\hat{n}_{i,t,o} = q_n N_{i,t,o}$ | None |
| M.17 | | $t \geq y_c$ | $\hat{n}_{i,t,c} = q_n N_{i,t,c}$ | None |
| M.18 | | $1 \leq t \leq y_c$ | $\hat{u}_{i,t} = u_{i,t}$ | $\hat{u}_{i,t} = u_{i,t}$ |
| M.19 | | $t > y_c$ | $\hat{u}_{i,t,o} = u_{i,t,o}$ | None |
| M.20 | | $t > y_c$ | $\hat{u}_{i,t,c} = u_{i,t,c}$ | None |

| Residuals | | Time domain | Georges Bank region | Mid-Atlantic region |
|---|---|---|---|---|
| E.1 | Initial State | $t = 1$ | None | None |
| E.2 | States ($t > 1$) | $1 < t \le y_c$ | $\xi_t = \log(N_{1,t}) - \log(\overline{R}) - \gamma[\log(N_{1,t-1}) - \log(\overline{R})]$ | $\xi_t = \log(N_{1,t}) - \log(\overline{R}) - \gamma[\log(N_{1,t-1}) - \log(\overline{R})]$ |
| E.3 | Estimated Observations | $1 \le t < y_c$, $t \le 94$ | $\delta_t = \log(I_t) - \log(\hat{I}_t)$ | $\delta_t = \log(I_t) - \log(\hat{I}_t)$ |
| E.4 | | $t \ge y_c$, $t \le 94$ | $\delta_t = \log(I_{t,o}) - \log(\hat{I}_{t,o})$, NOT USED | None |
| E.5 | | $1 \le t \le y_c$ | $\eta_{i,t} = \log(n_{i,t}) - \log(\hat{n}_{i,t})$ | $\eta_{i,t} = \log(n_{i,t}) - \log(\hat{n}_{i,t})$ |
| E.6 | | $t \ge y_c$ | $\eta_{i,t,o} = \log(n_{i,t,o}) - \log(\hat{n}_{i,t,o})$ | None |
| E.7 | | $t \ge y_c$ | $\eta_{i,t,c} = \log(n_{i,t,c}) - \log(\hat{n}_{i,t,c})$ | None |
| E.8 | | $1 \le t \le y_c$ | $\tau_{i,t} = \log(u_{i,t}) - \log(\hat{u}_{i,t}) - 0.5\sum[\log(u_{i,t}) - \log(\hat{u}_{i,t})]$ | $\tau_{i,t} = \log(u_{i,t}) - \log(\hat{u}_{i,t}) - 0.5\sum[\log(u_{i,t}) - \log(\hat{u}_{i,t})]$ |
| E.9 | | $t \ge y_c$ | $\tau_{i,t,o} = \log(u_{i,t,o}) - \log(\hat{u}_{i,t,o}) - 0.5\sum[\log(u_{i,t,o}) - \log(\hat{u}_{i,t,o})]$ | None |
| E.10 | | $t \ge y_c$ | $\tau_{i,t,c} = \log(u_{i,t,c}) - \log(\hat{u}_{i,t,c}) - 0.5\sum[\log(u_{i,t,c}) - \log(\hat{u}_{i,t,c})]$ | None |

| Density Function | | Time domain | Georges Bank region | $\alpha_k$ | Mid-Atlantic region | $\alpha_k$ |
|---|---|---|---|---|---|---|
| F.1 | Residuals | $1 \leq t \leq y_c$ | $\eta_{1,t} \sim N(0,\sigma_1^2)$ | 1 | $\eta_{1,t} \sim N(0,\sigma_1^2)$ | 1 |
| F.2 | | $t \geq y_c$ | $\eta_{1,t,o} \sim N(0,\sigma_2^2)$ | 1 | None | None |
| F.3 | | $t \geq y_c$ | $\eta_{1,t,c} \sim N(0,\sigma_3^2)$ | 1 | None | None |
| F.4 | | $1 \leq t \leq y_c$ | $\eta_{2,t} \sim N(0,\sigma_4^2)$ | 1 | $\eta_{2,t} \sim N(0,\sigma_4^2)$ | 1 |
| F.5 | | $t \geq y_c$ | $\eta_{2,t,o} \sim N(0,\sigma_5^2)$ | 1 | None | None |
| F.6 | | $t \geq y_c$ | $\eta_{2,t,c} \sim N(0,\sigma_6^2)$ | 1 | None | None |
| F.7 | | $1 \leq t \leq y_c$ | $\xi_t \sim N(0,\sigma_7^2)$ | 10 | $\xi_t \sim N(0,\sigma_7^2)$ | 10 |
| F.8 | | $1 \leq t \leq T$ | $\delta_t \sim N(0,\sigma_8^2)$ | 2 | $\delta_t \sim N(0,\sigma_8^2)$ | 2 |
| F.9 | | $1 \leq t \leq y_c$ | $\tau_{2,t} \sim N(0,\sigma_9^2)$ | 1 | $\tau_{2,t} \sim N(0,\sigma_9^2)$ | 1 |
| F.10 | | $t \geq y_c$ | $\tau_{2,t,o} \sim N(0,\sigma_{10}^2)$ | 1 | None | None |
| F.11 | | $t \geq y_c$ | $\tau_{2,t,c} \sim N(0,\sigma_{11}^2)$ | 1 | None | None |
| F.12 | Priors | | $M \sim LogN(\mu_M = 0.1, \sigma_M^2 = 0.01)$ | | $M \sim LogN(\mu_M = 0.1, \sigma_M^2 = 0.01)$ | |
| F.13 | | | $q_n \sim N(\mu_{q_n} = 0.4087, \sigma_{qn}^2 = 0.014884)$ | | $q_n \sim N(\mu_{q_n} = 0.4087,\ \sigma_{qn}^2 0.014884)$ | |
| F.14 | | | $q_a \sim N(\mu_{qa} = 0.6743, \sigma_{qa}^2 = 0.009815)$ | | $q_a \sim N(\mu_{qa} = 0.4725, \sigma_{qa}^2 = 0.004444)$ | |
| F.15 | | | $\gamma \sim N(\mu_\gamma = 0.2838, \sigma_\gamma^2 = 0.05579)$ | | $\gamma \sim N(\mu_\gamma = 0.3573, \sigma_\gamma^2 = 0.05712)$ | |

| Likelihood | | Georges Bank region | Mid-Atlantic region |
|---|---|---|---|
| L.1 | Likelihood $k = 1, 2, \ldots, 11$ | $L_k = \left(\frac{1}{\sqrt{2\pi\sigma_k^2}}\right)^{K_k} \exp\left(-\frac{SS_k}{2\sigma_k^2}\right)$ | $L_k = \left(\frac{1}{\sqrt{2\pi\sigma_k^2}}\right)^{K_k} \exp\left(-\frac{SS_k}{2\sigma_k^2}\right)$ |
| L.2 | Joint Likelihood | $L = \prod_{k=1}^{11} L_k = \prod_{k=1}^{11}\left(\frac{1}{\sqrt{2\pi\sigma_k^2}}\right)^{K_i} \exp\left(-\frac{SS_k}{2\sigma_k^2}\right)$ | $L = \prod_{k=1}^{11} L_k = \prod_{k=1}^{11}\left(\frac{1}{\sqrt{2\pi\sigma_k^2}}\right)^{K_i} \exp\left(-\frac{SS_k}{2\sigma_k^2}\right)$ |
| L.3 | -log L | $-\log L = 0.5\left[\left(\sum_{k=1}^{11} K_k\right)\log(2\pi) + \sum_{k=1}^{11} K_k \log(\sigma_k^2) + \sum_{k=1}^{11}\frac{SS_k}{\sigma_k^2}\right]$ | $-\log L = 0.5\left[\left(\sum_{k=1}^{11} K_k\right)\log(2\pi) + \sum_{k=1}^{11} K_k \log(\sigma_k^2) + \sum_{k=1}^{11}\frac{SS_k}{\sigma_k^2}\right]$ |
| L.4 | EVM $k = 1, 2, \ldots, 11$ | $\alpha_k = \sigma_k^2/\sigma_1^2;\ \alpha = \sum \alpha_k;\ \sigma^2 = \sum \sigma_k^2$ | $\alpha_k = \sigma_k^2/\sigma_1^2;\ \alpha = \sum \alpha_k;\ \sigma^2 = \sum \sigma_k^2$ |
| L.5 | | $\sigma_k^2 = \sigma^2(\alpha_k/\alpha)$ | $\sigma_k^2 = \sigma^2(\alpha_k/\alpha)$ |
| L.6 | Apply EVM to -logL | $-\log L = 0.5\left\{\left(\sum_{k=1}^{11} K_k\right)\ln(2\pi) + \sum_{k=1}^{11}\left[K_k \ln\left(\frac{\alpha_k}{\alpha}\right)\right] + \left(\sum_{k=1}^{11} K_k\right)\ln\left(\sigma^2\right) + \frac{1}{\sigma^2}\sum_{k=1}^{11}\left(\frac{\alpha}{\alpha_k}\right)SS_k\right\}$ | $-\log L = 0.5\left\{\left(\sum_{k=1}^{11} K_k\right)\ln(2\pi) + \sum_{k=1}^{11}\left[K_k \ln\left(\frac{\alpha_k}{\alpha}\right)\right] + \left(\sum_{k=1}^{11} K_k\right)\ln\left(\sigma^2\right) + \frac{1}{\sigma^2}\sum_{k=1}^{11}\left(\frac{\alpha}{\alpha_k}\right)SS_k\right\}$ |
| L.7 | Iterative estimate of $\sigma^2$ | $\sigma^{2(j)} = \sum_k SS_k^{(j)}(\alpha/\alpha_k) \Big/ \sum_k K_k$ | $\sigma^{2(j)} = \sum_k SS_k^{(j)}(\alpha/\alpha_k) \Big/ \sum_k K_k$ |
| L.8 | M prior | $p(M) = \left(\frac{1}{\sqrt{2\pi\sigma_M^2}}\right)\exp\left(-\frac{(\log M - \log \mu_M)^2}{2\sigma_M^2}\right)$ | $p(M) = \left(\frac{1}{\sqrt{2\pi\sigma_M^2}}\right)\exp\left(-\frac{(\log M - \log \mu_M)^2}{2\sigma_M^2}\right)$ |
| L.9 | $q_n$ prior | $p(q_n) = \left(\frac{1}{\sqrt{2\pi\sigma_{qn}^2}}\right)\exp\left(-\frac{(q_n - \mu_{qn})^2}{2\sigma_{qn}^2}\right)$ | $p(q_n) = \left(\frac{1}{\sqrt{2\pi\sigma_{qn}^2}}\right)\exp\left(-\frac{(q_n - \mu_{qn})^2}{2\sigma_{qn}^2}\right)$ |
| L.10 | $q_a$ prior | $p(q_a) = \left(\frac{1}{\sqrt{2\pi\sigma_{qa}^2}}\right)\exp\left(-\frac{(q_a - \mu_{qa})^2}{2\sigma_{qa}^2}\right)$ | $p(q_a) = \left(\frac{1}{\sqrt{2\pi\sigma_{qa}^2}}\right)\exp\left(-\frac{(q_a - \mu_{qa})^2}{2\sigma_{qa}^2}\right)$ |

| | | | |
|---|---|---|---|
| L.11 | γ prior | $p(\gamma)=\left(\frac{1}{\sqrt{2\pi\sigma_\gamma^2}}\right)\exp\left(-\frac{(\gamma-\mu_\gamma)^2}{2\sigma_\gamma^2}\right)$ | $p(\gamma)=\left(\frac{1}{\sqrt{2\pi\sigma_\gamma^2}}\right)\exp\left(-\frac{(\gamma-\mu_\gamma)^2}{2\sigma_\gamma^2}\right)$ |
| L.12 | P(Θ\|y) | $p(\Theta \mid y)\propto p(\Theta)p(y \mid \Theta)$ | $p(\Theta \mid y)\propto p(\Theta)p(y \mid \Theta)$ |
| L.13 | -log P(Θ\|y) | $-\left[\log p(M)+\log p(q_n)+\log p(q_a)+\log p(\gamma)\right]-\log L$ | $-\left[\log p(M)+\log p(q_n)+\log p(q_a)+\log p(\gamma)\right]-\log L$ |
| L.14 | Objective Function | $-\log L=0.5\left\{P\ln(2\pi)+\sum_{p=1}^{P}\ln(\sigma_p)+\sum_{p=1}^{P}\frac{(x_p-\mu_p)^2}{\sigma_p^2}\right\}+ 0.5\left\{\left(\sum_{k=1}^{11}n_k\right)\ln(2\pi)+\sum_{k=1}^{11}\left[n_k\ln\left(\frac{\alpha_k}{\alpha}\right)\right]+ \left(\sum_{k=1}^{11}n_k\right)\ln\left(\sigma^2\right)+\frac{1}{\sigma^2}\sum_{k=1}^{11}\left(\frac{\alpha}{\alpha_k}\right)SS_k\right\}$ | $-\log L=0.5\left\{P\ln(2\pi)+\sum_{p=1}^{P}\ln(\sigma_p)+\sum_{p=1}^{P}\frac{(x_p-\mu_p)^2}{\sigma_p^2}\right\}+ 0.5\left\{\left(\sum_{k=1}^{11}n_k\right)\ln(2\pi)+\sum_{k=1}^{11}\left[n_k\ln\left(\frac{\alpha_k}{\alpha}\right)\right]+ \left(\sum_{k=1}^{11}n_k\right)\ln\left(\sigma^2\right)+\frac{1}{\sigma^2}\sum_{k=1}^{11}\left(\frac{\alpha}{\alpha_k}\right)SS_k\right\}$ |

## Appendix B: Comparisons of the two stage dynamic model with the modified Delury model

| TWO STAGE DYNAMIC MODEL | DATA | MODIFIED DELURY MODEL |
|---|---|---|
| **Observed Equations**<br>Partial Recruits $n_{1,t} = q_n N_{1,t}$<br>Full Recruits $n_{2,t} = q_n N_{2,t}$<br>Proportion $u_{i,t} = n_{i,t} / (n_{1,t} + n_{2,t})$<br>CPUE $I_t = q_a N_{2,t}$<br><br>**System Equation**<br>$N_{2,t}=(N_{1,t-1}+N_{2,t-1})e^{-M-F_t}$<br>**Assumptions**<br>1. Equilibrium t < 1, average partial recruits, $R_o$ (M.2)<br>2. Autoregressive recruits (M.3)<br>3. In the year of closure, population is divided into two segments, in the open areas and in the closed areas, according to the observed swept area indices from survey. (M.6 and M.7)<br>4. Indices are proportional to population size. (M.13-M.17)<br>5. Random errors are log-normally distributed. (F.1-F.11)<br>**Estimation**<br>Ordinary MLE<br>Likelihood (L.1-L.3)<br>Error-in-Variable: Ratio of variance as weighted factor (L.4-L.7)<br>MPLE, the prefer method<br>Priors for $q_n$, M, $q_a$, γ (F.12-F.15, L.8-L.11)<br>Posterior likelihood (L.14)<br>MCMC<br>**F estimation**<br>Solving F from Baranov catch eq. using Newton-Ralphson algorithm within optimization loop | Partial Recruits $n_{1,t} = q_n N_{1,t}$<br>Full Recruits $n_{2,t} = q_n N_{2,t}$<br>Proportion $u_{i,t} = n_{i,t} / (n_{1,t} + n_{2,t})$<br>CPUE $I_t = q_a N_{2,t}$<br>Catch control variable | **Observed Equations**<br>Partial Recruits $n_{1,t} = q_n N_{1,t}$<br>Full Recruits $n_{2,t} = q_n N_{2,t}$<br><br>**System Equation**<br>$N_{2,t}=(N_{1,t-1}+N_{2,t-1}-C_{t-1})e^{-M}$<br>Substitution the observed equations<br>$n_{2,t} = (n_{2,t-1} + \frac{q_n}{q_r} n_{1,t})e^{-M} - q_n C_{t-1} e^{-M}$<br>**Assumption**<br>$q_r = 1$.<br>**Estimation**<br>Nonlinear least squares (regression)<br>Process error<br>$\varepsilon_t = \log(n_{2,t}) - \log(\hat{n}_{2,t})$<br>Measurement error<br>$\eta_t = \log(n_{2,t}) - \log(q_n N_{2,t})$<br>$\xi_t = \log(n_{2,t}) - \log(q_n N_{1,t})$<br><br>Weighted least squares<br>$SS = \lambda_\varepsilon \sum_{t=2}^{T} \varepsilon_t^2 + \lambda_\eta \sum_{t=1}^{T} \eta_t^2 + \lambda_\xi \sum_{t=1}^{T-1} \xi_t^2$<br>**F estimation**<br>$F_t = -\ln\left(\frac{n_{2,t+1}}{n_{1,t} + n_{2,t}}\right) - M$ |

## Appendix C: Mixture of the results from three analyses as Prior of $q_n$

Survey catchability ($q_n$, gear efficiency since the model uses swept area indices) is a critical parameter of the two stage dynamic model. However, the model is not capable of resolving resolve the problems surrounding survey catchability.

These three analyses, i.e., Stokesbury et al. (memo. 1999), Rago et al. (memo. 1999), and Cai (memo. 1999), yield different catchability estimates. In order to make these estimates available to the model, a mixture of three estimates are treated equally. The blended probability density function (pdf), called mixed pdf, is used as prior for $q_n$ that enters the two-stage dynamic model described in (L.13).

The three estimations for catchability can be treated as three independent events. Each has the mean at its own point estimate and the S.D. to describe the uncertainty around the point estimate. The probability density functions (pdf) of the three events are given in App. Fig. 1.

Let $q_n$ be the variable for survey catchability,
$p(q_n|\theta_i)$ be the pdf of Stokesbury et al. (i = 1), Cai (i = 2), Rago et al. (i = 3),
$\theta_i = (q_{n,i}, s^2_i)$
$\pi(i)$ be the probability for the ith event to be true, and
$p(q_n | \theta)$ be the mixed pdf of the selected events.

Then,

$$P(q_n | \theta) = \sum_{i=1} \pi(i) p(q_n | \theta_i)$$

where

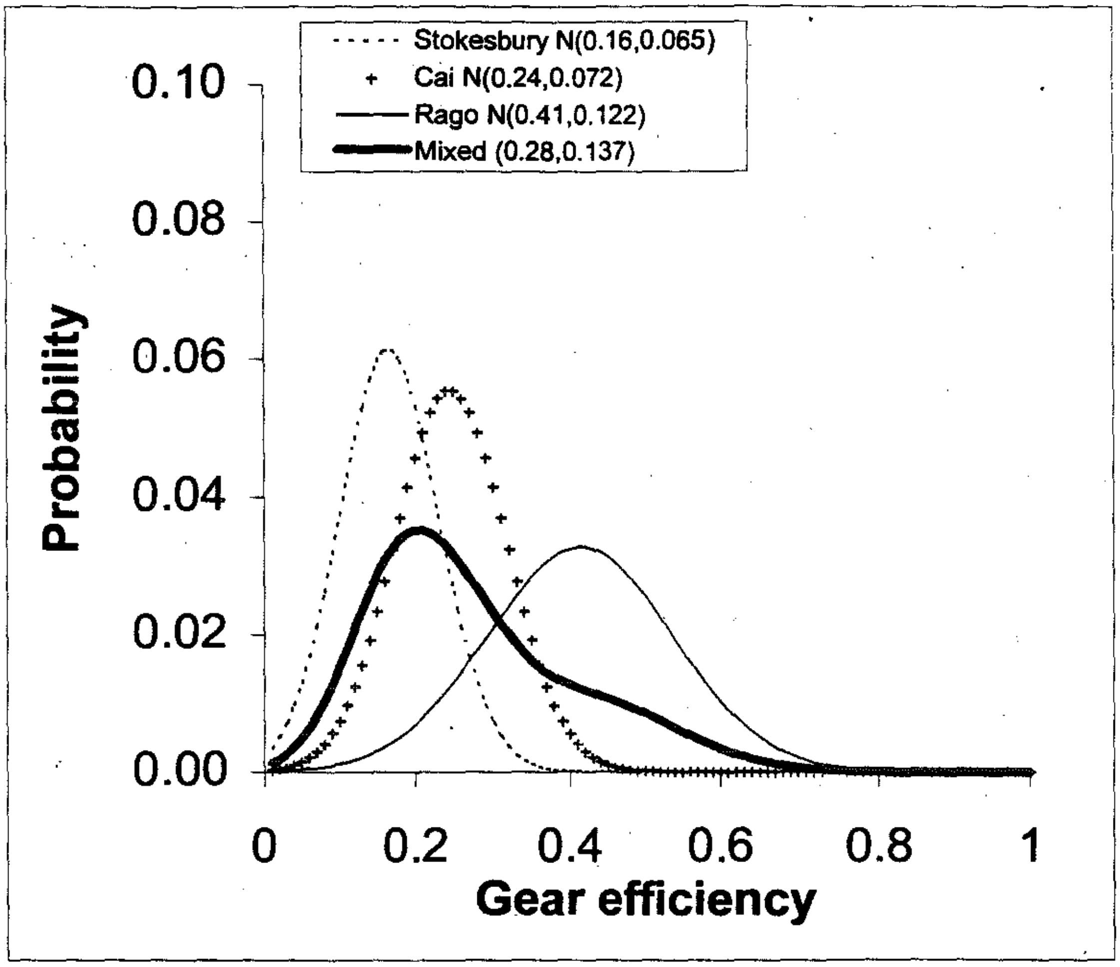
$$p(q_{n,i} | \theta_i) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left[ -\frac{(q_n - \bar{q}_{n,i})^2}{2\sigma_i^2} \right]$$

We use $p(q_n | \theta)$ as the prior for $q_n$. its likelihood is

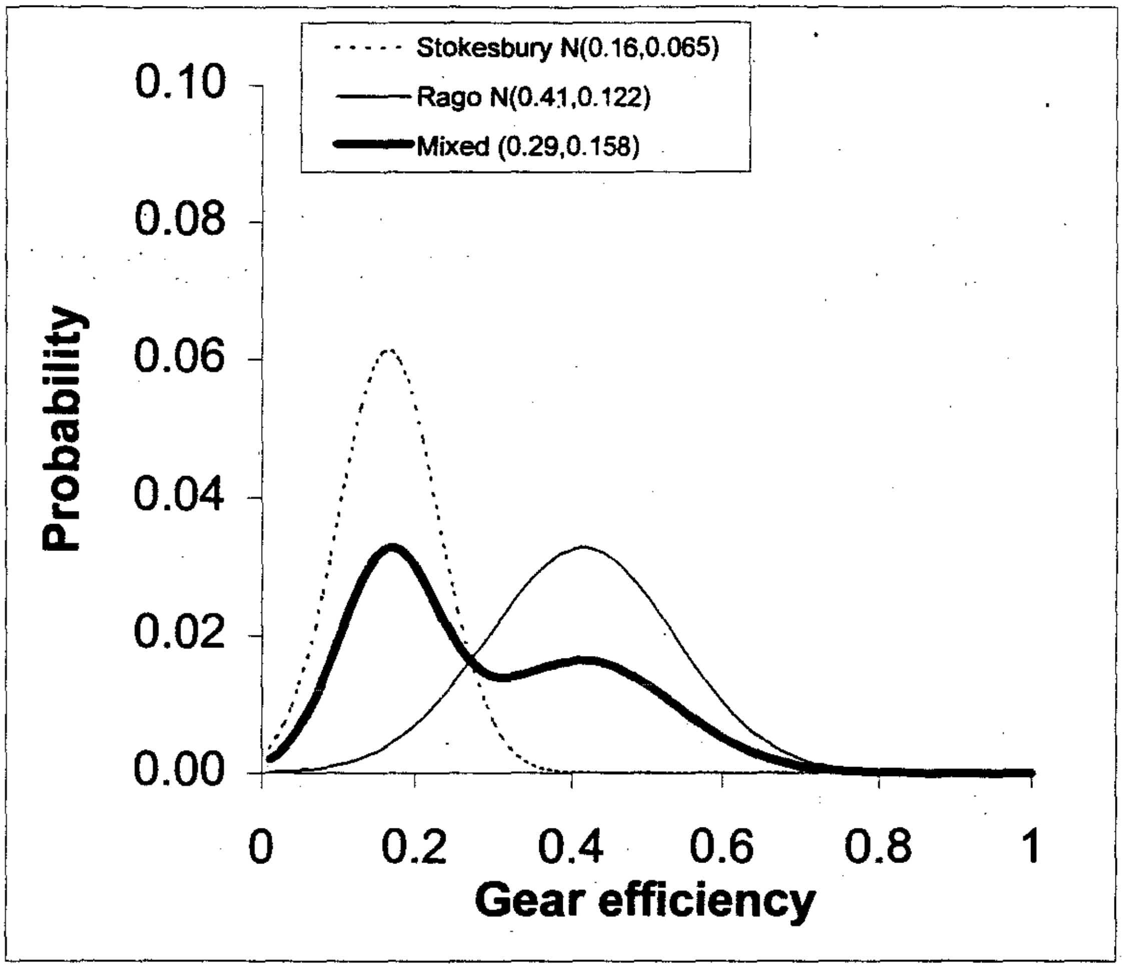
$$L = \sum_i \frac{\pi(i)}{\sqrt{2\pi\sigma_i^2}} \exp\left[ -\frac{(q_n - \bar{q}_{n,i})^2}{2\sigma_i^2} \right].$$

The mixed pdf of all three events (SCR Run) has with $\pi(i) = 1/3$ and is shown in App. Fig. 1. The mean and S.D. of mixture are 0.28 and 0.137, respectively. The mixed pdf of Stokesbury et al. and Rago et al. (SR Run) has with $\pi(i) = 1/2$ and is shown in App. Fig. 2. The mean and S.D. of mixture are 0.29 and 0.158, respectively. Although it is arguable whether or not the estimate of Cai should be used because Cai relies only on one experiment, the mixture pdf of Cai and Rago et al. (CR Run) is shown in App. Fig. 3. The mean and S.D. of this mixture is 0.33 and 0.131, respectively.

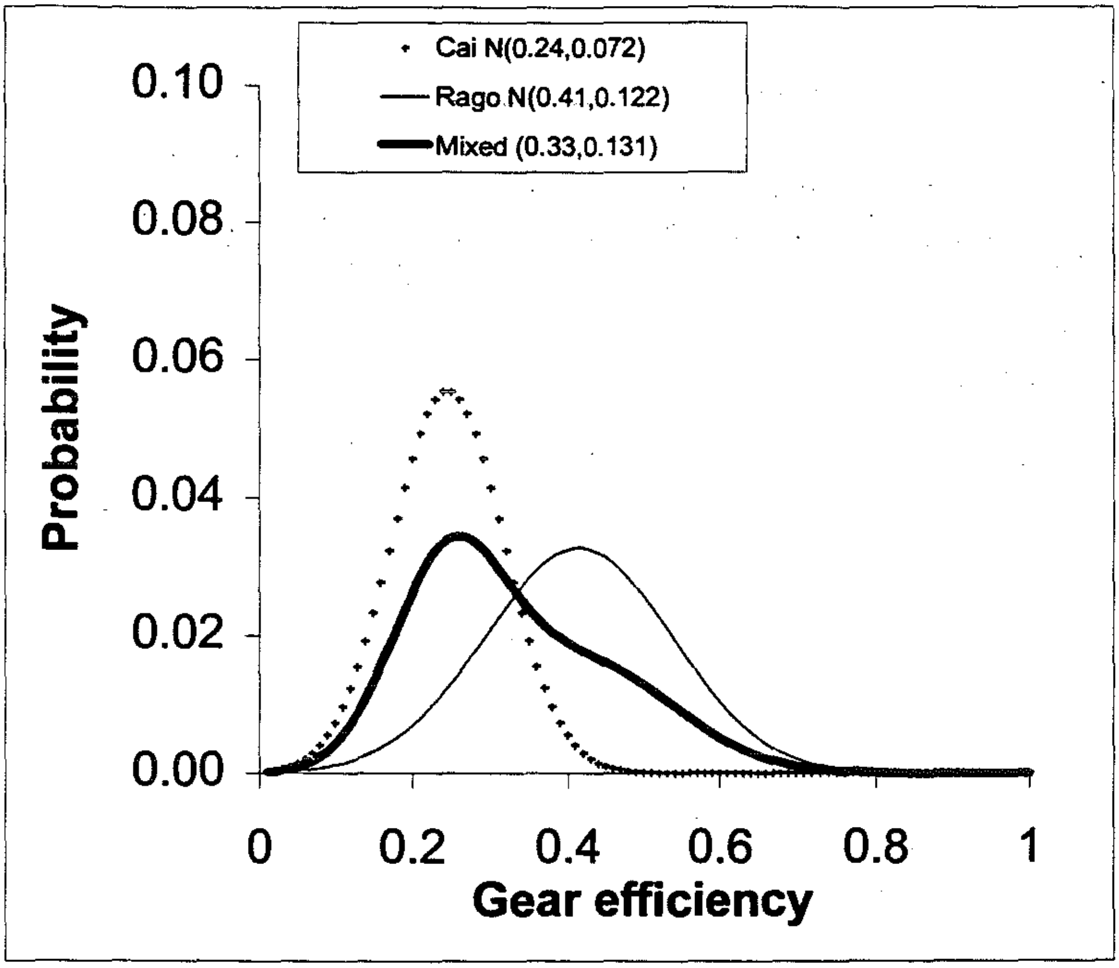
Using these three mixed pdf as the priors of $q_n$ and re-run the model. These three sets of results are compared with the basic model, which is essentially using Rago et al. only. The results for Georges Bank region are summarized in App. Fig. 4. The estimates of parameters and state moments are essentially identical although the value of $-\log L$ are different. The change of value of $-\log(q_n\_prior)$ does not affect the point estimates of parameters and interested state moments.



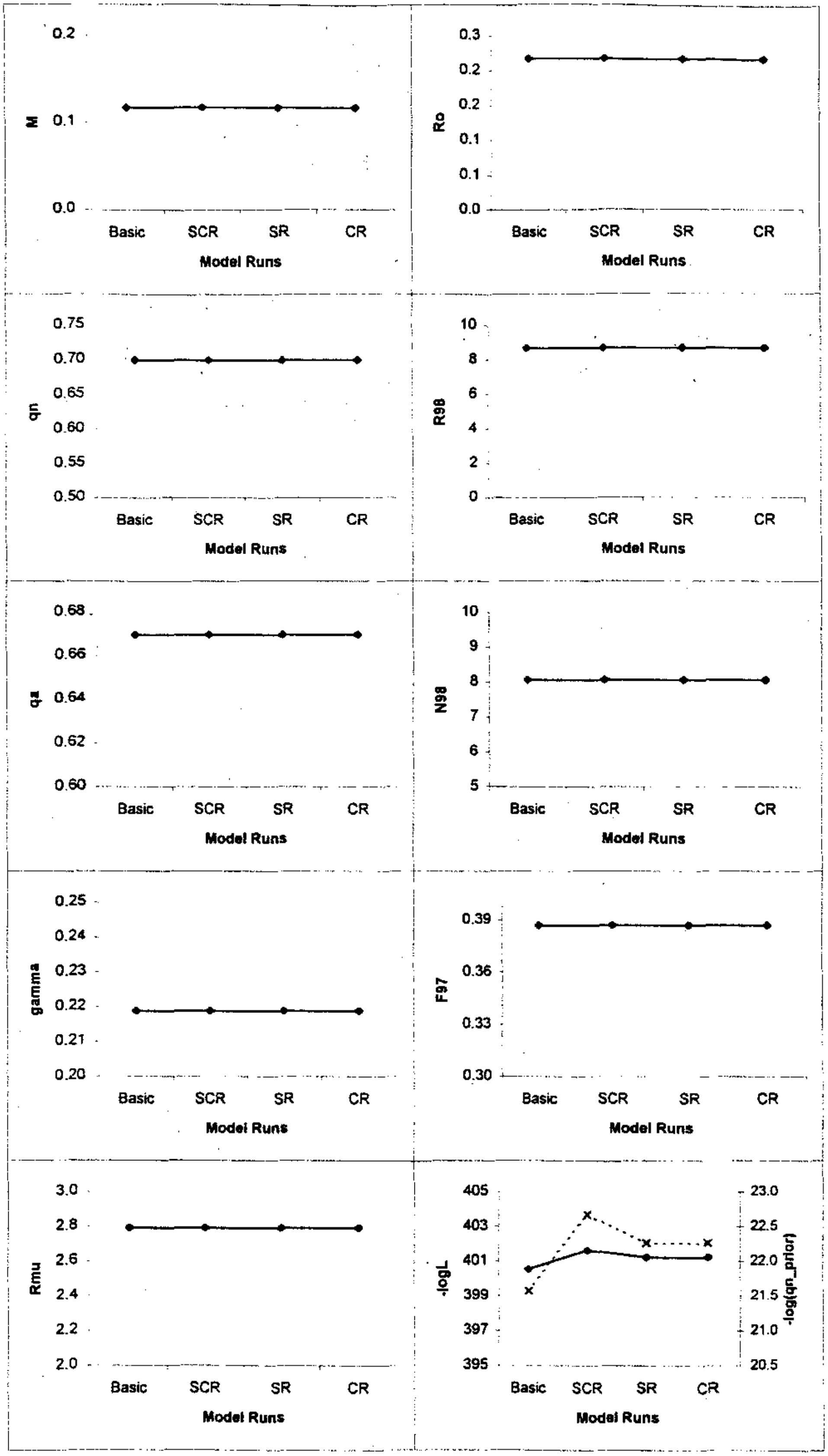

App. Fig. B1. Probability distributions (pdf) of survey catchability estimated by Stokesbury et al., Cai, and Rago et al (SCR Run). The mixture pdf is based on equal probability for each of the three estimates to be true. The mean and S.D. in Stokesbury et al. and Rago et al. are calculated from all included depletion experiments. The mean in Cai is the point estimate and its S.D. assumed to be 30% of mean.




App. Fig. B2. Probability distributions (pdf) of survey catchability estimated by Stokesbury et al., and Rago et al. (SR Run). The mixture pdf is based on equal probability for each of these four estimates to be true. The mean and S.D. in Stokesbury et al. and Rago et al. are calculated from all included depletion experiments.




App. Fig. B3. Probability distributions (pdf) of survey catchability estimated by Cai and Rago et al (CR RUN). The mixture pdf is based on equal probability for each of these two estimates to be true. The mean and S.D. in Rago et al. are calculated from all included depletion experiments. The mean in Cai is the point estimate and its S.D. assumed to be 30% of mean.




App. Fig. B4. Fluctuation of estimated parameters on four mixtures of qn, Georges Bank region.
Basic: the basic model, (i.e., qn from Rago et al. only)
SCR: mixture of qn from Stokebury et al., Cai, Rago et al.
SR: mixture of qn from Stokebury et al. and Rago et al.
CR: mixture of qn from Cai and Rago et al.

## C. INSHORE LONGFIN SQUID (*Loligo*)

### TERMS OF REFERENCE

a. Update the status of the *Loligo pealeii* squid fishery through 1998 and characterize uncertainty in stock size and fishing mortality rate estimates.

b. Update estimates of biological reference points based on new data, if possible.

c. Determine, with reference to the current overfishing definition, the status of *L. pealeii* squid.

d. Relative to the Sustainable Fisheries Act overfishing definitions, reference points, and current management measures, determine if *L. pealeii* squid is overfished or likely to be overfished during the next two years and whether overfishing is occurring or is likely to occur during the next two years.

e. If stock biomass is less than threshold biomass (½ $B_{MSY}$), determine likely rebuilding scenarios under current management measures.

f. Examine relationships between the winter and summer fisheries for *L. pealeii* squid.

Terms of reference were addressed through several meetings of the SARC Invertebrate Working Group (general approach February 19, 1999; trophic dynamics March 31, 1999; seasonal production modeling May 6, 1999, comprehensive assessment May 17 to 19, 1999). Further details on assessment results are reported by Cadrin and Hatfield (1999).

### INTRODUCTION

Life History

Stock assessment and management of *L. pealeii* are highly dependent on basic biological information, because recent findings have recast our perception its life history. The "longfin inshore squid" schools in waters of the continental shelf and slope, from Canada to the Caribbean (Cohen 1976). Within its range of commercial exploitation (Southern Georges Bank to Cape Hatteras) the population is considered to be a unit stock (NEFC 1986). However, heterogeneous subpopulations may exist (NEFSC 1996). Verrill (1882) reported different morphotypes from Vineyard Sound samples, but differences were likely caused by extremely variable rates of growth and maturation within the population. Genetic variation was extremely low among samples from NEFSC surveys, but allele frequencies were different at one locus among samples from Georges Bank, Cape Cod, and Cape Hatteras (Garthwaite et al. 1989). South of Cape Hatteras, the geographic distribution of *L. pealeii* overlaps with that of a congener, *L. plei*, which is morphometrically similar (Cohen 1976). *L. pealeii* migrate seasonally. They move offshore during late autumn to overwinter in warmer waters along the edge of the continental shelf and move inshore during the spring and early summer (Summers 1969, Serchuk and Rathjen 1974).

*L. pealeii* are sexually dimorphic with males growing faster and to larger sizes than females. Some males grow to more than 40 cm dorsal-mantle length (ML), although most squid harvested in the commercial fishery are less than 30 cm ML (Tibbetts 1975; NEFC 1986, 1990; McKiernan and Pierce 1995). Recent research indicates that *L. pealeii* live for less than one year, grow rapidly, and spawn year-round (Brodziak and Macy 1994, Macy 1994). Ageing studies show that growth is essentially exponential, size at age is extremely variable, and squid hatched in summer grow more rapidly than those hatched in winter (Macy 1994, Brodziak and Macy 1996). Age data indicates that major hatching periods are in summer-fall and early winter (Macy 1998). Age and growth information from 353 individuals indicated that size at age is extremely variable, but growth of summer-hatched individuals is faster and less variable than winter-hatched individuals (Brodziak and Macy 1996). New age data, based on 212 additional observations, generally confirm the earlier conclusions, but also show that length at age varies significantly within seasons (Macy 1998). The samples analyzed by Brodziak and Macy (1996) and Macy (1998) were taken opportunistically from the fishery with limited geographic and temporal coverage. Therefore, the limited information on age and growth may not be representative of the entire population.

Size at sexual maturity is extremely variable, but generally occurs at about 15 cm ML and 6 months of age in the waters of southern New England and the mid Atlantic Bight (Macy 1982, 1998; NEFSC 1996). *L. pealeii* mature at larger size in the northern extent of the range (Dawe et al. 1990). Similar to the limitations of available information on age and growth, maturity data reported by Macy (1982, 1998) have restricted spatio-temporal coverage. For example, hatch dates were distributed throughout the year, but no mature females were sampled in the fall, presumably because they spawn outside the sampled area (Macy 1998).

A NEFSC study was initiated in fall of 1997 to investigate geographic and seasonal patterns of growth and maturity (Hatfield and Cadrin 1999). Large portions of juvenile squid in the fall survey are produced by known areas of inshore, summer spawning. Similarly large portions of juveniles in winter and spring surveys implies significant winter spawning activity. To locate areas and times of spawning activity, 50 individuals were sampled in each of three geographic regions (Gulf of Maine, Georges Bank-southern New England, and mid-Atlantic Bight; a fourth region, south of Cape Hatteras was added later) and five depth zones (1 to 26 m, 27 to 55 m, 56 to 110 m, 111 to 185 m, >185 m) from five research surveys (NEFSC fall, winter, and spring, Massachusetts, and Connecticut) and sampled for morphometric maturity (Macy 1982). Statoliths were subsampled according to a uniform design described by Dawe and Natsukari (1991; three per cm per sex per maturity stage). A total of 2,274 individuals were processed, and 915 statoliths were collected. Cooperative work with University of Rhode Island has commenced to age statoliths from NEFSC samples, but data are presently unavailable. Results on size at maturity from recent field sampling (Hatfield and Cadrin 1999) is similar to previous information (NEFSC 1996, Macy 1998). Overall, few mature individuals were sampled. Spawning observations during late spring and early summer were in the well-documented spawning grounds of inshore southern New England in spring. During the fall NEFSC and Massachusetts surveys, spawning was observed in Cape Cod Bay and off Chesapeake Bay. Minimal spawning activity was observed from winter survey samples. A large portion of mature observations from the spring survey (45%) were from stations south of Cape Hatteras. This finding confirms earlier reports of substantial spawning of *L. pealeii* off the southeast U.S. (Whitaker 1978). Opportunistic commercial samples from early winter were also processed to bridge the temporal gap in survey coverage, but no mature squid were found. It appears that more extensive sampling is required to understand geographic and seasonal spawning patterns.

Reproductive dynamics of *L. pealeii* are also being studied at the Marine Biological Laboratory (MBL). A high frequency of alternative mating behavior has been observed in field and culture studies (Hanlon 1996, Hanlon et al. 1997). As an alternative to side-to-side copulation, which involves placement of spermatophores into the female mantle cavity by large males, smaller 'sneaker' males have been observed in head-to-head copulation, which involves storage of spermatophores in the female buccal receptacle. Nearly all females arriving inshore in the spring and early summer have stored spermatophores, presumably from offshore copulation (Hanlon 1996, Hanlon et al. 1997). Multiple spawning of individual females has been observed in culture, and spawning can last for over a month (Hanlon 1998, Maxwell et al. 1999). Preliminary data on fecundity indicate little relationship to size or age (Maxwell et al. 1999). Data on sex ratios over time suggest that demographics can change substantially within a season (M. Maxwell, MBL, personal communication).

Environmental effects on growth and productivity have been studied in culture and in the field. As an extension to the analysis of temperature effects on survey catches of *L. pealeii* reported by Brodziak and Hendrickson (1999), correlation analyses indicate that survey indices of biomass and abundance are positively related to sea surface and bottom water temperatures, and some temperature variations have lagged effects on abundance, suggesting that temperature affects early life history stages (Hatfield et al. 1998). Culture experiments show that small *L. pealeii* grow significantly faster at 20° C than at 15°C (Hatfield et al., in prep.).

Brodziak (1998) identified the need to consider trophic dynamics and community-level interactions with *L. pealeii*. Diet observations from NEFSC surveys indicate that the primary finfish predators are bluefish, monkfish, fourspot flounder, and spiny dogfish (J. Link, pers. comm.). Estimates of total consumption by predatory fish (Overholtz et al. 1999) and marine mammals (Kenney et al. 1995) are significant in comparison to fishery yields.

Recently collected data on *L pealeii* biology confirms that rates of growth and maturity are extremely variable, and the few available samples may not adequately represent the population or the fishery. Opportunistic samples may be biased, but even structured sampling designs require an extremely large number of observations to represent temporal and geographic patterns. Boyle and Boletzky (1996) concluded that useful generalizations about squid populations are difficult, because of short lifespans, little generational overlap, rapid growth, early maturity, and extensive migrations.

<u>The Fishery</u>

The Northwest Atlantic *L. pealeii* squid fishery began in the late 1800s as a source of bait, and annual squid landings from Maine to North Carolina (including *Illex illecebrosus* landings) averaged approximately 2,000 mt per year from 1928 to 1966 (Lange 1980). A directed foreign fishery for *L. pealeii* developed in 1967, and catches were used for human consumption. During the 1970s and early 1980s, the foreign fleet generally fished on the edge of the continental shelf in the winter, and the domestic fleet generally fished inshore in spring and summer (Lange et al. 1984). Annual landings increased to a peak of 37,600 mt in 1973 (Table C1). Foreign catches were gradually restricted, and in 1987, foreign fishing effort ceased. As the distant water fishery came to an end, the domestic fishery expanded to include an offshore, winter component.

Management History

From 1974 to 1977, the International Commission for the Northwest Atlantic Fisheries managed the Northwest Atlantic *L. pealeii* resource by regulating total allowable catch (TAC). A TAC of 44,000 mt was allowed in 1976 and 1977 (Lange and Sissenwine 1980). In 1978, management of the U.S. *L. pealeii* stock shifted to the Mid-Atlantic Fishery Management Council, which is currently under provisions of the Atlantic Mackerel, Squid, and Butterfish Fishery Management Plan (MAFMC 1998).

In 1996, management targets were reevaluated to reflect recent research on its life history, and domestic annual harvest was limited to 21,00o mt (Brodziak 1998). The current overfishing definition is the fishing mortality rate (F) which produces maximum yield per recruit ($F_{max}$), and the F target is $F_{50\%}$ (the F that preserves 50% of the unfished spawning potential) (MAFMC 1997). In 1998, an overfishing definition was proposed based on $F_{max}$ as a proxy for the level which will produce maximum sustainable yield ($F_{MSY}$), a minimum biomass threshold of half the level which can produce MSY ($B_{MSY}$ = 80,000 mt and ½ $B_{MSY}$ = 40,000 mt, as indexed by the combined spring and fall NEFSC survey swept-area biomass), and a target F of 75% $F_{MSY}$ (MAFMC 1998).

Assessment Background

Stock abundance and biomass of *L. pealeii* have been monitored by area-swept methods using bottom trawls for over 30 years. Estimates of stock size have varied widely from different approaches (Edwards 1968, Summers 1969, Serchuk and Rathjen 1974, Ikeda and Nagasaki 1975, Tibbetts 1975, Lange and Sissenwine 1983, Lange 1984, NEFSC 1996, Brodziak 1998).

Annual assessment reports based on survey and catch trends concluded that the stock was fluctuating around the long-term average and catches were sustainable during the 1970s and early 1980s (Serchuk and Rathjen 1974, Tibbets 1975, Lange and Sissenwine 1977, Lange 1984). Regular status of stocks reports stated that the *L. pealeii* stock was underexploited and at high levels of abundance from 1989 to 1993 (NEFC 1989, NEFSC 1993). In 1994, the stock was determined to be at a medium level of abundance and fully-exploited (NEFSC 1994a), and that status continued through the most recent determination (Cadrin 1998).

Historical attempts to model abundance and F were generally conditional on obsolete life history paradigms involving a multi-year life span. For example, Ikeda and Nagasaki (1975) and Lange et al (1984) performed cohort analysis of length modes, assuming a three-year lifespan. . Historical estimates of biological reference points based on dynamic pool models (Sissenwine and Tibbetts 1977, Lange 1981, Lange and Sissenwine 1983) and stock-recruit analyses (Lange 1984, Lange et al. 1984) also assumed a multi-year life cycle. A Collie-Sissenwine model was applied to the *L. pealeii* fishery, but results were sensitive to the assumed natural mortality rate (NEFSC 1992). Brodziak and Rosenberg (1993) developed an extended Leslie-DeLury model to estimate abundance and exploitation rate based on catch per unit effort (CPUE) data from the inshore Massachusetts fishery, but migrations to and from adjacent areas made interpretations difficult.

The most recent stock assessments of *L. pealeii* have continued area-swept estimates of biomass and revised dynamic pool approaches with updated information on growth, maturity, and natural mortality (NEFSC 1994b, 1996).

Previous assessments did not successfully estimate fully-recruited F for comparison to dynamic pool reference points. Status determination was based on ratios of catch to area-swept biomass, assuming no seasonal growth or recruitment and equal catchability of spring and summer surveys (NEFSC 1996, Brodziak 1998).

## DATA AND ASSESSMENT

Landings

Annual landings were estimated from northeast dealer weighout and canvass data (Burns et al. 1983). Annual landings from 1982 to 1987 were revised to include prorated unspecified squid landings (which include *I. illecebrosus*). Unspecified landings were prorated according to the relative proportions of *L. pealeii* and *I. illecebrosus* by month and 2-digit statistical reporting area. Some landings of *L. plei* may be included in *Loligo* catches south of Cape Hatteras, because landings are categorized to genus, not species. There is substantial uncertainty in the estimates of foreign landings and historical domestic landings. There was no observer coverage of distant water fleets before 1978, and observer coverage was low in the early 1980s (P. Gerrior, personal communication). The relative proportion of total landings from unspecified squid landings was substantial in some years (e.g., 20% in 1983), but has been generally low since 1985 (<5%; with the exception of 1996, when 10% of total landings estimates were from unspecified records). Differences between dealer weighout and canvass data were also substantial until the early 1980s, but annual differences have been less than 2% of the total since 1987. Accuracy of landings estimates has improved as a result of better reporting of landings by species and prohibitions on foreign fishing.

Estimated landings increased rapidly in the 1960s and early 1970s to a peak of 38,000 mt in 1973, with nearly all landings from distant water fleets (Table C1, Figure C1). During the 1980s, domestic landings replaced foreign landings. Landings in 1998 were approximately equal to average annual landings from 1967 to 1998 (18,400 mt), with most landings taken in the first quarter.

Landings are predominately taken by small-mesh otter trawlers, but substantial landings are taken from inshore fish traps. Since 1989, most landings were taken from the winter fishery (first and fourth quarters; Table C2, Figure C2). Most landings in recent years were taken during winter months along the edge of the continental shelf from the Mid-Atlantic Bight (statistical areas, 613, 616, 622) to southern New England waters (area 537; Table C3, Figure C3).

The size distribution of landings was sampled in every quarter, from 1987 to the third quarter of 1998, but samples were not distributed across all months, nor were all market categories sampled (Table C4a). Approximately 80% of all landings from 1987 to 1998 were landed as 'unclassified', with variable proportions of specific market categories (Table C4b). Catch at length was estimated using quarterly samples by market category where available. Landings from unsampled categories were characterized by samples from adjacent categories (i.e., 'large' were pooled with 'extra large'; 'small' were pooled with 'boogers'; 'medium' were pooled with 'unclassified'). When adjacent categories were not available, landings were characterized by 'unclassified' samples. Sample lengths were expanded to quarterly landings using predicted sample weights (Lange and Johnson 1981).

Estimated catch at length generally indicates an increase in catch from small, partially-recruited

recruited sizes (approximately 9 to12 cm ML) to a mode at approximately 13 to 15 cm ML and a gradual decrease in catch at length greater than 13 cm ML (Figure C4). Most landings range from 10 to 20 cm ML, with variable portions of large individuals (>25 cm ML). This pattern is similar to those reported in previous assessments (Tibbetts 1975; NEFC 1986, 1990, McKiernan and Pierce 1995).

Discarded Catch

The previous assessment recommended that more data were needed on the magnitude and composition of discards (NEFSC 1996, Brodziak 1998). The magnitude of *L. pealeii* discards appears to be relatively low. Analysis of data from 22 directed trips in Nantucket and Vineyard Sounds from 1989 to 1993 indicated that the magnitude of *L. pealeii* discards were negligible (McKiernan and Pierce 1995). Information from observed trips that caught *L. pealeii* (1989 to 1998 NEFSC and Massachusetts observer data) suggests that the magnitude of discards varies by time, fishing gear, and target species. Determining directed trips is difficult from observer databases because target species are not coded (NEFSC 1996), and traditional directed trips land a mix of other species (e.g., silver hake). Data from observed otter trawl trips that caught *L. pealeii* were analyzed in two categories: those that landed *L. pealeii* (producing an average discard:kept ratio of 6%; Table C5), and those that discarded all *L. pealeii* (10 mt of observed discard from 207 trips, averaging approximately 50 kg/trip). Discarded catch from other fishing gear also appears to be relatively low in magnitude: 78 observed scallop trips caught *L. pealeii* and discarded 500 kg (averaging 6 kg/trip); five observed gillnet trips caught *L. pealeii* and discarded 2 kg (averaging less than 1 kg/trip). These discard observations are not randomly sampled and may not represent the entire directed fishery or bycatch fisheries (NEFSC 1996).

Observed lengths of discarded *L. pealeii* are generally small (mode <10 cm ML in most years; Figure C5). However, some discard samples also include substantial portions of large individuals, presumably from trips that are not landing *L. pealeii*.

Commercial CPUE

Generalized linear models (GLMs) of catch rates in domestic fisheries for *L. pealeii* were developed in the previous stock assessment (NEFSC 1996, Figure C6; Brodziak 1998). Port interview data from 1982 to 1993 were partitioned into two seasons: winter (October-March) and summer (April-September). The two GLMs included statistical area, vessel size, and month as main effects. The standardized CPUE series could not be updated for this assessment, because port interview data are not available from 1994-1998. A quarterly series of CPUE was derived from the standardization coefficients for statistical area and vessel size reported in the last stock assessment (NEFSC 1996, Brodziak 1998). Quarterly CPUE estimates for 1987 to 1993 were from dealer weighout and interview data, and estimates for from 1994 to 1998 were from vessel logbook data. Quarterly CPUE generally increased in the late 1980s, generally decreased from 1988 to 1991, and fluctuated without trend in the 1990s (Figure C6). There is no apparent seasonal periodicity in CPUE. However, effort statistics from logbook data may be unreliable and may not be comparable to interview data (NEFSC 1997, Mayo 1998).

Research Surveys

Geographic patterns in survey catches show that *L. pealeii* are distributed over the entire continental shelf (from inshore to offshore) in the fall, are concentrated at the edge of the continental shelf (and likely outside the surveyed area) in winter and spring, and are concentrated inshore in the summer (Summers

1967, 1969, Figure C7; Mercer 1969a, 1969b, 1970; Serchuk and Rathjen 1974; Vovk 1978; Whitaker 1980). Catches in the mid-Atlantic Bight are significantly greater than those in more northern strata during all seasons (Hatfield and Cadrin 1999). Some catches of *L. plei* may be included in *Loligo* survey catches off Cape Hatteras, because data are categorized to genus, not species.

Many studies found day/night differences in *L. pealeii* survey catches (Sissenwine and Bowman 1978, Serchuk and Rathjen 1974, Tibbetts 1975, Sissenwine and Tibbetts 1976, Brodziak and Hendrickson 1999). The most recent *L. pealeii* stock assessment used diel correction factors for prerecruits (≤ 8 cm ML) and recruits (>8 cm ML) derived from a generalized linear model (GLM) of NEFSC fall survey data with cruise, stratum, and time zone main effects (NEFSC 1996, Brodziak and Hendrickson 1999). The previous stock assessment applied fall diel corrections to spring survey data. Brodziak and Hendrickson's (1999) methods were applied to winter and spring survey data to derive seasonal correction factors. All correction factors for spring and winter surveys were statistically significant, but diel differences were substantially less for spring, and nighttime catches of large *L. pealeii* by the winter survey were slightly greater than daytime catches. Survey indices of abundance and biomass were revised and updated using season-specific diel corrections, excluding short tows, and reducing the strata set for the winter survey to regularly sampled strata (Table C6, Figure C8).

A comparison of length frequencies from recent surveys (i.e., those sampled since the last assessment, NEFSC 1996) and previous surveys indicates that size distributions are similar (Figure C9a). Approximately 80% of *L. pealeii* sampled by the fall survey are prerecruits (≤ 8 cm ML). There are relatively fewer small *L. pealeii* sampled by the winter survey (approximately 60% prerecruits) and the spring survey (65% prerecruits). Survey length modes range from three to six cm ML (i.e., the most frequent size sampled is generally 3 to 6 cm ML. and frequency decreases at greater sizes), suggesting that 6 cm squid are fully recruited to the survey gear. Size distributions from offshore, deep stations were larger than those from inshore, shallow stations (Hatfield and Cadrin 1999; Figure C9b).

*L. pealeii* are also sampled by state surveys. The Massachusetts spring survey (Howe 1989) samples an aggregation of *L. pealeii* in Nantucket Sound, Vineyard Sound and Buzzards Bay (statistical area 538, Figure C3), where the inshore spring fishery operates. The Massachusetts survey index generally increased in the 1980s and decreased in the 1990s (Table C7, Figure C10).

The previous stock assessment of *L. pealeii* reported a significant negative relationship between winter effort and summer catch rates (NEFSC 1996, Brodziak 1998). Unfortunately, the series of interview effort used in the analysis cannot be updated because of the switch to logbook-based effort estimates, described above. However, the relationship between the winter and summer fisheries for *L. pealeii* was examined using the Massachusetts survey biomass index and offshore removals (yield during the previous fourth and first quarters). The relationship was negative (Figure C10; $r = -0.41$), but was only marginally significant ($P = 0.095$), suggesting a weak relationship between offshore removals and subsequent biomass available for the inshore fishery or a low power of detection.

In summary, survey biomass indices suggest some long-term patterns in stock biomass. Biomass appears to have increased in the 1960s and early 1970s, decreased in the late 1970s, slightly increased in the early 1980s, and decreased in the late 1980s and early 1990s.

Estimates of Relative Exploitation - Descriptive approach.

Ratios of landings to survey biomass indices were calculated to investigate patterns of relative exploitation rate (NEFSC 1996). Ratios were based on seasonal surveys and the corresponding quarterly landings. Patterns in relative exploitation indices were inconsistent among surveys, but the fall and winter indices suggest that exploitation rate was high in 1998 (Figure C11).

Estimates of Stock Size and Fishing Mortality - Length-based approach.

Length-based virtual population analysis (LVPA) was used to estimate abundance and mortality from average monthly catch at size, by season. Visual inspection of commercial length samples (Figure C4), suggests that information on mortality rate can be indicated from the rate of decrease in catch as size increases if a general growth rate is assumed. LVPA is a modification of Jones' (1974, 1981) length-based cohort analysis, which uses Pope's (1972) approximate solution to the catch equation:

$$N_{t-\Delta t} = (N_t\, e^{-0.5M\Delta t} - C_t)\, e^{-0.5M\Delta t} \qquad (1)$$

where abundance of a size class at the end of a time period ($N_{t-\Delta t}$) can be estimated from abundance at the beginning of the period ($N_t$) decreased by a half-period of natural mortality ($e^{0.5M\Delta t}$), catch at mid-period ($C_t$), and another half year of M on the survivors from the fishery. Monthly M was assumed to be 0.3 (NEFSC 1996). The period ($\Delta t$) is the predicted time to grow from one size class to the next, in months. A sequential population analysis with variable time periods was performed using an iterative search algorithm (Sims 1982) for a more exact solution of F. given $N_{t+\Delta t}$, $M\Delta t$, and $C_t$ in a modified catch equation:

$$C_t = (1-e^{-Z\Delta t})\, N_{t+\Delta t}e^{-Z\Delta t}\, F_{\Delta t}/Z_{\Delta t} \qquad (2)$$

and

$$N_t = N_{t+\Delta t}e^{-Z\Delta t} \qquad (3)$$

where Z is total mortality (F+M). Monthly F was derived as $F_{\Delta t}/\Delta t$. Therefore, a size distribution of landings (catch at a sequence of length classes) was used to approximate catch at a sequence of time intervals.

Jones (1974) used vonBertalanffy growth parameters to estimate $\Delta t$, but any continuous growth function can be used (Cadrin and Estrella 1996). The seasonal, pooled-sex Schnute growth functions for *L. pealeii* reported by Brodziak and Macy (1996, Figure C12) were used to derive $\Delta t$ for successive two-cm ML size classes. The preliminary growth estimates reported in Macy (1998, Figure C12) were not used, because they are simple power functions, which may not be appropriate for squid, and they are grouped by sample date, rather than hatch date. Growth of *L. pealeii* is sexually dimorphic, but separate-sex analyses are not possible, because sex is not identified in commercial length samples. Seasonal growth models were used for corresponding seasonal catches: growth of individuals hatched from November to May was used to analyze summer catch (April to September), and growth of individuals hatched from June to October was used to analyze winter catch (October to May, labeled as the calendar year in January).

Length-based VPA assumes stationary recruitment, because a single-month length frequency, which comprises several cohorts, is used to approximate abundance of a single cohort over time. This approximation assumes that all size classes in the catch were equally abundant at the time of recruitment to the fishery. Somerton and Kobayashi (1991) proposed that catch at length should be averaged over successive periods to reduce bias from disequilibria. Catch at length was averaged over six month periods to derive an average monthly catch for each fishing season (summer: April to September; winter: October to May) in an attempt to integrate variable recruitment within a season.

Backward sequential population analysis requires an assumption about abundance at the oldest age (or largest size class for LVPA). Abundance of the largest size class was estimated from observed catch and F (using equation 2), and F was approximated as a log catch ratio:

$$F_t = Ln\ (C_{7+}/C_{8+}) - M \qquad (5)$$

Catch at ages-7+ and age-8+ months were based on predicted size at age (Brodziak and Macy 1996, Figure C12). Catch at age 7+ was approximated from catch of 13+ cm ML for the winter fishery (summer hatched) and 16+ cm ML for the summer fishery (winter hatched). Catch at age 8+ was approximated from catch of 19+ cm ML for the winter fishery (summer hatched) and 20+ cm ML for the summer fishery (winter hatched).

Results of LVPA indicate that stock biomass fluctuated around a seasonal average of 7,700 mt, but generally decreased since 1991 (Figure C13). Four of the five most recent biomass estimates are among the lowest in the series (approximately 2,900 mt; Figure C13). Biomass estimates are substantially less than the area-swept estimates from the fall survey (Figure C7). The pattern of F at size from LVPA and predicted age at size from Brodziak and Macy (1996) indicates that 19 to 24 cm ML squid are fully-recruited to the fishery. A size of 19 cm ML corresponds to approximately age-8 months in the winter fishery and approximately age-7.5 months in the summer fishery (Table C8). Estimates of fully-recruited F (19 to 24 cm ML) averaged 1.6 over the entire time series, but were consistently lower in summer than in winter (the summer average was 1.0, and the winter average was 2.2), and generally increased, since 1991 within seasons.

Results of length-based sequential population analysis are extremely sensitive to assumed growth rates (Jones 1986, Lai and Gallucci 1988, Cadrin and Estrella 1996). Sensitivity analyses were performed on summer 1998 data (average F of 19 to 24 cm ML was 1.09), using the range of M estimates reported in the last assessment (0.26 to 0.34, NEFSC 1996), a range of relative change in Δt of 50% to 150% of the deterministic estimates, and a range of relative change in terminal F values of 50% to 150% of the assumed values. Results confirm that F estimates are extremely sensitive to assumed Δt (F estimates ranged from 0.7 to 1.8), moderately sensitive to terminal F (F estimates ranged 0.8 to 1.2), and relatively robust to the assumed value of M (F estimates ranged 1.0 to 1.2; Figure C14).

The uncertainty of biomass and F estimates from LVPA were approximated using Monte Carlo methods similar to the approach used by Lai and Gallucci (1988). The relative variation from deterministic estimates of Δt were assumed to be normally distributed with a mean of 1 (no difference than the deterministic estimate) and a standard deviation of 0.1 (based on 10% relative standard error of growth in ML per month, Brodziak and Macy 1996). The level of M was assumed to vary normally (mean = 0.3, standard deviation = 0.04, based on alternative estimates of 0.26, 0.30, and 0.34, NEFSC 1996). The value of terminal F was assumed to vary normally (mean = 0.6, standard deviation = 0.15, based on variation among length samples).

Results suggest that the 80% confidence interval of F is 0.94 to 1.24 (CV=11%) and the 80% confidence interval of stock biomass is 2,240 to 2,540 mt (CV=5%, Figure C15). These estimates are conditional on the assumed level and distribution of variance of input data and the assumption of no error in catch at length. The true variance of estimates is likely to be greater than indicated by these Monte Carlo results, because growth and mortality estimates were for pooled-sexes, length samples may not represent the fishery, and the variance in M and growth is probably underestimated.

There are several theoretical and practical problems with applying length-based assessment methods to squid. In a review of cephalopod stock assessment methods, Pierce and Guerra (1994) reported that results from length-based analyses are highly questionable given the extreme variability of growth rates. Another problem with length-based determinations of mortality is movement of squid in and out of fishing areas. Hatfield and Rodhouse (1994) found that commercial size frequencies provided misleading information on size structure of the *L. gahi* population. Jackson et al. (1997) observed similar biases and concluded that catch at size approaches should be abandoned for *Lolliguncula brevis*. Apparent signals in mortality from *Loligo pealeii* commercial length data may reflect rates of migration to and from fishing grounds. For example, the high estimates of F may result from a net emigration of large squid (Caddy 1991). Low sampling intensity and incomplete sampling of all market categories may also bias length-based estimates.

Biological Reference Points - Dynamic pool approach.

Thompson and Bell (1934) dynamic pool models were used to derive $F_{max}$, $F_{0.1}$ (the F at which increase in yield per unit F is decreased to 10% of the initial increase in yield from F=0 to F>0), and $F_{50\%}$ (the F that decreases mature biomass per recruit to half that of an unfished cohort). The previous assessment, which used seasonal size at age data from Brodziak and Macy (1996), preliminary maturity at age data based on proportion developing and mature (stages 3 and 4, Macy 1982), and assumed a 9 cm ML length at full recruitment, indicated that $F_{0.1}$=0.22, $F_{max}$=0.36, $F_{50\%}$=0.14 for summer-hatched squid; and $F_{0.1}$=0.23, $F_{max}$=0.38, $F_{50\%}$=0.13 for winter-hatched squid (NEFSC 1996, Brodziak 1998).

Despite variability in LVPA results, it appears that the size of full-recruitment is somewhat larger than 9 cm ML and the largest squid may be partially recruited. Dynamic pool models were revised using the seasonal fishing mortality patterns at age indicated by LVPA (Table C8), and revised estimates of maturity (stage-4) at weight data (Hatfield and Cadrin 1999). Results (in monthly fishing mortality rates) indicate that summer-hatched/winter fishery $F_{0.1}$=0.61, $F_{max}$=1.24, $F_{50\%}$=0.34; winter-hatched/summer fishery $F_{0.1}$=0.39, $F_{max}$=0.66, $F_{50\%}$=0.21 (Table C9, Figure C16).

Uncertainty in yield per recruit estimates was assessed using Monte Carlo methods. Similar to the approach used by Restrepo and Fox (1988), uncertainty in growth and natural mortality were used to assess uncertainty in $F_{max}$ and yield per recruit at several levels of F for the Thompson-Bell model. Relative variation from deterministic estimates of weight at age were assumed to be normally distributed with a mean of 1 (no difference than the deterministic estimate) and standard deviations of 0.20 and 0.25 for summer-hatched and winter-hatched, respectively (based on a relative standard errors of growth in g per month, Brodziak and Macy 1996). Partial recruitment (PR) was assumed to be determined by the stochastic estimate of weight at age ($R^2$>0.98 for both summer and winter-hatched logistic relationships between the ascending portion of PR and mean weight, Table C9). The level of M was assumed to vary normally (mean = 0.3, standard deviation = 0.04, based on alternative estimates of 0.26, 0.30, and 0.34, NEFSC 1996). Results indicate that the 80% confidence interval of $F_{max}$ is 0.88 to 1.55 (CV=21%) for summer-hatched and 0.50 to 0.71 (CV=14%) for winter-hatched (Figure C17). Similar to Monte Carlo results for LVPA, confidence intervals for dynamic pool model estimates are conditional on the assumed level and distribution of simulated errors; true variance of estimates is probably greater than reported here.

Reported estimates of long-term potential yield (LTPY), which were derived for each seasonal cohort by applying an average area-swept survey recruitment value (≤8 cm ML) to the yield-per-recruit at $F_{max}$, were 18,000 mt for summer-hatched squid and 3,000 mt for winter-hatched squid (NEFSC 1996, Brodziak 1998). However, the reported estimates implicitly assume that survey catchabilities were equal for the spring and fall surveys. Attempts to derive proxies for biomass reference points using average area-swept recruitment with estimates of biomass-per-recruit were considered to be unrealistically high, because the $B_{MSY}$ proxy was substantially greater than all area-swept biomass observations from 1968 to 1997 (Applegate et al. 1998). This discrepancy suggests that area-swept survey recruitment observations (≤ 8 cm ML) do not represent cohort size at month-0. The observed ages reported in Brodziak and Macy (1996) indicate that 8 cm *L. pealeii* are older than five months, and swept-area abundance of ≤ 8 cm ML individuals is likely to include several monthly cohorts thereby overestimating the average level of monthly recruitment (see Figure C12). Estimates of LTPY were not attempted for the present assessment, because reliable estimates of average monthly cohort size are not available.

Estimates of Stock Size, Fishing Mortality, and Reference Points - Biomass dynamics approach. Recent advances in life history information of *L. pealeii* suggest that there is a great deal of natural variability and statistical uncertainty in estimates of growth and natural mortality. Therefore, estimates of abundance and fishing mortality or biological reference points from demographic models (i.e., length-based or age-based) have a great deal of uncertainty. Surplus production models can be useful in situations where information on age structure is unavailable or unreliable, and provide an alternative perspective for stock assessment. Production models can also provide guidance on maximum sustainable yield (MSY), the biomass which could produce MSY ($B_{MSY}$), and fishing mortality at MSY ($F_{MSY}$). A study group on squid stock assessment concluded that production models are the best prospect for determining stock status (ICES 1988). Production models have provided the basis of management advice for *L. vulgaris* and *L. forbesi* (Bravo de Laguna 1989).

The previous *L. pealeii* assessment recommended investigation of a seasonal stock production model (NEFSC 1996). A production model of quarterly landings and biomass indices was explored to estimate stock biomass, fishing mortality, and maximum sustainable yield reference points. A nonequilibrium surplus production model incorporating covariates

(ASPIC; Prager 1994, 1995) was applied to quarterly catch (1987 to 1998) and biomass indices. Data on the fishery prior to 1987 were excluded because of uncertainty in foreign and domestic catches (Table C1). The production model assumes logistic population growth, in which the change in stock biomass over time ($dB_t/dt$) is a quadratic function of biomass (B):

$$dB_t/dt = rB_t - (r/K)B^2_t \quad (5)$$

where $r$ is the intrinsic rate of population growth, and $K$ is carrying capacity. For a fished stock, the rate of change is also a function of catch biomass (Y):

$$dB_t/dt = rB_t - (r/K)B_t^2 - Y_t \quad (6)$$

Maximum sustainable yield reference points can be calculated from the production model parameters:

$$MSY = Kr/4 \quad (7)$$
$$B_{MSY} = K/2 \quad (8)$$
$$F_{MSY} = r/2 \quad (9)$$

Initial biomass (expressed as a ratio to $B_{MSY}$: $B1R$), $r$, MSY, and catchability coefficients for each biomass index ($q_i$) were estimated using nonlinear least squares of survey residuals (Prager 1994).

Potential biomass indices for *L. pealeii* are standardized CPUE, NEFSC spring, fall and winter surveys, and the Massachusetts spring survey. Several combinations of biomass indices were attempted for alternative production analyses and are reported as sensitivity analyses. The most acceptable configuration tuned biomass estimates to NEFSC spring and fall survey indices and the two seasonal CPUE series based on interview data. A small portion of total variance in the biomass indices was explained by the model ($R^2 = 0.0$ to 0.3), but model residuals appear to be randomly distributed (Cadrin and Hatfield 1999).

The production model suggests that MSY is 4,900 mt per quarter (19,600 mt per year; Table C10; Figure C18). Performance of ASPIC on simulated data indicates that ratios to MSY reference points (Bratio: $B_t/B_{MSY}$ and Fratio: $F_t/F_{MSY}$) are generally more reliable than absolute estimates of biomass or F, particularly when the observed dynamic range is limited (Prager et al. 1996, NRC 1998, Prager 1998). Estimates of absolute biomass from ASPIC are generally lower than area-swept biomass estimates from the fall survey (i.e., $q_{fall} > 1$), but greater than those from LVPA. The range of *L. pealeii* biomass estimates represents 44% of the potential dynamic range (0 to $K$). Therefore, in lieu of reliable information on absolute levels of stock biomass, ratios to MSY conditions (i.e., Bratio = $B_t/B_{MSY}$; Fratio = $F_t/F_{MSY}$) should be used for assessing trends in biomass and F.

The production model indicates that stock biomass fluctuated around $B_{MSY}$ from the late 1980s to the early 1990s, decreased to low levels in the late 1990s, and was approximately 60% of $B_{MSY}$ at the beginning of 1999 (Figure C19). Fishing mortality was generally greater in winter than in summer.

Survey residuals were randomly resampled 500 times to derive probability distributions of parameter estimates and derived variables. Variance of estimates was evaluated using bias-corrected bootstrap percentiles (Manly 1997). Bootstrap results suggest that MSY is well estimated (the relative interquartile range was 7%). Biological reference points, other model parameters , and current F and biomass ratios were estimated with moderate precision (IQRs were 44% to 60%; Cadrin and Hatfield 1999).

The most recent Fratio (fourth quarter of 1998) was 1.7 with an 80% confidence limit of 1.1 to 3.0 (Figure C20), and the most recent Bratio (January, 1999) was 0.57 with an 80% confidence limit of 0.27 to 0.94. Therefore, despite low precision in estimates of current biomass and F, the model indicates that there is approximately 90% chance that F is greater than $F_{MSY}$ and biomass is less than $B_{MSY}$. However, a relatively large portion of bootstrap trials (approximately 10%) were replaced for lack of convergence.

Stochastic, 3-year projections of ASPIC results were performed assuming status quo F (estimated as seasonal averages from 1994 to 1998) in 1999. Three alternative F scenarios were forecast for 2000-2001: status quo F, the Amendment 8 overfishing definition ($F_{MSY}$), and target F (75% $F_{MSY}$). Projected biomass was extremely variable, particularly for the status quo projection. At $F_{94\text{-}98}$, biomass is projected to fluctuate at slightly less than 50% $B_{MSY}$ (Figure C21a), yielding approximately 4,000 mt per quarter (16,000 mt per year; Figure C21b). At $F_{MSY}$, the stock is projected to increase, with quarterly yield increasing to more than 4,000 mt per quarter (17,800 mt per year), but with low probability of attaining $B_{MSY}$ by the year 2002 (Figure C21). At 75% $F_{MSY}$, the stock is projected to increase more rapidly, with quarterly yield increasing to more than 4,000 mt per quarter (17,000 mt per year), and high probability of attaining $B_{MSY}$ by the year 2002 (Figure C21).

Results from alternative production analyses show thatthe winter survey series, the Massachusetts survey series, and CPUE estimates derived from logbook data do not fit the model well (Table C11). The winter and Massachusetts surveys may sample an unrepresentative geographic portion of total stock area, and logbook effort may not be reliable (as demonstrated by other stock assessments; NEFSC 1997, Mayo 1998). Despite poor statistical fit, estimates of MSY from runs 4T, 3S, and 3M are similar to those from models with good fit (runs 3T and 2S; approximately 5,000 mt), and all alternative analyses indicated that current biomass was low relative to $B_{MSY}$, and current F is high relative to $F_{MSY}$. Mean square error and bootstrap variance for run 2S was slightly greater than the results for run 3T. Run 2C was considered to be the most reliable, because it did not assume equal catchability of winter and summer fishing effort.

A second set of alternative ASPIC analyses were conducted to investigate sensitivity of estimates to values of survey catchability, because the model estimate of $q_{fall}$ (2.4) is unrealistically high. Three alternative model solutions were performed with catchability for the fall survey set at 1.0, 0.9, and 0.8 to assume complete sampling efficiency during daytime, 90% efficiency, and 80% efficiency, respectively. Setting $q_{fall}$ to lower than 0.8 resulted in unstable solutions. As expected, estimates of biomass, MSY and $B_{MSY}$ are inversely proportional to the assumed value of $q_{fall}$, but the perception of current stock status worsens as $q_{fall}$ decreases (i.e., $B_{1999}/B_{MSY}$ decreases and $F_{1998}/F_{MSY}$ increases; Table C12). Model variance is greater when $q_{fall}$ is removed from the estimation, and increases as the assumed value of $q_{fall}$ decreases. For example, 15% of bootstrap trials did not converge, and the 80% confidence interval of MSY was 4,620 mt to 47,220 mt (IQR=288%) when $q_{fall}$ was assumed to be 1.0. Results from these alternative analyses suggest that the unconstrained ASPIC solution may underestimate MSY and may be overly optimistic with respect to current stock conditions.

The previous stock assessment of *L. pealeii* further recommended that season-specific production functions should be investigated, because growth of summer-hatched squid was greater than growth of winter-hatched squid, and apparent biomass is consistently greater from the fall survey than the spring survey (NEFSC 1996, Brodziak 1998). It is possible that ASPIC explained a small portion of total variance in observed biomass indices because it assumed constant production parameters. A model building exercise was conducted to test for changes in production parameters using an approach described by Fournier (1999). The parameters $B1$, $r$, $K$, and $q_i$ were set at the estimated values for a 'second phase' of estimation to evaluate the effect of an additional parameter that accounts for seasonal change in $r$. The parameter $r$ was assumed to vary over time according to a time vector of quantities $r_t$ consisting of an overall mean $r$ and a set of deviations ($\delta_t$) from the mean, where t is a quarter-year time step (1 to 4):

$$r_t = r + \delta_t \qquad \text{where } \textstyle\sum \delta_t = 0 \qquad (10)$$

A regular pattern of $\delta_t$ was assumed:

$$\delta_t = \boldsymbol{s} \cdot \cos(t \cdot \pi/2) \qquad (11)$$

and

$$r_t = r + \boldsymbol{s} \cdot \cos(t \cdot \pi/2) \qquad (12)$$

where $s$ is the maximum absolute seasonal deviation from $r$. This assumes that $r_t$ is at the greatest value ($r + s$) during the fourth quarter (i.e., during the fall survey of summer-hatched individuals); is at the lowest value ($r - s$) during the second quarter (i.e., during the spring survey of winter-hatched individuals); and isat an average value ($r + 0$) during the first and third quarters (Figure C22).

The parameter $\boldsymbol{s}$ was estimated by minimizing lognormal residuals ($\epsilon$) of a discrete-time approximation of equation 6:

$$B_{t+1} = B_t + r_t B_t - (r_t/K)B_t^2 - Y_t + e^{\epsilon} \quad (13)$$

The residual sum of squares was minimized at a solution of $s$ = 0.0017 (Figure C23), which implies that $r_t$ = 0.516 in the spring and 0.519 in the fall, and that MSY is only slightly greater in the fall (5,040 mt) than in the spring (5,010 mt). The estimated biomass trajectory from the seasonal production model was nearly identical to the estimates from ASPIC (Figure C24). However, the reduction in mean square error was insignificant (P=0.53, F-test, Sokal and Rohlf 1995), and adding the parameter did not significantly improve the model.

Another production parameter that may vary seasonally is the carrying capacity ($K$), because the available resources and density dependent effects may change as squid move from inshore, summer habitats to offshore, winter habitats. A parameter $\boldsymbol{k}$, the maximum absolute deviation from $K$, was also tested using second stage estimation:

$$K_t = K + \boldsymbol{k} \cdot \cos(t \cdot \pi/2) \qquad (14)$$

Similar to the results for s, the estimated value of $\boldsymbol{k}$ was relatively small (<2,000 mt; and adding the parameter did not result in a significant improvement to the model. Estimating both $\boldsymbol{s}$ and $\boldsymbol{k}$ simultaneously was also attempted, but solutions were similar to those from separate estimations (Figure C25). Less restrictive patterns of seasonal deviations than the simple cosine amplitude parameter were unsuccessful, because converged solutions could not be found. More complicated models included adding four parameters (i.e., $\delta_{spring}$, $\delta_{summer}$, $\delta_{fall}$, $\delta_{winter}$) and adding two parameters for amplitude ($\boldsymbol{s}$) and phase ($c$, where $\delta_t = s \cdot \cos[(t+c) \cdot \pi/2]$) were attempted by did not converge on a solution.

Presumably, if population growth was substantially greater in the fall than in the spring, the revised models would explain a significantly greater portion of the variance in biomass indices. It appears that resolution in biomass indices is not sufficient to detect a significant seasonal difference in productivity. Perhaps the disparate components of production (e.g., natural mortality rate, reproductive rate) offset seasonal differences in individual growth rate and geographic ranges. However, results of second stage estimations are conditional on the accuracy of results from the first stage. A more fruitful extension of the simple production model may be to incorporate response to trends in predator biomass.

## WORKING GROUP DISCUSSION

The Invertebrate Working Group reviewed and discussed the analyses and results above, and reached consensus on the following items, organized by specific terms of reference and miscellaneous assessment decisions:

Update status of the fishery. NMFS fall, winter and spring survey data, surplus production model runs, and results from length based virtual population analyses all indicate declines in stock size across broad geographic areas since 1990. Massachusetts survey data indicate low abundance locally since 1991. Recent CPUE data (preliminary and un-audited) indicate catch rates varied without trend after 1994. The Working Group agreed that spring and fall NMFS survey data were the most reliable and concluded that abundance appears to have declined since 1990. The decline in abundance, together with relatively stable catches, likely resulted in increased exploitation rates after 1990 and this pattern is reflected in time series plots of the simple exploitation index computed as catch divided by survey abundance.

Estimate biological reference points. Biological reference points for males and females combined were re-computed based on new partial recruitment and maturity data. The Working Group decided to use the ascending and descending limbs of the PR vector from LVPA to estimate PR for yield per recruit analysis.

A production model was used in the assessment but the Working Group agreed that we don't have a credible estimate of the absolute magnitude of $F_{MSY}$. However, estimated trends and ratios (such as B/Bmsy) may be useful for status determination.

Determine status with respect to the Amendment 6 overfishing definition. The Working Group did not carry out this term of reference because Council and NMFS staff report the "current" overfishing definition (Amendment 6) has been replaced with definitions in Amendment 8 (subject to publication of final regulations).

Determine status with respect to the SFA overfishing definition. A surplus production model gave estimates of stock biomass less than estimates from the fall survey and this casts doubt on best fit estimates of F for the stock from the surplus production model. It was agreed to use the surplus production model to profile over a range of fall survey $q$ values to determine how well fall survey $q$ and biomass were estimated. Even if point estimates of biomass and F prove unreliable, estimated trends and ratios (such as B/Bmsy) may be useful.

In addition to problems described above, F estimates may be biased high due to stock outside the shelf and to the south (outside the range of the survey). This issue was addressed with alternative model runs with fall survey $q$ values of 0.8 and 0.9, 1.0, and best fit. Bootstraps for each alternative run showed that current F exceeds $F_{MSY}$ with high probability. The Working Group recognized a fundamental problem in its terms of reference that may have wider significance in management of the fishery. The problem is that biological reference points based on fishing mortality are difficult to apply because of difficulties in estimating for F for the stock.

Determine likely rebuilding scenarios. The Working Group specified several F-based scenarios which were evaluated with stochastic projections of production model results. However, results are complicated by difficulties in estimating current biomass, described above.

Examine relationships between the winter and summer fisheries. The Working Group devoted little time to this term of reference due to lack of time. Limited information is provided in the stock assessment document.

Miscellaneous assessment decisions. The Working Group agreed on the following.

- Catch should be analyzed quarterly and models should extend back to 1987 when quarterly catch data become available. However, as a research recommendation, consider extending the time series back by consulting unpublished data on foreign catches.

- Discards and by-catch were likely less than 10% during the period following 1987 when there was no foreign fishery and small enough to be ignored for this assessment. However, discards are an important topic for future research.

- CPUE from interview data and logbooks should not be combined.

- Analytical methods that assume abundance in the spring is less than abundance in the fall should be avoided. Fall survey abundance may be higher than spring survey abundance due to differences in survey catchability parameters.

- Yield-per-recruit analyses can only be completed for combined sex because sex-specific catch at length (used in the LVPA to estimate partial recruitment vectors) is not available.

- Conventional data, modeling tools, and biological reference points seem ill-suited for squid which are short lived, highly variable and difficult to model.

- The seasonally varying production model was more complicated and seemed to provide no additional benefits.

- Real time management based on depletion estimators, changes in fishing seasons and closed/open area management might be investigated as potential management measures.

## SARC DISCUSSION

Data Issues

The SARC discussed the nature of the inshore and offshore fisheries and the representativeness of the sampling. Most of the landings were unclassified and it was believed that the sampling captured the length frequency of the unclassified market category.

The LPUE of the winter and summer fisheries were different, as in previous assessments. It was suggested that further work be done to examine the relationship between the winter fishery LPUE and biomass available in the summer fishery. The CPUE from the trap net fishery on Cape Cod could be used as an alternative index of inshore biomass.

*L. pealeii* have been shown to exhibit diel differences in catchability. The SARC recommended that LPUE be adjusted for time of day if possible. Logbook data and sea sample data since 1994 can be examined for possible adjustments in future assessments.

In the 1960s and 1970s, the landings were much greater from the foreign fleets. A longer time series of biomass indices should be examined to provide some insight into the magnitude of the biomass estimates.

The descriptive exploitation ratios assume that fishable biomass was reflected in the survey indices. The average size of squid in the fishery and survey should be examined. Differences between the two have implications in the relative exploitation indices if fewer large squid appear in the survey.

Although discards appear to be relatively low, discards of small *Loligo* may be higher than estimated. An increase in sampling certain fisheries was suggested.

Modeling Issues

The SARC discussed the dome-shaped PR used in the yield and spawning biomass per recruit model. It was felt that there was some biological basis for the decline in catchability in at the largest sizes. Possible reasons included net avoidance, behavioral changes with size, distribution differences, and reduced fishing effort in spawning areas (e.g., many inshore trawling closures and winter refuges in southern or deep waters).

The SARC suggested possible simulation models to examine the implication of the large variability in the parameters. Particularly applicable to the LVPA to determine if the length distribution of the catch could be simulated under various Fs. Similar Monte Carlo simulations can be performed using the yield per recruit parameters.

The ASPIC model used the combined winter and summer fisheries in one model and estimated a single q. The two fisheries are distinct in time and space and probably have unique q's. It was suggested that an ASPIC run be made separating the fisheries to produce fishery specific q's. It could be done in one run or as a mixing model involving separate ASPIC models. The simpler single run was attempted and accepted as the 'key run'. Additional models incorporating different shape parameters may improve the fit.

It was noted that predation was an important component of squid mortality. The variation in predation may account for some of the variability in the model results. The impact of predation should be considered when developing management advice. The assumption of an additive model of M and F was questioned. M may not be proportional to abundance but rather the result of a constant removal of biomass. Therefore, models with compensatory assumptions, such as ASPIC, may be appropriate.

Management Issues

The management of squid was discussed and a suggestion made that a distribution of effort throughout the year would be more risk averse than periods of intense effort. Spawning occurs year round and removing too much biomass during one period could have negative impacts on the life cycle. *L. pealeii* are a continuous rather than time segregated population. The SARC noted the importance of incoming recruitment to the fishable biomass. In the last 5-7 years, the survey indices have suggested low recruitment. Improving recruitment should be an objective of management. Research recommendations should include further study of recruitment dynamics. Managers may want to consider a management approach which optimizes escapement to ensure continued recruitment.

The current overfishing definition was discussed. A suggestion was made that $F_{max}$ was a poor proxy for $F_{MSY}$ with a low fecundity species. The associated risk of overfishing may be unacceptable. The summer and winter fisheries are distinct and should perhaps have separate F targets. An alternative target such as $F_{0.1}$ for the winter fishery was suggested which would result in little loss in yield. Since the Y/R model for the summer fishery was flat topped, $F_{max}$ was poorly determined. However, it was noted that if the production model was accepted, the estimate of $F_{MSY}$ would be used rather than a proxy and 75% $F_{MSY}$ would be the new target. The current status of the stock was overfished and the projections in the model indicated the rebuilding potential of the species was much faster than modeled in the SFA control rule. The mismatch could result in an overly conservative approach to rebuilding.

## CONCLUSIONS

Although advances have been made in understanding the life history of *L. pealeii*, data on age and growth are extremely variable. Length-based population estimates may not be reliable, because they are sensitive to differences in assumed growth rates. Provisional length-based VPA suggests that fully-recruited fishing mortality is greater than than $F_{max}$, and stock biomass is low (Figure C26).

A surplus production model could only explain a small portion of variance in biomass indices, and survey catchability estimates from the model are probably unrealistic. The provisional surplus production analysis suggests that current biomass is low relative to $B_{MSY}$, and is near the proposed biomass threshold of ½ $B_{MSY}$. There is high probability that fishing mortality exceeded $F_{MSY}$ in 1998 and biomass in 1999 is less than $B_{MSY}$. These results indicate that the stock is approaching an overfished state, and overfishing is occurring. However, the production model also indicates that the stock has demonstrated the ability to quickly rebuild from similarly low stock sizes. Although production model projections are extremely variable, they suggest that F should be reduced to rebuild stock biomass to $B_{MSY}$.

## RESEARCH RECOMMENDATIONS

- Determine ages of archived statoliths from NEFSC maturity sampling.
- Investigate methods and effectiveness of sampling catch at length by sex.
- Investigate methods for monitoring in-season catch rates and size distributions.

- Continue efforts to record landings of squid by species and market category.
- Collect and provide information on target species and discard reason in the observer database.
- Continue research on trophic aspects of *L. pealeii* population dynamics and multispecies interactions.
- More extensive sampling is required to understand geographic and seasonal spawning patterns.
- Investigate the mix of *L. pealeii* and *L. plei* in NEFSC spring survey catches south of Cape Hatteras with respect to the adequacy of species identification and including southern strata in the spring biomass index of *L. pealeii.*
- Investigate the effectiveness of seasonal closures.
- Explore ancillary information on magnitude of biomass, $B_{MSY}$, and K.
- Examine catchability of survey gear for *L. pealeii.*
- Investigate seasonal distribution of historical foreign and domestic catches.

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Table C1. Estimates of *Loligo pealei* annual landings (thousand mt). Estimates for 1982-1998 are from dealer weighout records and include prorated unspecified squid landings.

| Year | U.S. | Foreign | Total |
|---|---|---|---|
| 1963 | 1.294 | 0.000 | 1.294 |
| 1964 | 0.576 | 0.002 | 0.578 |
| 1965 | 0.709 | 0.099 | 0.808 |
| 1966 | 0.772 | 0.226 | 0.998 |
| 1967 | 0.547 | 1.130 | 1.677 |
| 1968 | 1.084 | 2.327 | 3.411 |
| 1969 | 0.899 | 8.643 | 9.542 |
| 1970 | 0.653 | 16.732 | 17.385 |
| 1971 | 0.727 | 17.442 | 18.169 |
| 1972 | 0.725 | 29.009 | 29.734 |
| 1973 | 1.105 | 36.508 | 37.613 |
| 1974 | 2.274 | 32.576 | 34.850 |
| 1975 | 1.621 | 32.180 | 33.801 |
| 1976 | 3.602 | 21.682 | 25.284 |
| 1977 | 1.088 | 15.586 | 16.674 |
| 1978 | 1.291 | 9.355 | 10.646 |
| 1979 | 4.252 | 13.068 | 17.320 |
| 1980 | 3.996 | 19.750 | 23.746 |
| 1981 | 2.316 | 20.212 | 22.528 |
| 1982 | 2.848 | 15.805 | 18.653 |
| 1983 | 10.867 | 11.720 | 22.587 |
| 1984 | 7.689 | 11.031 | 18.720 |
| 1985 | 6.899 | 6.549 | 13.448 |
| 1986 | 11.525 | 4.598 | 16.123 |
| 1987 | 10.367 | 0.002 | 10.369 |
| 1988 | 18.593 | 0.003 | 18.596 |
| 1989 | 23.733 | 0.005 | 23.738 |
| 1990 | 15.399 | 0.000 | 15.399 |
| 1991 | 20.299 | 0.000 | 20.299 |
| 1992 | 19.018 | 0.000 | 19.018 |
| 1993 | 23.020 | 0.000 | 23.020 |
| 1994 | 23.480 | 0.000 | 23.480 |
| 1995 | 18.880 | 0.000 | 18.880 |
| 1996 | 12.026 | 0.000 | 12.026 |
| 1997 | 16.308 | 0.000 | 16.308 |
| 1998 | 18.385 | 0.000 | 18.385 |
| average | 8.024 | 9.062 | 17.086 |

Table C2. Estimates of *Loligo pealei* quarterly landings (thousand mt) from dealer weighout records, including prorated unspecified squid landings.

| | quarter | | | | | quarter | | | |
|---|---|---|---|---|---|---|---|---|---|
| year | 1 | 2 | 3 | 4 | sum | 1 | 2 | 3 | 4 |
| 1987 | 2.505 | 4.265 | 1.815 | 1.782 | 10.367 | 24% | 41% | 18% | 17% |
| 1988 | 3.404 | 7.589 | 3.451 | 4.149 | 18.593 | 18% | 41% | 19% | 22% |
| 1989 | 9.838 | 6.919 | 1.164 | 5.812 | 23.733 | 41% | 29% | 5% | 24% |
| 1990 | 4.538 | 3.847 | 2.933 | 4.081 | 15.399 | 29% | 25% | 19% | 27% |
| 1991 | 2.877 | 6.297 | 3.443 | 7.682 | 20.299 | 14% | 31% | 17% | 38% |
| 1992 | 7.211 | 3.531 | 2.061 | 6.214 | 19.018 | 38% | 19% | 11% | 33% |
| 1993 | 11.438 | 4.736 | 1.725 | 5.121 | 23.02 | 50% | 21% | 7% | 22% |
| 1994 | 4.762 | 2.285 | 6.603 | 9.830 | 23.48 | 20% | 10% | 28% | 42% |
| 1995 | 5.815 | 3.820 | 3.933 | 5.312 | 18.88 | 31% | 20% | 21% | 28% |
| 1996 | 5.201 | 4.648 | 1.019 | 1.158 | 12.026 | 43% | 39% | 8% | 10% |
| 1997 | 3.347 | 2.961 | 2.753 | 7.248 | 16.308 | 21% | 18% | 17% | 44% |
| 1998 | 10.479 | 1.976 | 1.099 | 4.831 | 18.385 | 57% | 11% | 6% | 26% |
| average | 5.951 | 4.406 | 2.667 | 5.268 | 18.292 | 32% | 25% | 15% | 28% |

Table C3. Geographic distribution of *Loligo pealei* quarterly landings from dealer weighout records and logbook data.

| **1994** | | | quarter | | |
|---|---|---|---|---|---|
| area | 1 | 2 | 3 | 4 | sum |
| 52 | 2% | 0% | 0% | 0% | 2% |
| 53 | 4% | 4% | 15% | 9% | 32% |
| 61 | 9% | 2% | 12% | 18% | 41% |
| 62 | 5% | 2% | 1% | 11% | 19% |
| 63 | 0% | 2% | 1% | 3% | 6% |
| sum | 20% | 10% | 28% | 42% | 100% |

| **1995** | | | quarter | | |
|---|---|---|---|---|---|
| area | 1 | 2 | 3 | 4 | sum |
| 52 | 3% | 2% | 0% | 0% | 5% |
| 53 | 7% | 8% | 6% | 3% | 24% |
| 61 | 12% | 6% | 9% | 9% | 37% |
| 62 | 9% | 4% | 5% | 14% | 31% |
| 63 | 0% | 0% | 0% | 2% | 3% |
| sum | 31% | 20% | 21% | 28% | 100% |

| **1996** | | | quarter | | |
|---|---|---|---|---|---|
| area | 1 | 2 | 3 | 4 | sum |
| 52 | 12% | 1% | 0% | 0% | 13% |
| 53 | 22% | 1% | 0% | 0% | 23% |
| 61 | 42% | 0% | 0% | 0% | 43% |
| 62 | 18% | 0% | 0% | 0% | 19% |
| 63 | 1% | 0% | 0% | 0% | 2% |
| sum | 97% | 2% | 0% | 1% | 100% |

| **1997** | | | quarter | | |
|---|---|---|---|---|---|
| area | 1 | 2 | 3 | 4 | sum |
| 52 | 0% | 1% | 0% | 0% | 1% |
| 53 | 3% | 10% | 2% | 8% | 24% |
| 61 | 7% | 6% | 11% | 27% | 51% |
| 62 | 10% | 1% | 3% | 6% | 20% |
| 63 | 0% | 0% | 0% | 3% | 4% |
| sum | 21% | 18% | 17% | 44% | 100% |

| **1998** | | | quarter | | |
|---|---|---|---|---|---|
| area | 1 | 2 | 3 | 4 | sum |
| 52 | 5% | 0% | 0% | 8% | 13% |
| 53 | 13% | 2% | 1% | 6% | 23% |
| 61 | 23% | 3% | 3% | 6% | 35% |
| 62 | 15% | 5% | 1% | 2% | 23% |
| 63 | 0% | 0% | 0% | 4% | 5% |
| sum | 57% | 11% | 6% | 26% | 100% |

Table C4a. Samples of *Loligo pealeii* catch at length (number of lengths measured).

| | | market category | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 8010 | 8011 | 8012 | 8013 | 8014 | 8015 | |
| year | quarter | unclassified | large | small | medium | booger | extra large | sum |
| 1987 | 1 | 518 | 49 | | | | | 567 |
| | 2 | 1063 | | | | | | 1063 |
| | 3 | 310 | | | | | | 310 |
| | 4 | 558 | | | | | | 558 |
| 1988 | 1 | 510 | | | | | | 510 |
| | 2 | 1665 | | | | | | 1665 |
| | 3 | 519 | | | | | | 519 |
| | 4 | 459 | | | | | | 459 |
| 1989 | 1 | 892 | | | | | | 892 |
| | 2 | 1682 | | | | | | 1682 |
| | 3 | 763 | | | | | | 763 |
| | 4 | 1118 | | | | | | 1118 |
| 1990 | 1 | 1331 | | | | | | 1331 |
| | 2 | 1760 | 50 | | | | | 1810 |
| | 3 | 658 | 52 | | | | | 710 |
| | 4 | 1154 | 50 | | | | | 1204 |
| 1991 | 1 | 756 | 152 | | | | | 908 |
| | 2 | 1214 | 50 | | | | | 1264 |
| | 3 | 600 | 50 | | | | | 650 |
| | 4 | 1056 | | | | | | 1056 |
| 1992 | 1 | 954 | | | | | | 954 |
| | 2 | 929 | 50 | | | | | 979 |
| | 3 | 975 | | | | | | 975 |
| | 4 | 994 | | | | | | 994 |
| 1993 | 1 | 968 | | | | | | 968 |
| | 2 | 584 | 151 | | | | | 735 |
| | 3 | 351 | | | | | | 351 |
| | 4 | 815 | | | | | | 815 |
| 1994 | 1 | 766 | | | | | | 766 |
| | 2 | 638 | | 50 | | | | 688 |
| | 3 | 1034 | 212 | 119 | 253 | | | 1618 |
| | 4 | 1024 | 104 | 167 | 68 | | 32 | 1395 |
| 1995 | 1 | 1020 | 731 | 315 | 481 | | | 2547 |
| | 2 | 555 | 275 | | | | | 830 |
| | 3 | 542 | | | | | | 542 |
| | 4 | 253 | 94 | | | | | 347 |
| 1996 | 1 | 1588 | 315 | | | | | 1903 |
| | 2 | 388 | 50 | | | | | 438 |
| | 3 | 636 | 111 | | | | | 747 |
| | 4 | 2509 | 757 | | | | | 3266 |
| 1997 | 1 | 3082 | 770 | 836 | | | | 4688 |
| | 2 | 2603 | 198 | 100 | 100 | 100 | | 3101 |
| | 3 | 1451 | 591 | 100 | | | | 2142 |
| | 4 | 1823 | 206 | 100 | | 100 | | 2229 |
| 1998 | 1 | 3533 | 1344 | 106 | | | | 4983 |
| | 2 | 998 | 199 | | | | | 1197 |
| | 3 | 414 | | | | | | 414 |
| sum | | 50013 | 6611 | 1893 | 902 | 200 | 32 | 59651 |

Table C4b. Proportion of *L. pealei* quarterly landings by market category.

| | | | | market | category | | |
|---|---|---|---|---|---|---|---|
| | | 8010 | 8011 | 8012 | 8013 | 8014 | 8015 |
| year | quarter | unclass. | large | small | medium | booger | extra large |
| 1987 | 1 | 0.94 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 |
| | 2 | 0.95 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 |
| | 3 | 0.98 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 4 | 0.95 | 0.01 | 0.04 | 0.00 | 0.00 | 0.00 |
| 1988 | 1 | 0.83 | 0.05 | 0.12 | 0.00 | 0.00 | 0.00 |
| | 2 | 0.97 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 3 | 0.83 | 0.02 | 0.15 | 0.00 | 0.00 | 0.00 |
| | 4 | 0.67 | 0.06 | 0.27 | 0.00 | 0.00 | 0.00 |
| 1989 | 1 | 0.66 | 0.05 | 0.29 | 0.00 | 0.00 | 0.00 |
| | 2 | 0.93 | 0.03 | 0.05 | 0.00 | 0.00 | 0.00 |
| | 3 | 0.89 | 0.02 | 0.08 | 0.00 | 0.00 | 0.00 |
| | 4 | 0.80 | 0.04 | 0.16 | 0.00 | 0.00 | 0.00 |
| 1990 | 1 | 0.89 | 0.05 | 0.03 | 0.03 | 0.00 | 0.00 |
| | 2 | 0.92 | 0.04 | 0.01 | 0.02 | 0.00 | 0.01 |
| | 3 | 0.93 | 0.03 | 0.02 | 0.00 | 0.01 | 0.00 |
| | 4 | 0.84 | 0.06 | 0.07 | 0.02 | 0.01 | 0.00 |
| 1991 | 1 | 0.89 | 0.06 | 0.02 | 0.01 | 0.02 | 0.00 |
| | 2 | 0.89 | 0.07 | 0.01 | 0.02 | 0.01 | 0.00 |
| | 3 | 0.97 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 4 | 0.96 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 1 | 0.97 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2 | 0.95 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 3 | 0.97 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 4 | 0.98 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 1 | 0.95 | 0.02 | 0.01 | 0.02 | 0.00 | 0.00 |
| | 2 | 0.93 | 0.05 | 0.00 | 0.02 | 0.00 | 0.00 |
| | 3 | 0.96 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 |
| | 4 | 0.89 | 0.07 | 0.01 | 0.03 | 0.00 | 0.00 |
| 1994 | 1 | 0.81 | 0.09 | 0.04 | 0.02 | 0.04 | 0.00 |
| | 2 | 0.72 | 0.14 | 0.05 | 0.04 | 0.04 | 0.02 |
| | 3 | 0.84 | 0.05 | 0.05 | 0.05 | 0.01 | 0.00 |
| | 4 | 0.70 | 0.16 | 0.05 | 0.04 | 0.04 | 0.00 |
| 1995 | 1 | 0.57 | 0.10 | 0.10 | 0.07 | 0.15 | 0.00 |
| | 2 | 0.73 | 0.09 | 0.05 | 0.04 | 0.08 | 0.01 |
| | 3 | 0.54 | 0.11 | 0.11 | 0.22 | 0.02 | 0.00 |
| | 4 | 0.68 | 0.07 | 0.14 | 0.05 | 0.05 | 0.00 |
| 1996 | 1 | 0.63 | 0.08 | 0.15 | 0.08 | 0.06 | 0.00 |
| | 2 | 0.53 | 0.20 | 0.10 | 0.15 | 0.01 | 0.01 |
| | 3 | 0.74 | 0.20 | 0.01 | 0.01 | 0.04 | 0.00 |
| | 4 | 0.82 | 0.04 | 0.08 | 0.02 | 0.04 | 0.00 |
| 1997 | 1 | 0.72 | 0.06 | 0.14 | 0.03 | 0.05 | 0.00 |
| | 2 | 0.69 | 0.12 | 0.09 | 0.06 | 0.03 | 0.00 |
| | 3 | 0.69 | 0.11 | 0.11 | 0.04 | 0.05 | 0.00 |
| | 4 | 0.67 | 0.07 | 0.11 | 0.05 | 0.10 | 0.00 |
| 1998 | 1 | 0.60 | 0.07 | 0.15 | 0.07 | 0.11 | 0.00 |
| | 2 | 0.54 | 0.16 | 0.12 | 0.10 | 0.07 | 0.01 |
| | 3 | 0.76 | 0.13 | 0.04 | 0.02 | 0.05 | 0.00 |
| | 4 | 0.54 | 0.08 | 0.16 | 0.05 | 0.17 | 0.00 |
| sum | | 0.80 | 0.06 | 0.07 | 0.03 | 0.03 | 0.00 |

Table C5. Observed trips, kept catch (kept mt), discarded catch (disc. mt), and discard ratios from all otter trawl trips that landed *Loligo pealeii.*

| | | quarter | | | | |
|---|---|---|---|---|---|---|
| year | | 1 | 2 | 3 | 4 | sum |
| 1989 | # trips | 14 | 20 | 30 | 25 | 89 |
| | mt kept | 24.1 | 17.2 | 7.2 | 25.1 | 73.6 |
| | mt disc | 1.5 | 0.3 | 4.1 | 1.3 | 7.2 |
| | ratio | 0.06 | 0.02 | 0.57 | 0.05 | 0.10 |
| 1990 | # trips | 14 | 23 | 8 | 27 | 72 |
| | mt kept | 17.5 | 5.9 | 0.1 | 4.5 | 27.8 |
| | mt disc | 0.7 | 0.2 | 0.0 | 1.4 | 2.3 |
| | ratio | 0.04 | 0.03 | 0.35 | 0.32 | 0.08 |
| 1991 | # trips | 23 | 17 | 20 | 72 | 132 |
| | mt kept | 12.0 | 5.9 | 37.6 | 71.5 | 126.9 |
| | mt disc | 0.9 | 0.4 | 1.1 | 2.8 | 5.2 |
| | ratio | 0.07 | 0.07 | 0.03 | 0.04 | 0.04 |
| 1992 | # trips | 45 | 12 | 10 | 26 | 93 |
| | mt kept | 39.7 | 1.4 | 0.9 | 28.2 | 70.1 |
| | mt disc | 2.7 | 0.1 | 1.1 | 1.5 | 5.4 |
| | ratio | 0.07 | 0.06 | 1.21 | 0.05 | 0.08 |
| 1993 | # trips | 14 | 24 | 12 | 22 | 72 |
| | mt kept | 25.2 | 2.4 | 2.4 | 7.4 | 37.5 |
| | mt disc | 1.5 | 0.1 | 2.3 | 1.4 | 5.3 |
| | ratio | 0.06 | 0.03 | 0.97 | 0.19 | 0.14 |
| 1994 | # trips | 18 | 15 | 18 | 25 | 76 |
| | mt kept | 13.9 | 1.3 | 0.1 | 5.8 | 21.1 |
| | mt disc | 0.8 | 0.5 | 0.0 | 0.7 | 2.0 |
| | ratio | 0.06 | 0.35 | 0.26 | 0.12 | 0.10 |
| 1995 | # trips | 25 | 39 | 40 | 39 | 143 |
| | mt kept | 3.3 | 6.0 | 10.9 | 1.3 | 21.6 |
| | mt disc | 1.0 | 0.4 | 0.5 | 0.2 | 2.1 |
| | ratio | 0.30 | 0.06 | 0.05 | 0.16 | 0.10 |
| 1996 | # trips | 12 | 38 | 39 | 34 | 123 |
| | mt kept | 12.6 | 6.2 | 4.4 | 3.9 | 27.1 |
| | mt disc | 0.7 | 0.2 | 0.2 | 0.1 | 1.2 |
| | ratio | 0.05 | 0.03 | 0.05 | 0.02 | 0.04 |
| 1997 | # trips | 33 | 16 | 20 | 5 | 74 |
| | mt kept | 15.8 | 3.8 | 26.6 | 8.3 | 54.4 |
| | mt disc | 2.3 | 0.4 | 1.3 | 0.0 | 4.0 |
| | ratio | 0.15 | 0.09 | 0.05 | 0.00 | 0.07 |
| 1998 | # trips | 27 | 7 | 6 | 1 | 41 |
| | mt kept | 70.1 | 11.7 | 1.8 | 0.0 | 83.6 |
| | mt disc | 0.5 | 0.0 | 0.0 | 0.0 | 0.5 |
| | ratio | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 |
| sum | # trips | 225 | 211 | 203 | 276 | 915 |
| | mt kept | 234.1 | 61.9 | 92.0 | 156.0 | 543.9 |
| | mt disc | 12.5 | 2.5 | 10.7 | 9.4 | 35.1 |
| | ratio | 0.05 | 0.04 | 0.12 | 0.06 | 0.06 |

Table C6. NEFSC survey estimates *Loligo pealeii* biomass (B in thousand mt), abundance (N in millions), abundance of precrecruits (prerec; ≤ 8 cm ML), and abundance of recruits (> 8 cm ML). Catch data are adjusted for season-specific diel differences and exclude short tows. Strata for spring and winter survey indices are 1-23, 25, 61-76, and strata for winter survey indices are 1-17, 61-76. Fall plus following spring biomass for annual assessment of stock biomass relative to the Amendment #8 $B_{MSY}$ proxy (80,000 mt).

| year | fall B | fall N | fall prerec | fall recruit | winter B | winter N | winter prerec | winter recruit | spring B | spring N | spring prerec | spring recruit | fall + spring B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1967 | 20.9 | 917 | 747 | 171 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 1968 | 35.2 | 1155 | 807 | 348 | ---- | ---- | ---- | ---- | 6.5 | 130 | 42 | 88 | 27.5 |
| 1969 | 45.6 | 1542 | 1098 | 444 | ---- | ---- | ---- | ---- | 4.3 | 67 | 11 | 56 | 39.5 |
| 1970 | 21.2 | 723 | 504 | 218 | ---- | ---- | ---- | ---- | 3.7 | 120 | 81 | 39 | 49.2 |
| 1971 | 14.8 | 936 | 784 | 153 | ---- | ---- | ---- | ---- | 6.8 | 156 | 94 | 62 | 28.0 |
| 1972 | 40.8 | 2143 | 1804 | 340 | ---- | ---- | ---- | ---- | 12.5 | 302 | 176 | 126 | 27.3 |
| 1973 | 60.9 | 2502 | 1880 | 622 | ---- | ---- | ---- | ---- | 11.6 | 194 | 91 | 103 | 52.4 |
| 1974 | 51.2 | 2129 | 1668 | 461 | ---- | ---- | ---- | ---- | 17.5 | 1043 | 890 | 153 | 78.4 |
| 1975 | 72.7 | 4261 | 3640 | 620 | ---- | ---- | ---- | ---- | 18.0 | 744 | 571 | 173 | 69.2 |
| 1976 | 64.9 | 3220 | 2604 | 616 | ---- | ---- | ---- | ---- | 23.2 | 967 | 760 | 207 | 96.0 |
| 1977 | 52.2 | 2909 | 2440 | 468 | ---- | ---- | ---- | ---- | 3.8 | 82 | 45 | 37 | 68.7 |
| 1978 | 25.8 | 1078 | 788 | 290 | ---- | ---- | ---- | ---- | 5.8 | 236 | 179 | 57 | 58.0 |
| 1979 | 26.1 | 1658 | 1449 | 208 | ---- | ---- | ---- | ---- | 9.8 | 495 | 417 | 78 | 35.6 |
| 1980 | 48.7 | 5850 | 5369 | 481 | ---- | ---- | ---- | ---- | 7.6 | 249 | 181 | 68 | 33.8 |
| 1981 | 31.9 | 1581 | 1246 | 336 | ---- | ---- | ---- | ---- | 7.8 | 224 | 138 | 86 | 56.5 |
| 1982 | 39.8 | 2085 | 1811 | 274 | ---- | ---- | ---- | ---- | 8.9 | 338 | 236 | 102 | 40.8 |
| 1983 | 62.1 | 2613 | 1918 | 695 | ---- | ---- | ---- | ---- | 10.6 | 234 | 95 | 138 | 50.3 |
| 1984 | 69.4 | 2134 | 1292 | 842 | ---- | ---- | ---- | ---- | 11.8 | 352 | 246 | 106 | 73.9 |
| 1985 | 69.2 | 3349 | 2634 | 715 | ---- | ---- | ---- | ---- | 9.6 | 407 | 310 | 98 | 79.0 |
| 1986 | 52.6 | 2995 | 2501 | 495 | ---- | ---- | ---- | ---- | 13.1 | 471 | 337 | 134 | 82.2 |
| 1987 | 12.8 | 464 | 330 | 134 | ---- | ---- | ---- | ---- | 8.7 | 145 | 63 | 82 | 61.3 |
| 1988 | 47.7 | 3029 | 2586 | 443 | ---- | ---- | ---- | ---- | 15.8 | 591 | 429 | 162 | 28.6 |
| 1989 | 63.3 | 2933 | 2155 | 779 | ---- | ---- | ---- | ---- | 21.5 | 695 | 423 | 273 | 69.2 |
| 1990 | 55.9 | 2781 | 2218 | 563 | ---- | ---- | ---- | ---- | 15.4 | 634 | 480 | 154 | 78.7 |
| 1991 | 53.6 | 2374 | 1744 | 630 | ---- | ---- | ---- | ---- | 19.2 | 852 | 634 | 218 | 75.1 |
| 1992 | 43.2 | 5273 | 5064 | 208 | 7.2 | 216 | 146 | 70 | 10.2 | 403 | 313 | 91 | 63.8 |
| 1993 | 25.9 | 1058 | 718 | 339 | 14.7 | 510 | 299 | 211 | 8.1 | 227 | 131 | 96 | 51.3 |
| 1994 | 80.4 | 3342 | 2465 | 878 | 7.3 | 222 | 150 | 72 | 4.7 | 161 | 113 | 48 | 30.6 |
| 1995 | 33.1 | 2078 | 1788 | 290 | 12.5 | 387 | 225 | 162 | 8.8 | 321 | 225 | 96 | 89.2 |
| 1996 | 18.0 | 1068 | 890 | 178 | 8.9 | 267 | 149 | 117 | 2.6 | 118 | 92 | 26 | 35.7 |
| 1997 | 36.1 | 1919 | 1566 | 352 | 6.6 | 221 | 130 | 90 | 8.7 | 382 | 271 | 111 | 26.7 |
| 1998 | 25.0 | 1368 | 1084 | 284 | 5.9 | 168 | 84 | 83 | 5.9 | 286 | 216 | 70 | 42.0 |
| mean | 43.8 | 2296 | 1862 | 434 | 9.0 | 284 | 169 | 115 | 10.4 | 375 | 267 | 108 | 54.8 |

Table C7. Massachusetts spring survey indices of *Loligo pealei* abundance and biomass (strata 11-21).

| year | #/tow | kg/tow |
|---|---|---|
| 1978 | 11.3 | 1.1 |
| 1979 | 47.4 | 3.9 |
| 1980 | 38.0 | 5.0 |
| 1981 | 11.5 | 1.1 |
| 1982 | 15.5 | 1.3 |
| 1983 | 85.8 | 6.7 |
| 1984 | 61.9 | 4.3 |
| 1985 | 113.3 | 7.0 |
| 1986 | 48.9 | 6.2 |
| 1987 | 59.8 | 5.9 |
| 1988 | 255.5 | 15.9 |
| 1989 | 64.9 | 5.5 |
| 1990 | 136.3 | 8.9 |
| 1991 | 43.2 | 4.3 |
| 1992 | 10.8 | 1.2 |
| 1993 | 22.5 | 3.4 |
| 1994 | 17.5 | 1.4 |
| 1995 | 117.4 | 4.7 |
| 1996 | 30.8 | 3.1 |
| 1997 | 29.2 | 1.4 |
| 1998 | 46.3 | 0.8 |
| average | 60.4 | 4.4 |

Table C8. Estimates of seasonal age at length (from Brodziak and Macy 1996), duration of 2-mm size classes (Δt), and partial recruitment (PR) from length cohort analysis, 1987-1998.

**Winter Fishery (summer hatched)**

| ML (cm) | Δt | predicted age (m) | geo.mean F | PR |
|---|---|---|---|---|
| 9.5 | 0.49 | 6.2 | 0.11 | 0.05 |
| 11.5 | 0.41 | 6.7 | 0.32 | 0.15 |
| 13.5 | 0.35 | 7.1 | 0.64 | 0.31 |
| 15.5 | 0.31 | 7.5 | 1.01 | 0.48 |
| 17.5 | 0.28 | 7.8 | 1.39 | 0.66 |
| 19.5 | 0.25 | 8.1 | 2.11 | 1.00 |
| 21.5 | 0.23 | 8.3 | 2.17 | 1.00 |
| 23.5 | 0.21 | 8.5 | 2.01 | 1.00 |
| 25.5 | 0.19 | 8.7 | 1.85 | 0.88 |
| 27.5 | 0.18 | 8.9 | 1.09 | 0.52 |

**Summer Fishery (winter hatched)**

| ML (cm) | Δt | predicted age (m) | geo.mean F | PR |
|---|---|---|---|---|
| 9.5 | 0.37 | 5.8 | 0.11 | 0.11 |
| 11.5 | 0.35 | 6.2 | 0.31 | 0.32 |
| 13.5 | 0.33 | 6.6 | 0.50 | 0.52 |
| 15.5 | 0.32 | 6.9 | 0.59 | 0.62 |
| 17.5 | 0.31 | 7.2 | 0.74 | 0.78 |
| 19.5 | 0.30 | 7.5 | 0.93 | 1.00 |
| 21.5 | 0.30 | 7.8 | 0.95 | 1.00 |
| 23.5 | 0.30 | 8.1 | 1.00 | 1.00 |
| 25.5 | 0.31 | 8.4 | 0.81 | 0.85 |
| 27.5 | 0.31 | 8.7 | 0.58 | 0.60 |

Table C9a. Yield and spawning biomass per recruit for summer-hatched (winter fishery) *Loligo pealeii.*

```
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:  1- 6-1999;  Time: 11:08:44.55
LOLIGO summer hatched (winter fishery) - SAW29

Proportion of F before spawning: 1.0000
Proportion of M before spawning: 1.0000
Natural Mortality is Constant at:  .300
Initial age is:  1; Last age is:  9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> LOLIGOS.DAT
```

Age-specific Input data for Yield per Recruit Analysis

| Age | Fish Mort Pattern | Nat Mort Pattern | Proportion Mature | Average Weights Catch | Average Weights Stock |
|---|---|---|---|---|---|
| 1 | .0000 | 1.0000 | .0000 | .000 | .000 |
| 2 | .0000 | 1.0000 | .0000 | .001 | .001 |
| 3 | .0000 | 1.0000 | .0000 | .002 | .002 |
| 4 | .0000 | 1.0000 | .2000 | .006 | .006 |
| 5 | .0000 | 1.0000 | .3000 | .017 | .017 |
| 6 | .0500 | 1.0000 | .7000 | .056 | .056 |
| 7 | .3000 | 1.0000 | 1.0000 | .134 | .134 |
| 8 | 1.0000 | 1.0000 | 1.0000 | .255 | .255 |
| 9+ | .5000 | 1.0000 | 1.0000 | .409 | .409 |

Summary of Yield per Recruit Analysis for:
LOLIGO summer hatched (winter fishery) - SAW29

```
Slope of the Yield/Recruit Curve at F=0.00: -->        .0950
  F level at slope=1/10 of the above slope (F0.1): ----->      .609
    Yield/Recruit corresponding to F0.1: ----->      .0217
  F level to produce Maximum Yield/Recruit (Fmax): ----->    1.243
    Yield/Recruit corresponding to Fmax: ----->      .0238
  F level at 50 % of Max Spawning Potential (F50): ----->     .335
    SSB/Recruit corresponding to F50: -------->      .0768
```

Listing of Yield per Recruit Results for:
LOLIGO summer hatched (winter fishery) - SAW29

| | FMORT | TOTCTHN | TOTCTHW | TOTSTKN | TOTSTKW | SPNSTKN | SPNSTKW | % MSP |
|---|---|---|---|---|---|---|---|---|
| | .000 | .00000 | .00000 | 3.8583 | .2185 | .7154 | .1535 | 100.00 |
| | .100 | .02623 | .00773 | 3.7716 | .1839 | .6290 | .1214 | 79.03 |
| | .200 | .04545 | .01287 | 3.7084 | .1589 | .5660 | .0985 | 64.13 |
| | .300 | .06005 | .01636 | 3.6606 | .1402 | .5184 | .0816 | 53.17 |
| F50% | .335 | .06439 | .01732 | 3.6464 | .1347 | .5043 | .0768 | 50.00 |
| | .400 | .07147 | .01878 | 3.6234 | .1258 | .4814 | .0690 | 44.91 |
| | .500 | .08061 | .02047 | 3.5937 | .1145 | .4520 | .0592 | 38.53 |
| | .600 | .08808 | .02164 | 3.5696 | .1054 | .4282 | .0515 | 33.53 |
| F0.1 | .609 | .08872 | .02173 | 3.5676 | .1046 | .4262 | .0509 | 33.12 |
| | .700 | .09429 | .02245 | 3.5498 | .0980 | .4085 | .0454 | 29.56 |
| | .800 | .09953 | .02300 | 3.5331 | .0919 | .3921 | .0405 | 26.35 |
| | .900 | .10400 | .02336 | 3.5189 | .0868 | .3782 | .0364 | 23.73 |
| | 1.000 | .10787 | .02359 | 3.5068 | .0826 | .3662 | .0331 | 21.57 |
| | 1.100 | .11126 | .02371 | 3.4962 | .0789 | .3559 | .0304 | 19.77 |
| | 1.200 | .11424 | .02375 | 3.4869 | .0758 | .3469 | .0280 | 18.26 |
| Fmax | 1.243 | .11542 | .02376 | 3.4833 | .0746 | .3433 | .0272 | 17.69 |
| | 1.300 | .11690 | .02374 | 3.4787 | .0731 | .3389 | .0261 | 16.98 |
| | 1.400 | .11929 | .02369 | 3.4713 | .0707 | .3318 | .0244 | 15.89 |
| | 1.500 | .12145 | .02362 | 3.4647 | .0686 | .3254 | .0230 | 14.95 |

Table C9b. Yield and spawning biomass per recruit for winter-hatched (summer fishery) *Loligo pealeii*.

```
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:  1- 6-1999;  Time: 11:09:15.80
LOLIGO winter hatched (summer fishery) - SAW29

Proportion of F before spawning: 1.0000
Proportion of M before spawning: 1.0000
Natural Mortality is Constant at:  .300
Initial age is:  1; Last age is:  9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> LOLIGOW.DAT
```

Age-specific Input data for Yield per Recruit Analysis

| Age | Fish Mort Pattern | Nat Mort Pattern | Proportion Mature | Average Weights Catch | Average Weights Stock |
|---|---|---|---|---|---|
| 1 | .0000 | 1.0000 | .0000 | .000 | .000 |
| 2 | .0000 | 1.0000 | .0000 | .001 | .001 |
| 3 | .0000 | 1.0000 | .0000 | .002 | .002 |
| 4 | .0000 | 1.0000 | .0500 | .006 | .006 |
| 5 | .0000 | 1.0000 | .1000 | .016 | .016 |
| 6 | .3000 | 1.0000 | .2000 | .036 | .036 |
| 7 | .7000 | 1.0000 | .5500 | .077 | .077 |
| 8 | 1.0000 | 1.0000 | .8500 | .152 | .152 |
| 9+ | .6000 | 1.0000 | .9800 | .283 | .283 |

```
Summary of Yield per Recruit Analysis for:
LOLIGO winter hatched (summer fishery) - SAW29

 Slope of the Yield/Recruit Curve at F=0.00: -->        .0772
   F level at slope=1/10 of the above slope (F0.1): ----->     .386
     Yield/Recruit corresponding to F0.1: ----->        .0118
   F level to produce Maximum Yield/Recruit (Fmax): ----->     .655
     Yield/Recruit corresponding to Fmax: ----->        .0126
   F level at 50 % of Max Spawning Potential (F50): ----->     .205
     SSB/Recruit corresponding to F50: -------->        .0452
```

Listing of Yield per Recruit Results for:
LOLIGO winter hatched (summer fishery) - SAW29

| | FMORT | TOTCTHN | TOTCTHW | TOTSTKN | TOTSTKW | SPNSTKN | SPNSTKW | % MSP |
|---|---|---|---|---|---|---|---|---|
| | .000 | .00000 | .00000 | 3.8583 | .1477 | .4690 | .0905 | 100.00 |
| | .100 | .03660 | .00582 | 3.7374 | .1160 | .3615 | .0635 | 70.11 |
| | .200 | .06203 | .00908 | 3.6538 | .0946 | .2895 | .0460 | 50.83 |
| F50% | .205 | .06318 | .00921 | 3.6500 | .0937 | .2863 | .0452 | 49.99 |
| | .300 | .08062 | .01091 | 3.5929 | .0796 | .2390 | .0342 | 37.83 |
| F0.1 | .386 | .09298 | .01180 | 3.5526 | .0700 | .2068 | .0270 | 29.86 |
| | .400 | .09474 | .01190 | 3.5469 | .0686 | .2023 | .0260 | 28.78 |
| | .500 | .10582 | .01240 | 3.5110 | .0604 | .1748 | .0202 | 22.31 |
| | .600 | .11473 | .01259 | 3.4824 | .0540 | .1538 | .0159 | 17.60 |
| Fmax | .655 | .11889 | .01261 | 3.4690 | .0512 | .1444 | .0141 | 15.57 |
| | .700 | .12205 | .01260 | 3.4589 | .0491 | .1374 | .0128 | 14.11 |
| | .800 | .12819 | .01250 | 3.4394 | .0451 | .1244 | .0104 | 11.47 |
| | .900 | .13341 | .01234 | 3.4229 | .0419 | .1139 | .0086 | 9.47 |
| | 1.000 | .13792 | .01214 | 3.4087 | .0393 | .1053 | .0072 | 7.91 |
| | 1.100 | .14185 | .01192 | 3.3964 | .0371 | .0982 | .0061 | 6.70 |
| | 1.200 | .14533 | .01170 | 3.3856 | .0353 | .0923 | .0052 | 5.74 |
| | 1.300 | .14844 | .01149 | 3.3760 | .0338 | .0872 | .0045 | 4.98 |
| | 1.400 | .15123 | .01128 | 3.3674 | .0324 | .0829 | .0039 | 4.36 |
| | 1.500 | .15376 | .01108 | 3.3597 | .0313 | .0792 | .0035 | 3.86 |

Table C10. Summary of results from surplus production analysis of *Loligo pealeii*.

| year | quarter | F/Fmsy | B/Bmsy |
|---|---|---|---|
| 1987 | 1 | 0.70 | 0.67 |
| 1987 | 2 | 1.10 | 0.78 |
| 1987 | 3 | 0.42 | 0.80 |
| 1987 | 4 | 0.35 | 0.96 |
| 1988 | 1 | 0.60 | 1.12 |
| 1988 | 2 | 1.38 | 1.20 |
| 1988 | 3 | 0.65 | 1.05 |
| 1988 | 4 | 0.74 | 1.13 |
| 1989 | 1 | 1.97 | 1.16 |
| 1989 | 2 | 1.68 | 0.90 |
| 1989 | 3 | 0.27 | 0.79 |
| 1989 | 4 | 1.24 | 0.98 |
| 1990 | 1 | 0.99 | 0.93 |
| 1990 | 2 | 0.80 | 0.95 |
| 1990 | 3 | 0.57 | 1.00 |
| 1990 | 4 | 0.74 | 1.11 |
| 1991 | 1 | 0.49 | 1.15 |
| 1991 | 2 | 1.07 | 1.24 |
| 1991 | 3 | 0.59 | 1.16 |
| 1991 | 4 | 1.37 | 1.23 |
| 1992 | 1 | 1.46 | 1.07 |
| 1992 | 2 | 0.73 | 0.95 |
| 1992 | 3 | 0.38 | 1.02 |
| 1992 | 4 | 1.12 | 1.17 |
| 1993 | 1 | 2.58 | 1.10 |
| 1993 | 2 | 1.30 | 0.75 |
| 1993 | 3 | 0.43 | 0.74 |
| 1993 | 4 | 1.17 | 0.90 |
| 1994 | 1 | 1.10 | 0.88 |
| 1994 | 2 | 0.49 | 0.89 |
| 1994 | 3 | 1.38 | 1.03 |
| 1994 | 4 | 2.55 | 0.94 |
| 1995 | 1 | 1.92 | 0.66 |
| 1995 | 2 | 1.34 | 0.58 |
| 1995 | 3 | 1.35 | 0.59 |
| 1995 | 4 | 1.94 | 0.60 |
| 1996 | 1 | 2.21 | 0.53 |
| 1996 | 2 | 2.38 | 0.44 |
| 1996 | 3 | 0.40 | 0.36 |
| 1996 | 4 | 0.42 | 0.49 |
| 1997 | 1 | 1.03 | 0.63 |
| 1997 | 2 | 0.83 | 0.69 |
| 1997 | 3 | 0.68 | 0.77 |
| 1997 | 4 | 1.84 | 0.88 |
| 1998 | 1 | 3.93 | 0.74 |
| 1998 | 2 | 0.95 | 0.39 |
| 1998 | 3 | 0.36 | 0.46 |
| 1998 | 4 | 1.66 | 0.61 |
| 1999 | 1 | ---- | 0.57 |
| average | | 1.16 | 0.85 |

Table C11. Summary of results from alternative configurations of biomass indices for surplus production analysis of *Loligo pealeii* (MSY in thousand mt; Bratio: January 1999 biomass/$B_{MSY}$; F ratio: fourth quarter 1998 F/$F_{MSY}$; MSE: mean square error).

| run | biomass indices | MSY | Bratio | Fratio | MSE | notes |
|---|---|---|---|---|---|---|
| 5 | all available indices | | | | | negative correlations |
| 6 | split CPUE index (87-93, 94-98) | | | | | negative correlations |
| 4T | spring, fall, winter, CPUE 87-93 | 4.95 | 0.48 | 1.95 | 0.21 | negative Rsquare |
| 4S | spring, fall, winter, & Mass | 3.65 | 0.38 | 3.31 | 0.32 | negative Rsquare |
| 3S | spring, fall & winter | 4.95 | 0.56 | 1.68 | 0.24 | negative Rsquare |
| 3M | spring,fall & Mass | 4.67 | 0.43 | 2.27 | 0.37 | negative Rsquare |
| 3T | CPUE 87-93, spring & fall | 5.03 | 0.51 | 1.82 | 0.22 | |
| 2S | spring & fall | 5.13 | 0.69 | 1.36 | 0.25 | |
| 2C | seasonal CPUEs, spring & fall | 4.91 | 0.57 | 1.66 | 0.19 | 'key run' |
| 1C | summer CPUE, spring & fall | 5.00 | 0.66 | 1.44 | 0.21 | |

Table C12. Summary of results from alternative surplus production analyses of *L. pealei* with freely estimated catchability for the fall survey (qfall=2.4), and catchability set at 1.0, 0.9 and 0.8 (MSY and Bmsy in thousand mt; Bratio: January 1999 biomass/$B_{MSY}$; Fratio: fourth quarter 1998 F/$F_{MSY}$; SSE: sum of squared error).

| **q(fall)** | **2.4** | **1.0** | **0.9** | **0.8** |
|---|---|---|---|---|
| MSY | 5.03 | 6.94 | 8.38 | 14.64 |
| Bmsy | 19.12 | 92.82 | 133.90 | 292.70 |
| Fmsy | 0.26 | 0.07 | 0.06 | 0.05 |
| q(cpue) | 0.16 | 0.07 | 0.06 | 0.05 |
| q(spring) | 0.69 | 0.27 | 0.24 | 0.21 |
| Bratio | 0.51 | 0.23 | 0.17 | 0.09 |
| Fratio | 1.80 | 2.95 | 3.18 | 3.55 |
| SSE(cpue) | 5.011 | 5.167 | 5.213 | 5.257 |
| SSE(spring) | 2.342 | 2.593 | 2.611 | 2.637 |
| SSE(fall) | 2.688 | 2.869 | 2.885 | 2.900 |

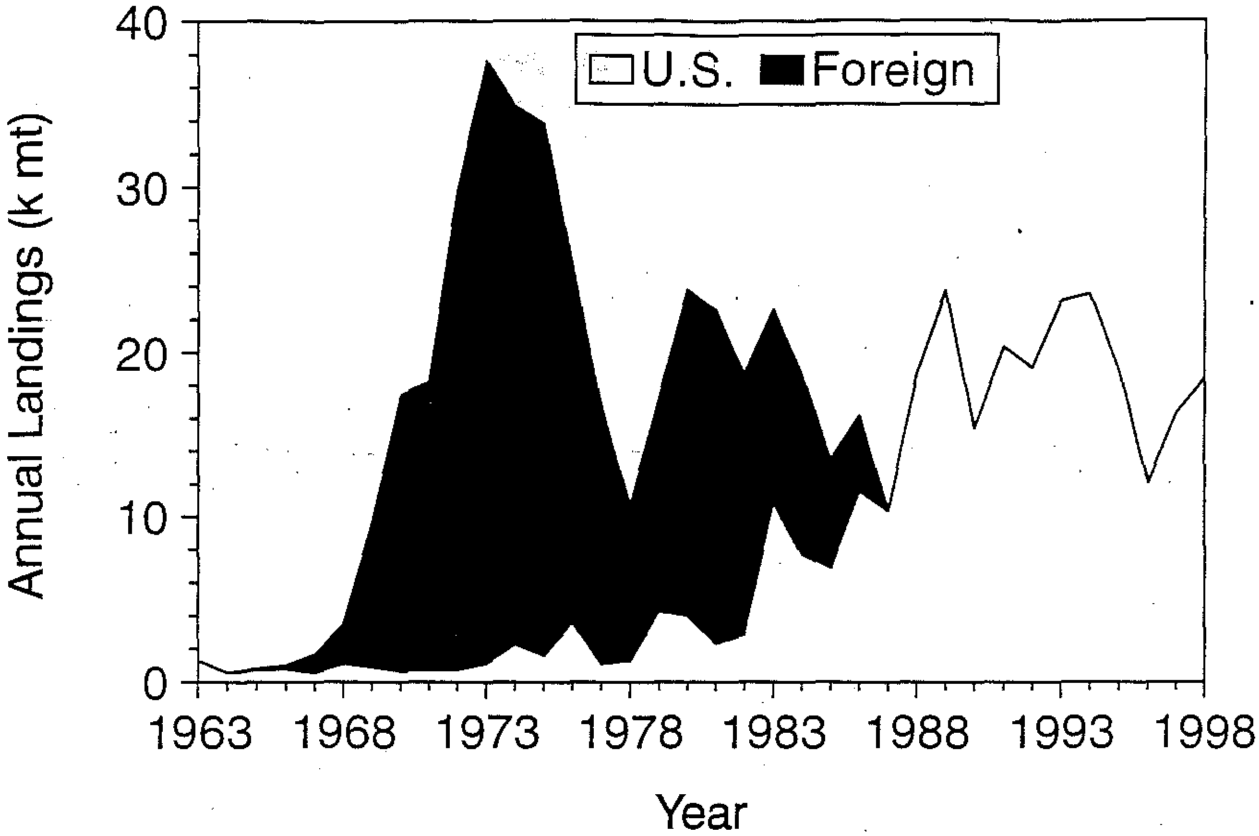



Figure C1. Annual landings of *Loligo pealeii*.

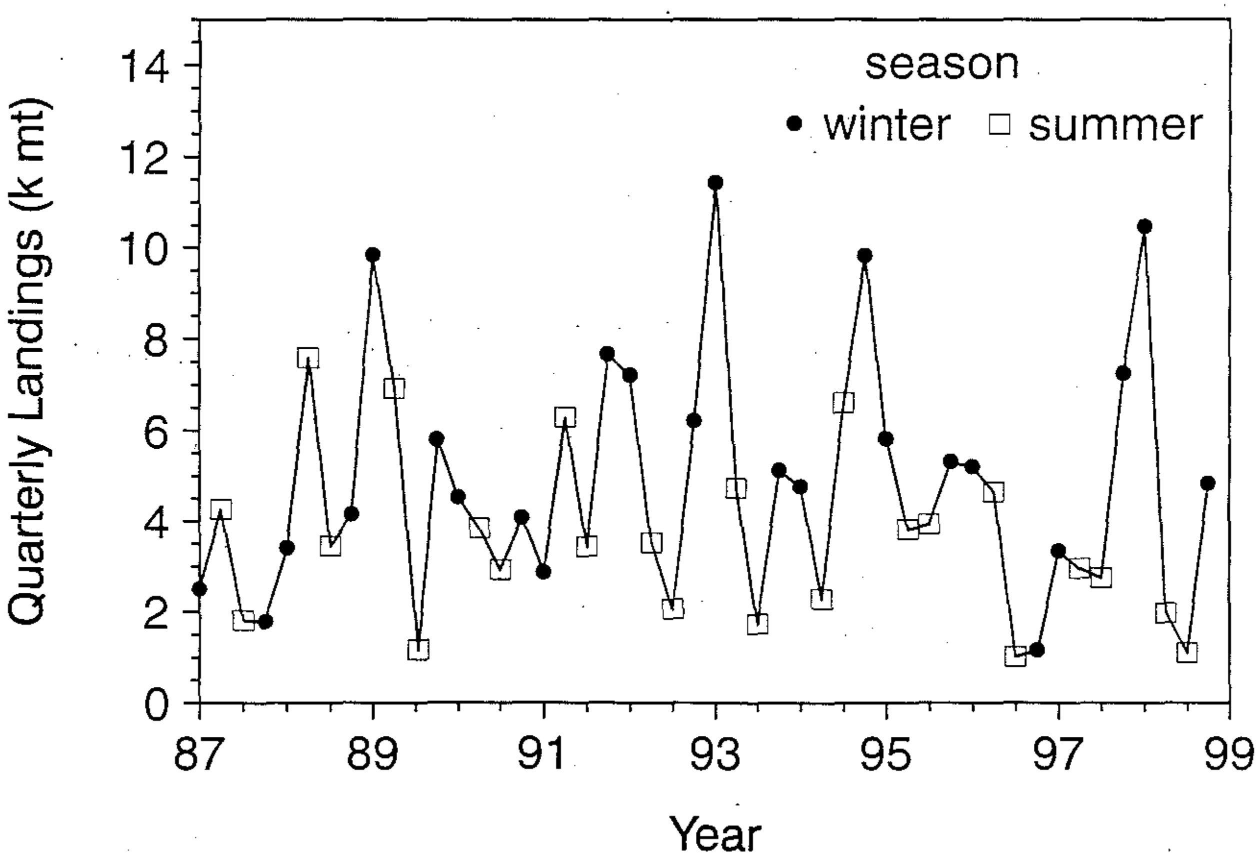



Figure C2. Quarterly landings of *Loligo pealeii*.

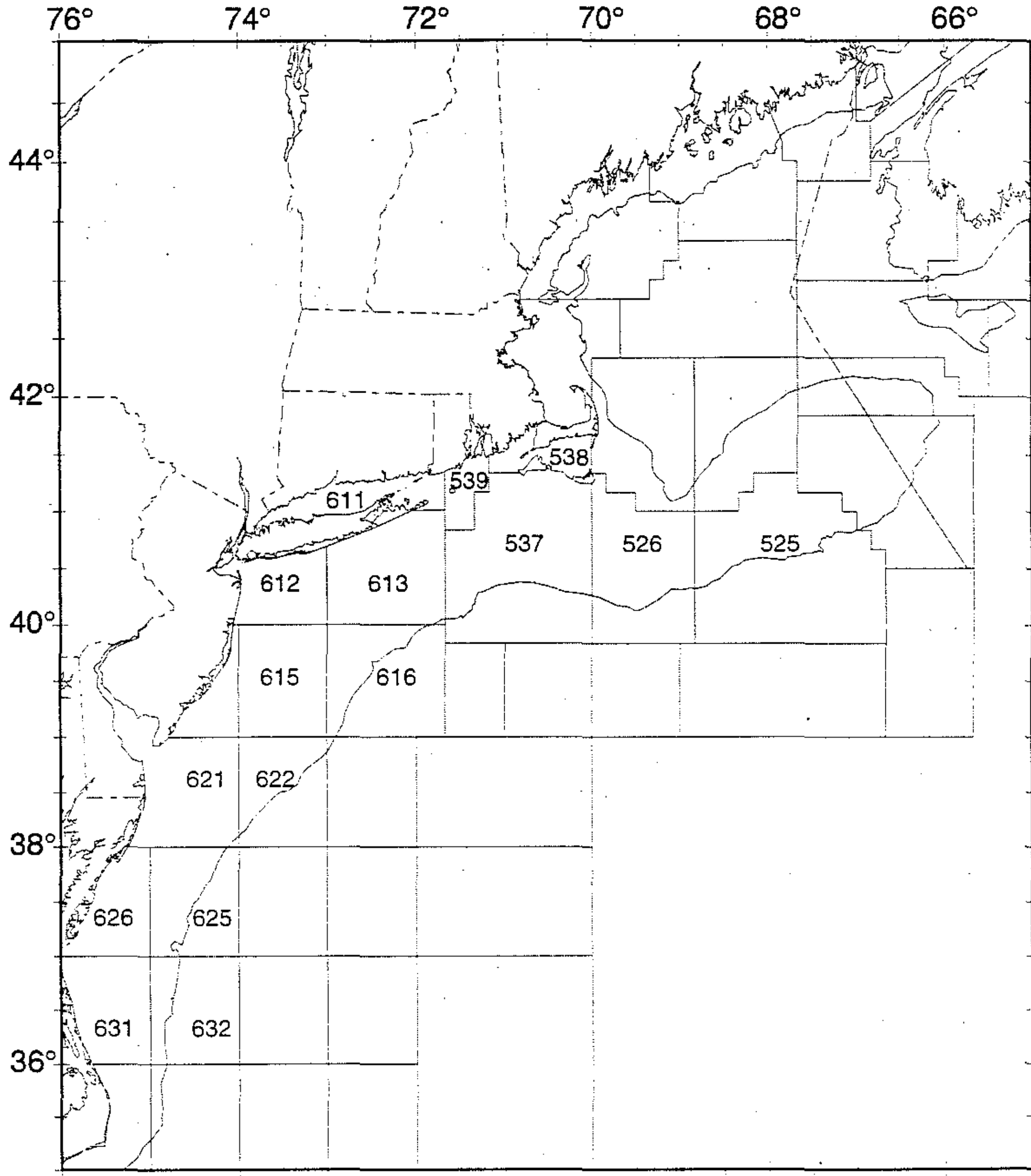



Figure C3. Principal statistical reporting areas of *Loligo pealeii* landings.

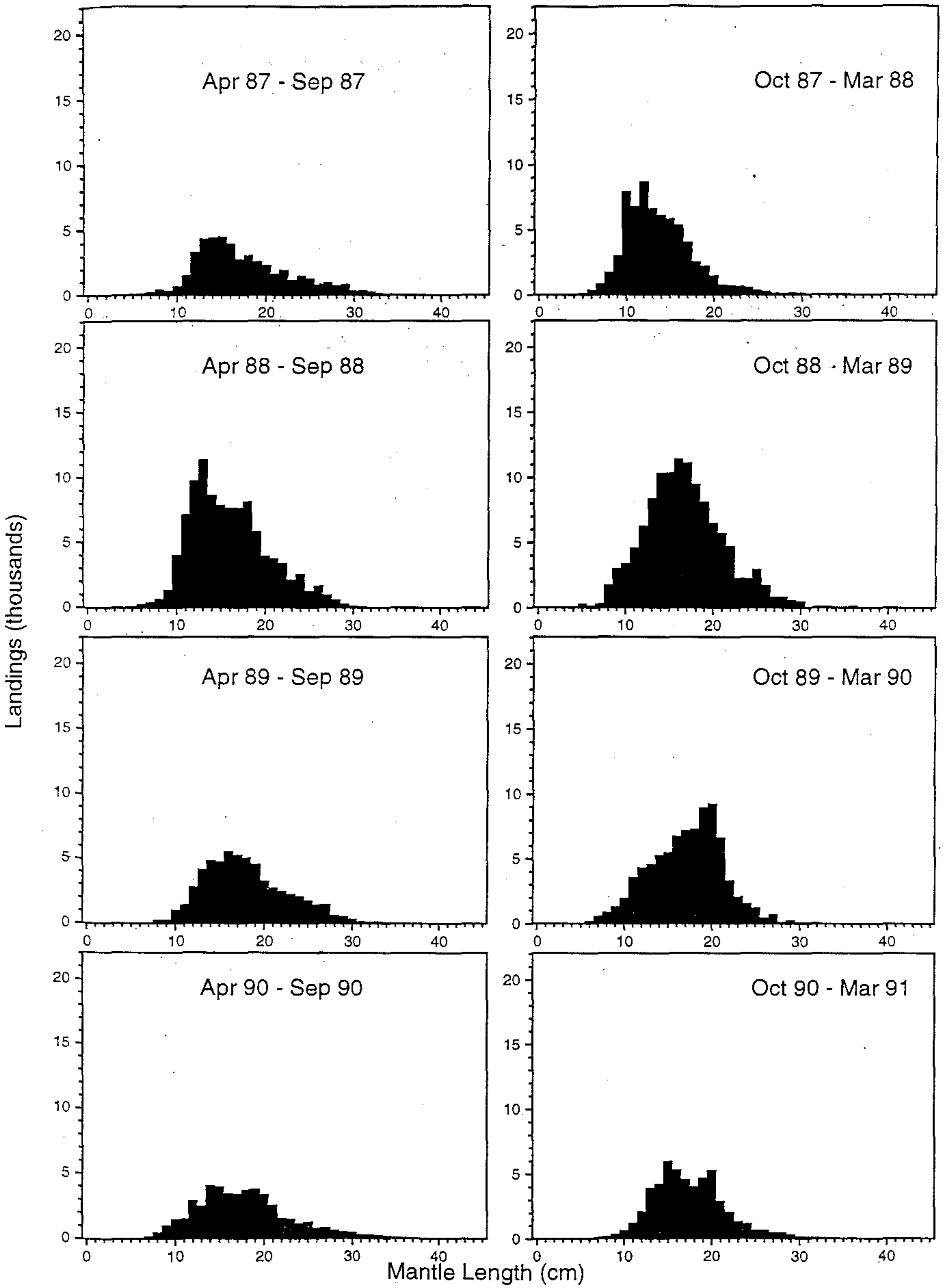



Figure C4a. Catch at length of *Loligo pealeii* landings, by season.

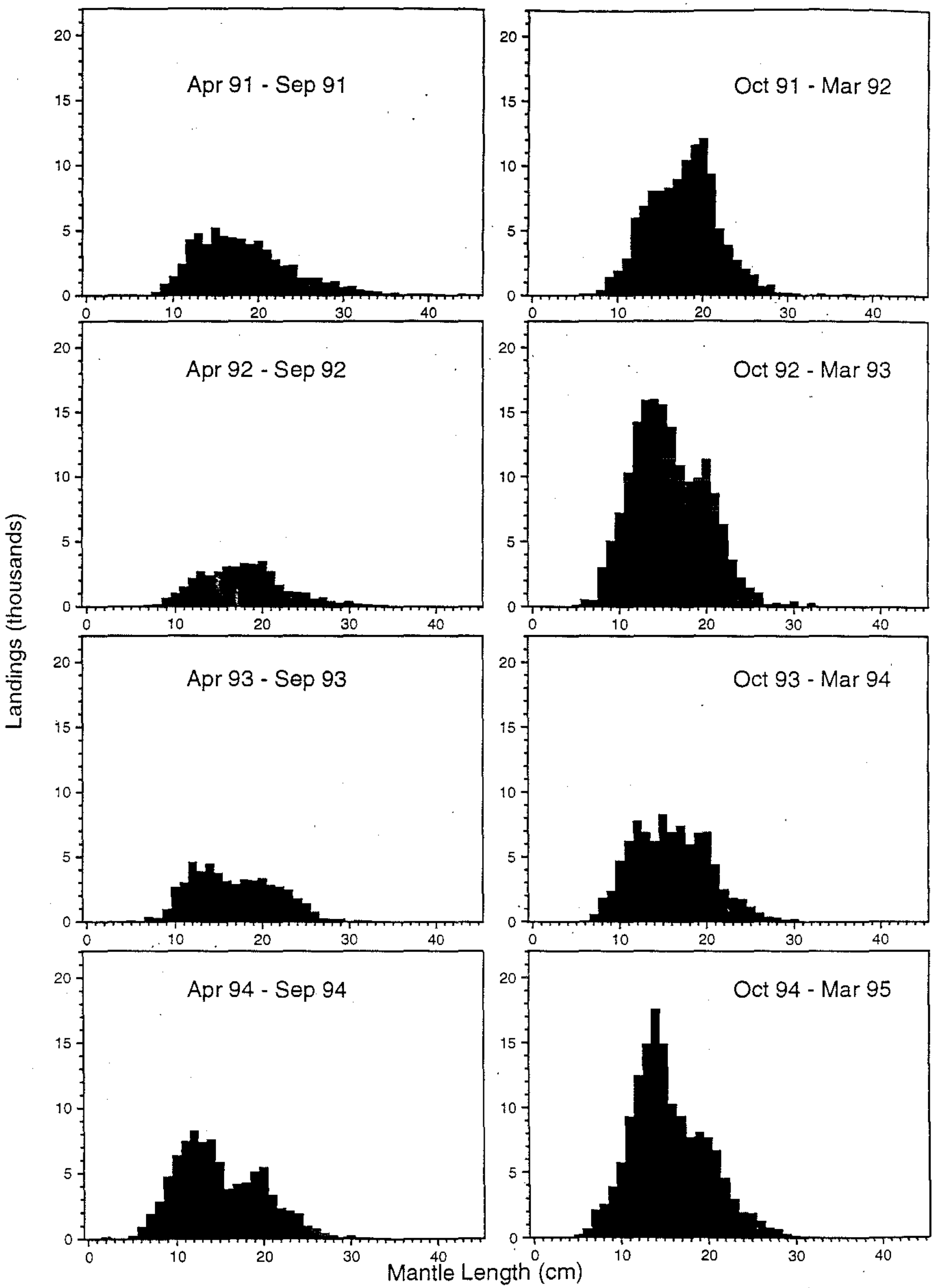



Figure C4b. Catch at length of *Loligo pealeii* landings, by season.

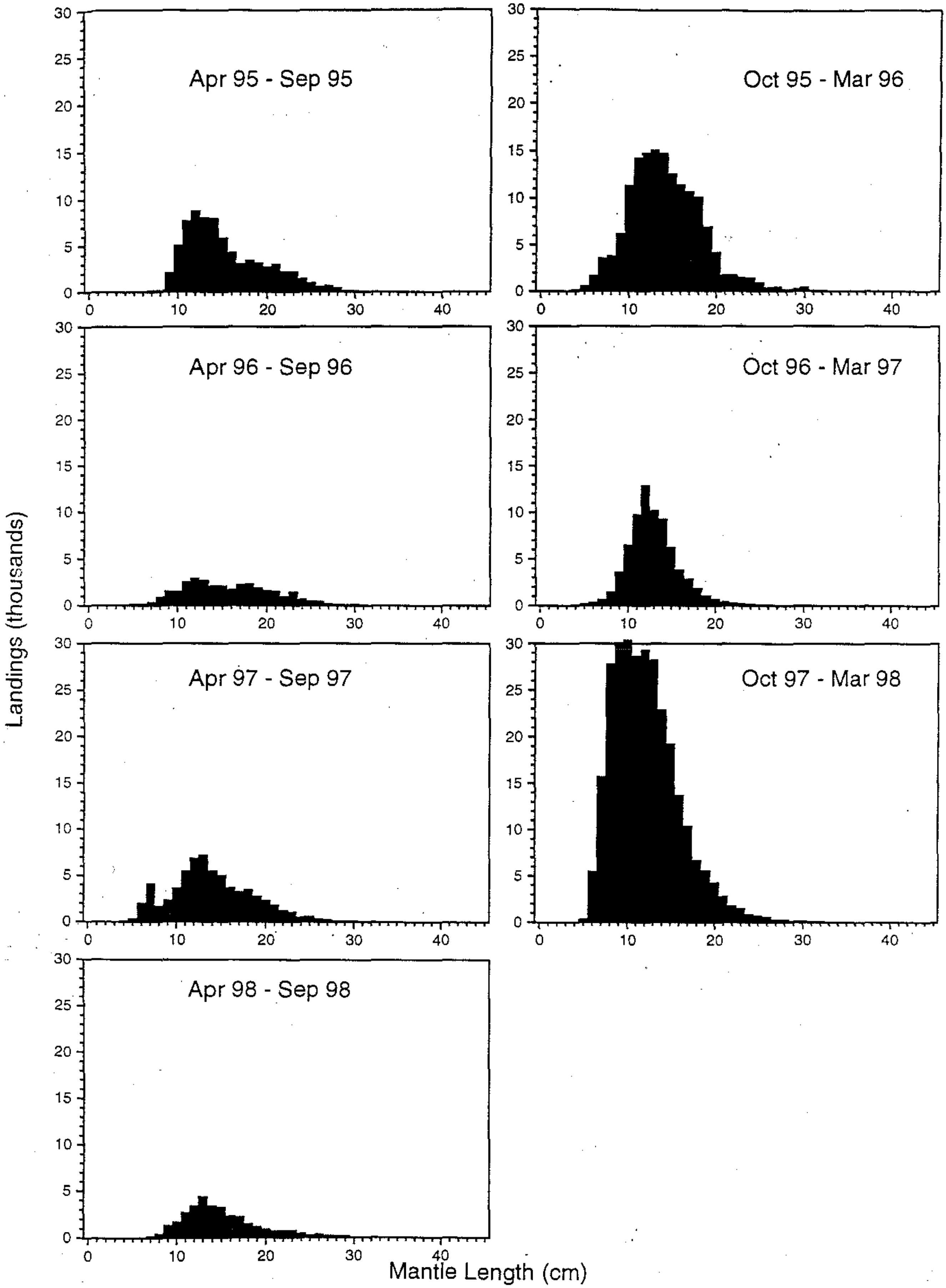



Figure C4c. Catch at length of *Loligo pealeii* landings, by season.

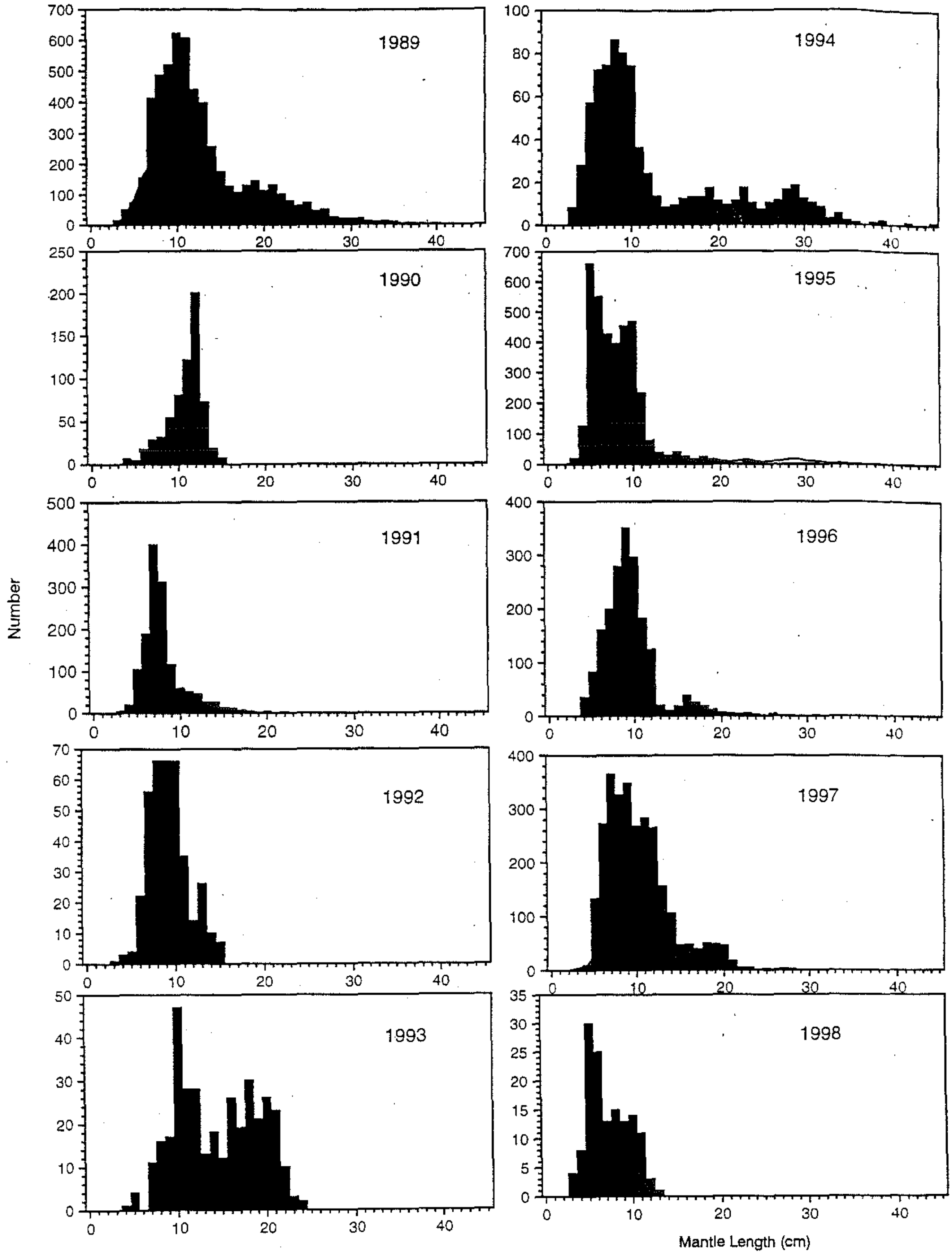



Figure C5. Size distributions of *Loligo pealeii* discards.

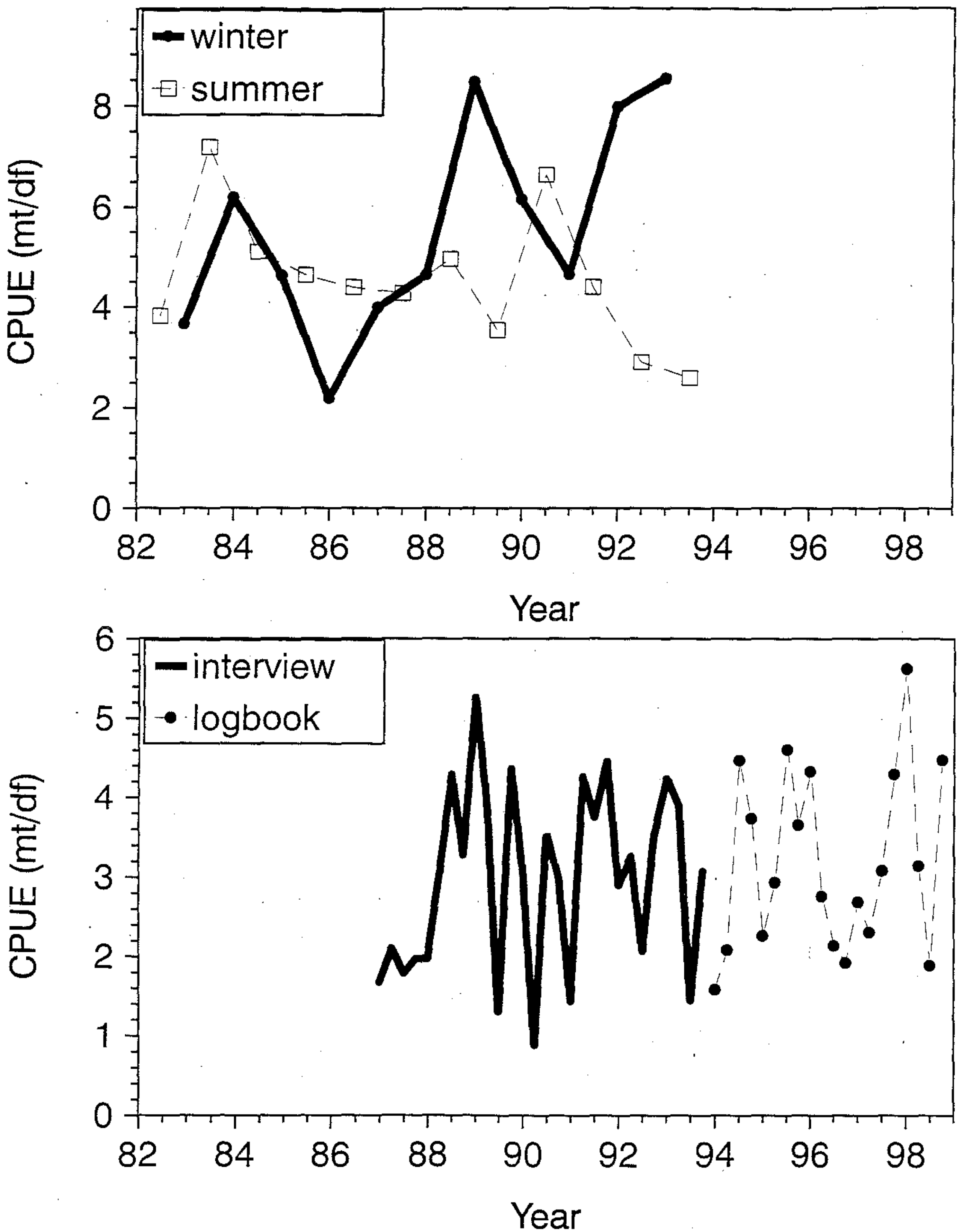



Figure C6. Standardized catch per unit effort of *Loligo pealeii*, by season (above, NEFSC 1996), and by quarter (below).

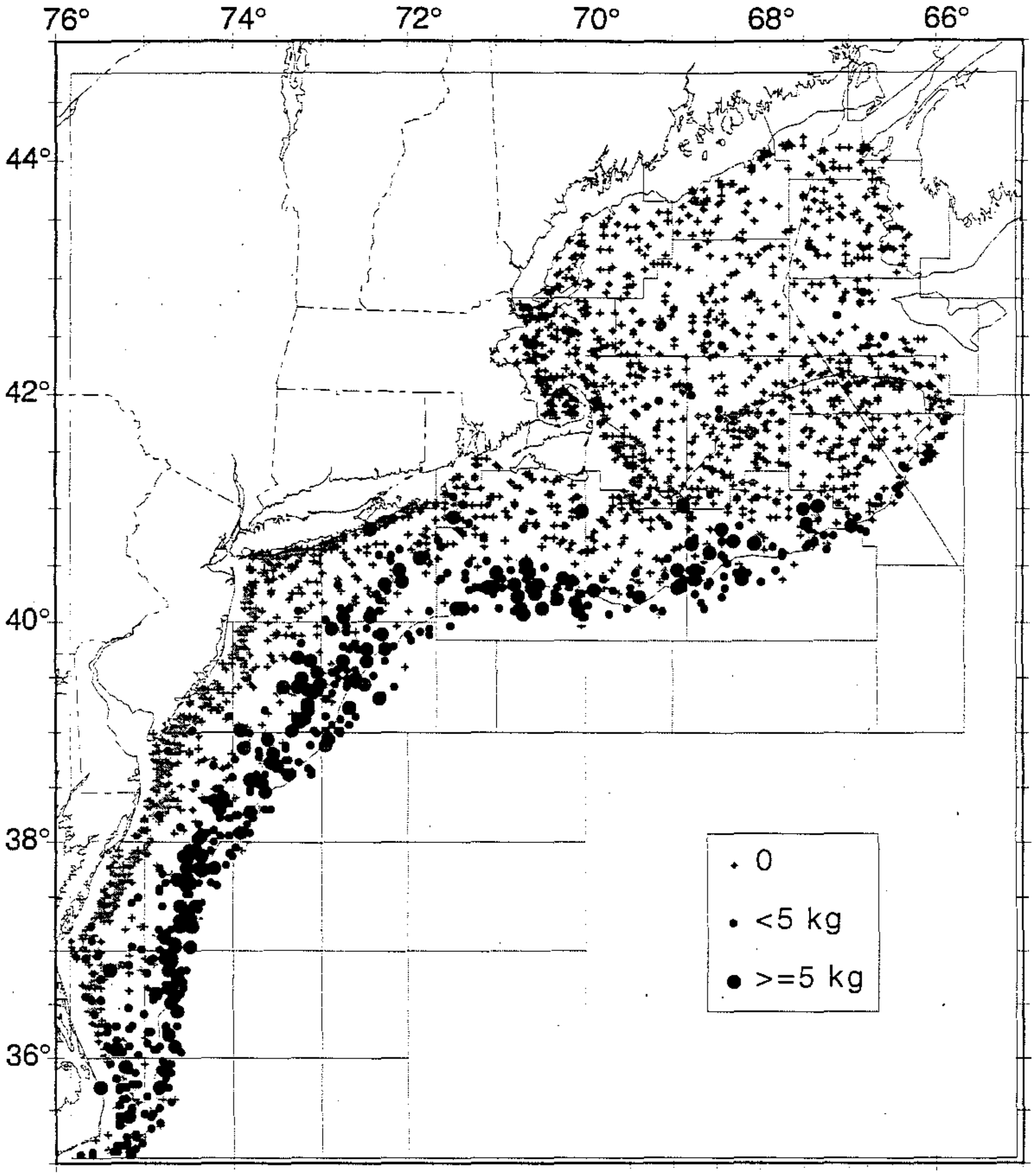



Figure C7a. Geographic distribution of *Loligo pealeii* catches from the NEFSC spring survey , 1992-1998.

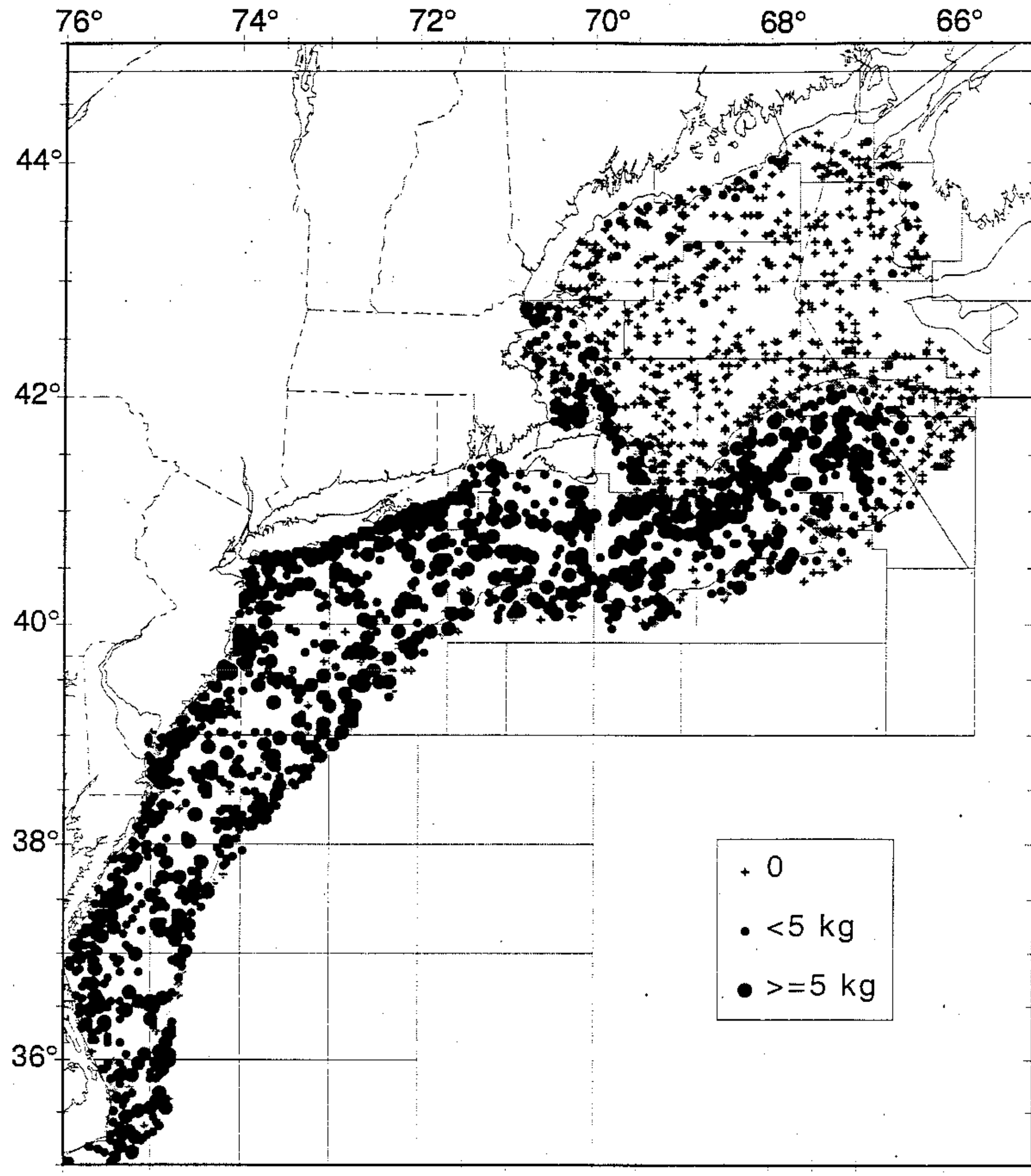



Figure C7b. Geographic distribution of *Loligo pealeii* catches from the NEFSC fall survey , 1992-1998.

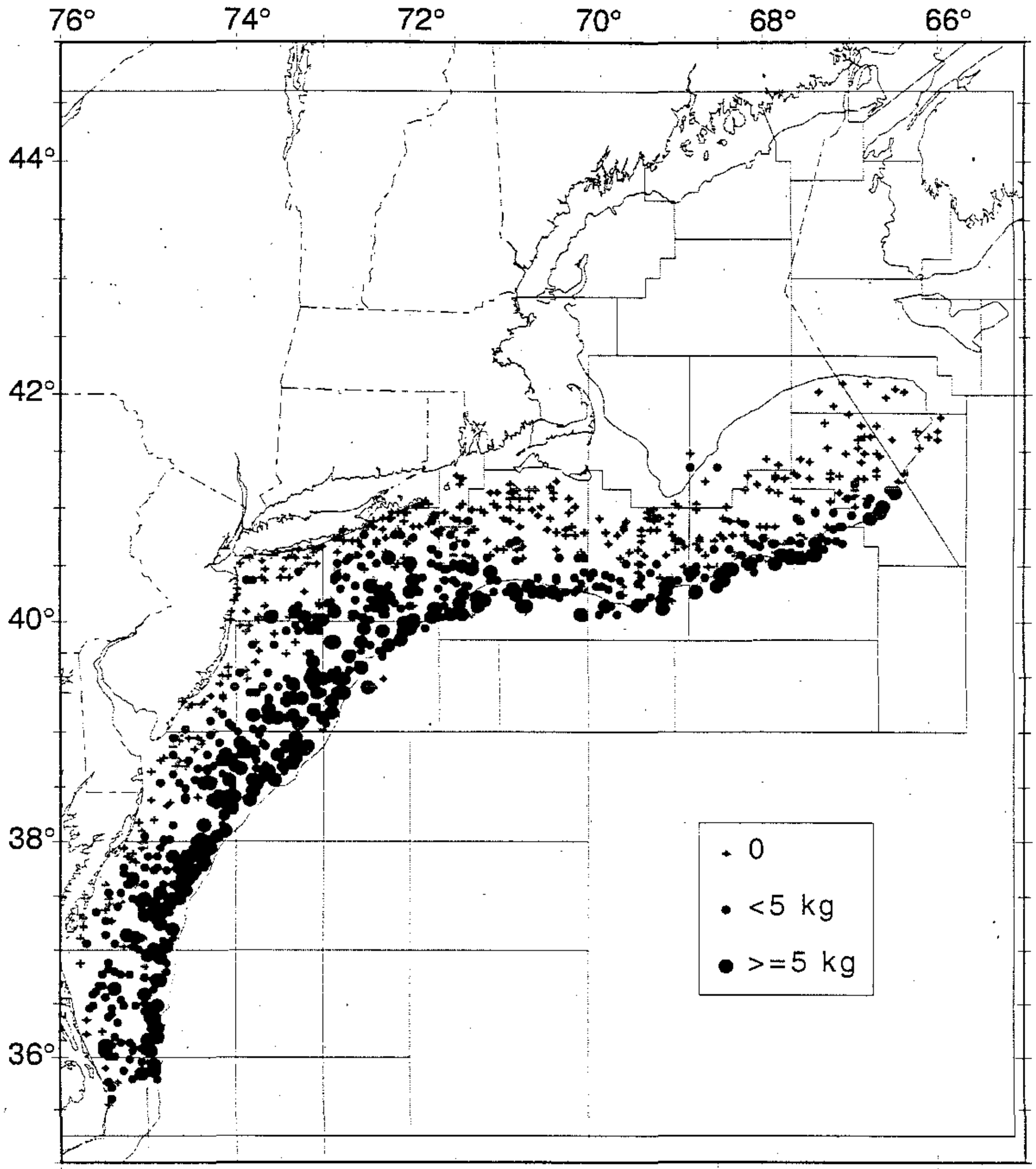
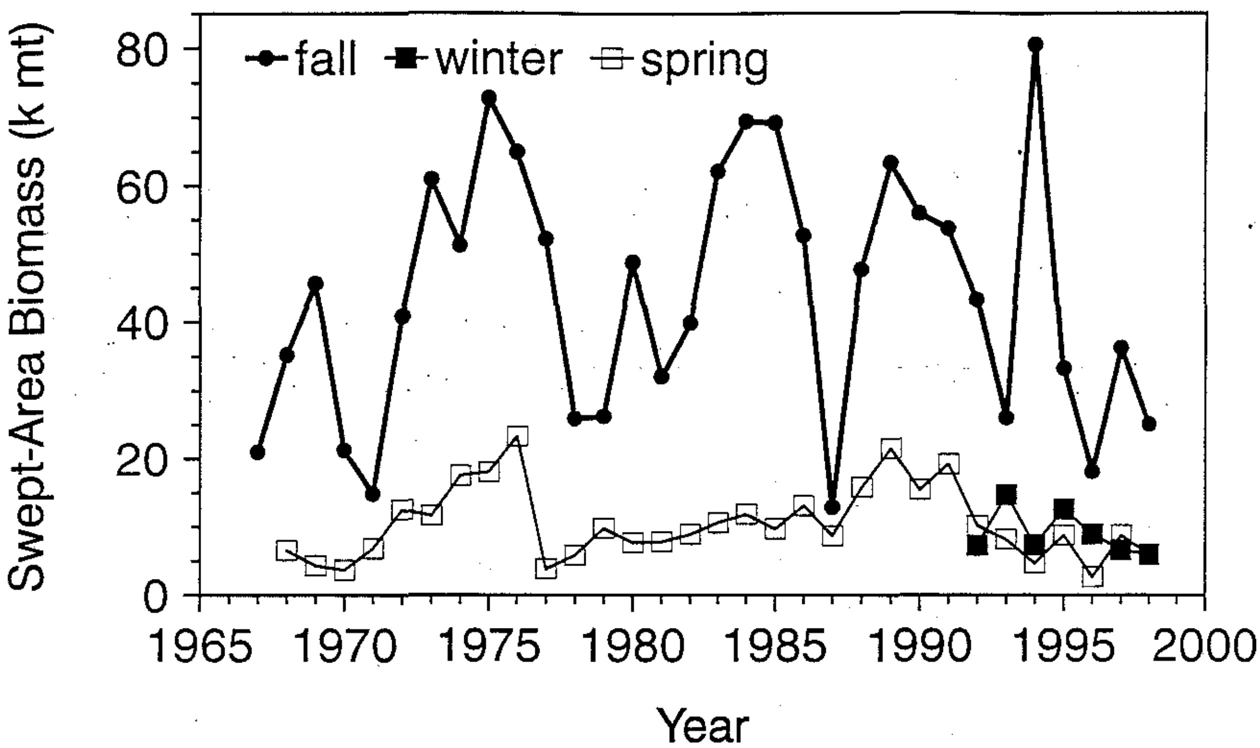



Figure C7c. Geographic distribution of *Loligo pealeii* catches from the NEFSC winter survey , 1992-1998.



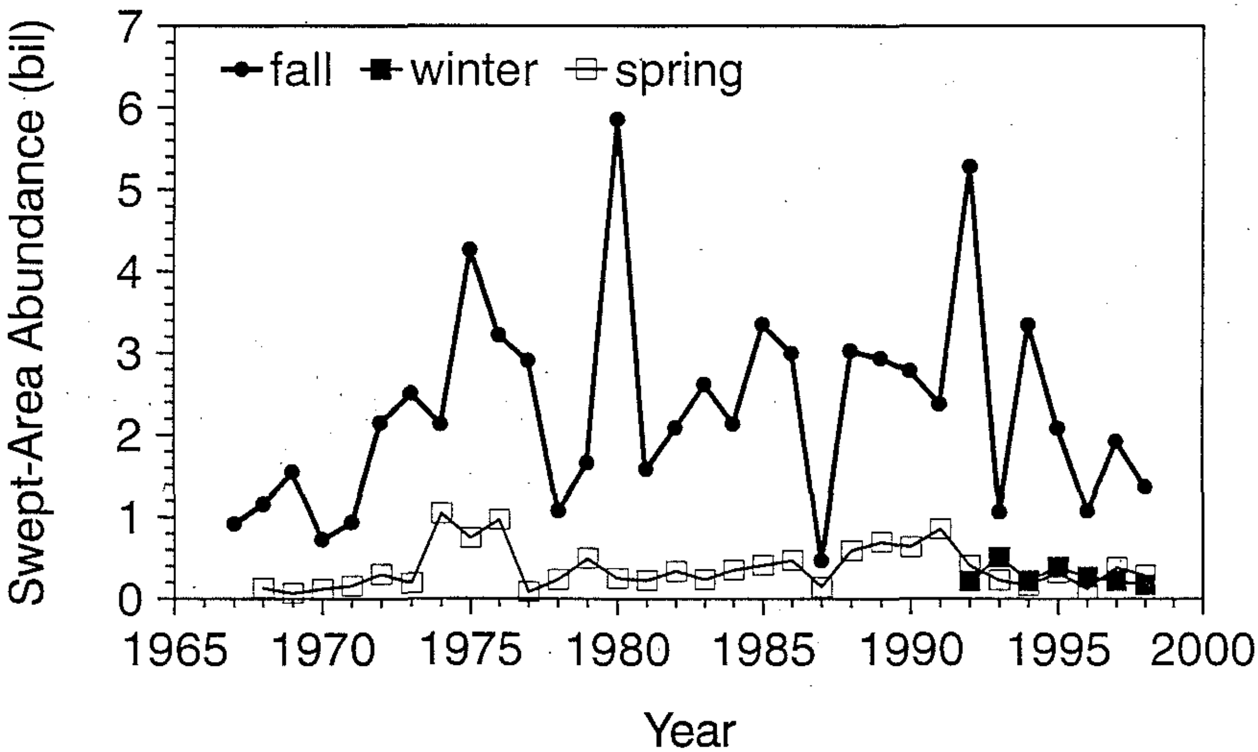




Figure C8a. Indices of *Loligo pealeii* stock biomass and abundance from NEFSC surveys.

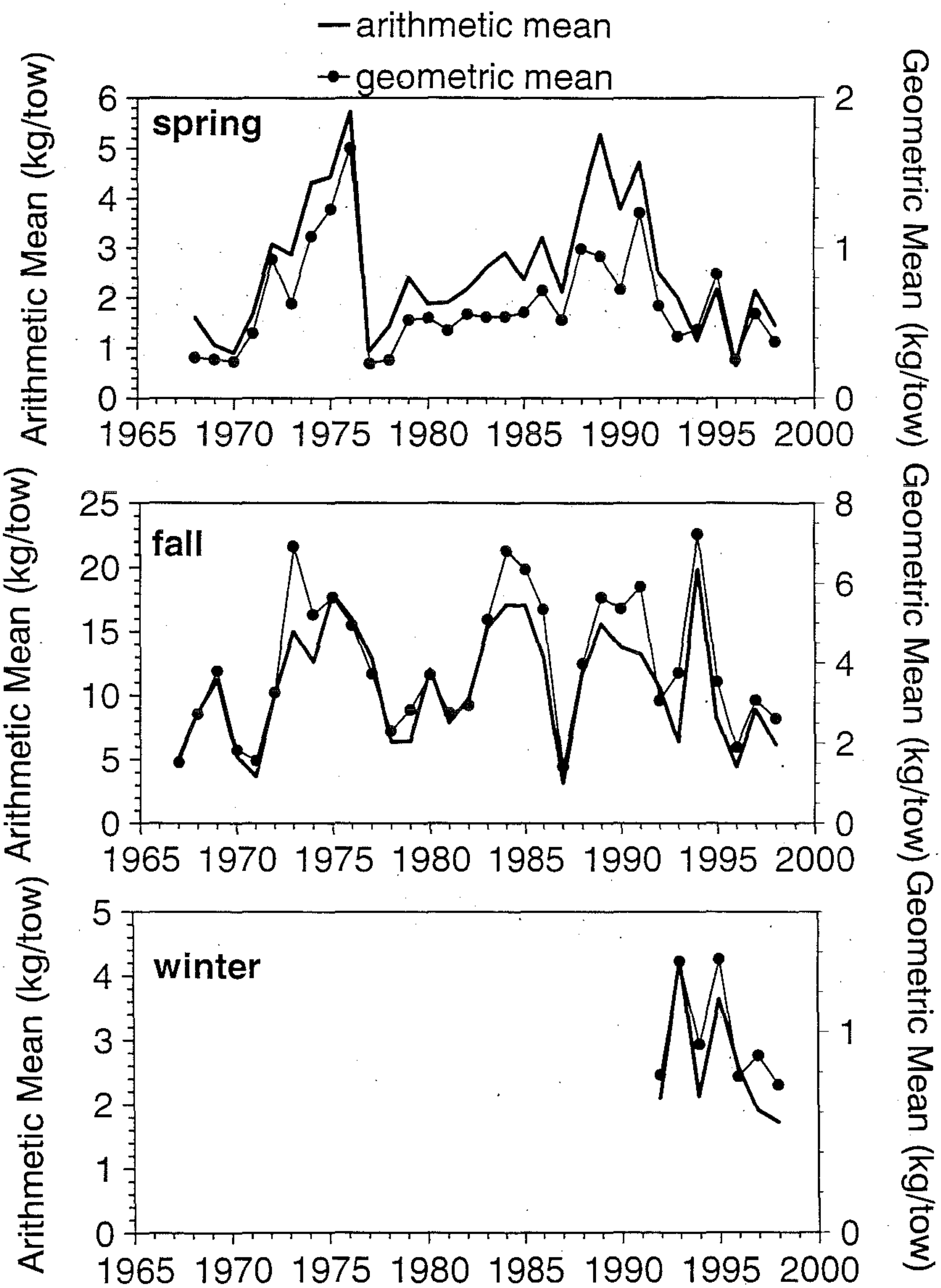



Figure C8b. Untransformed and log transformed indices of *Loligo pealeii* stock biomass from NEFSC surveys.

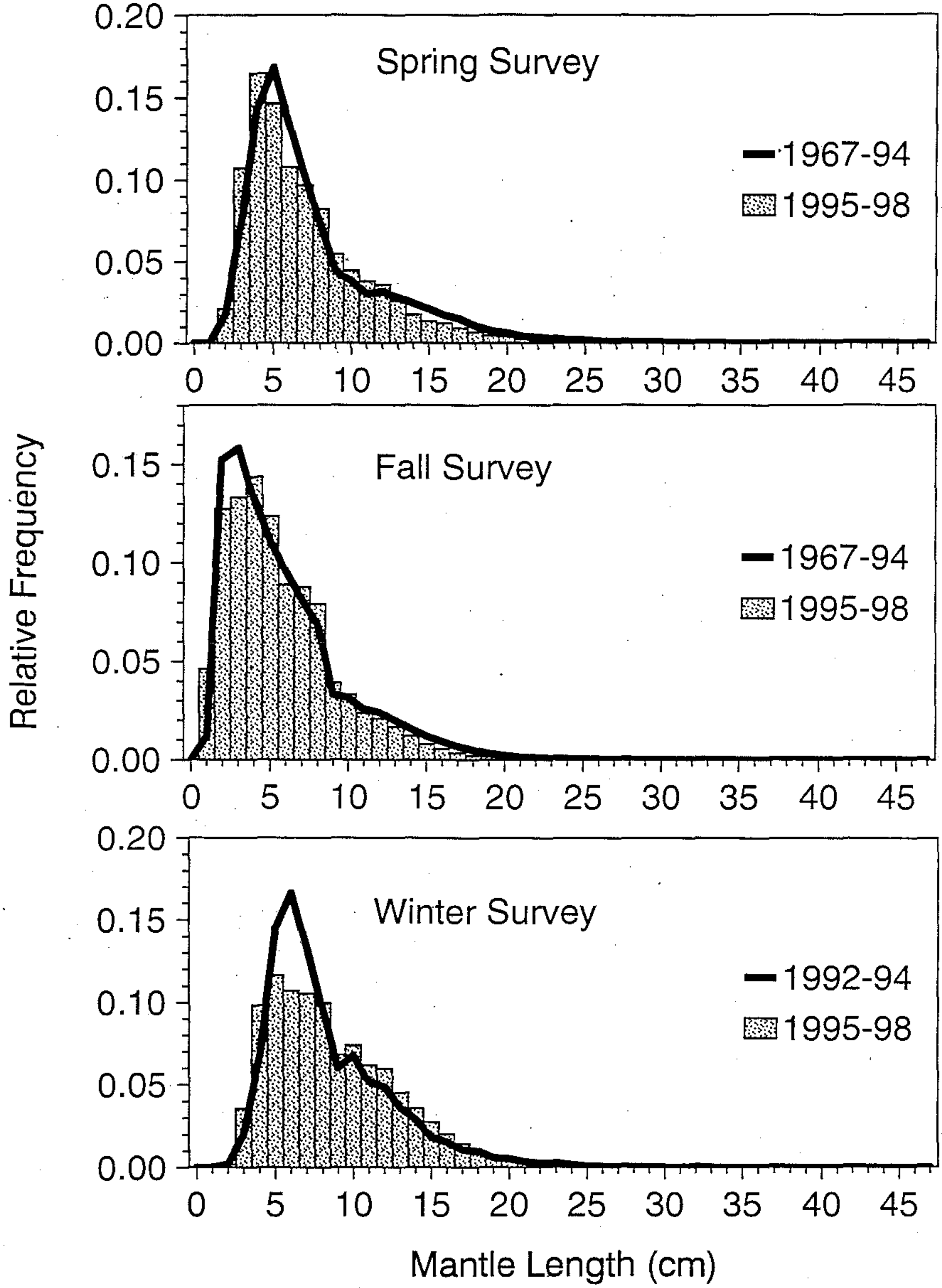



Figure C9a. Size distributions of *Loligo pealeii* from NEFSC surveys.

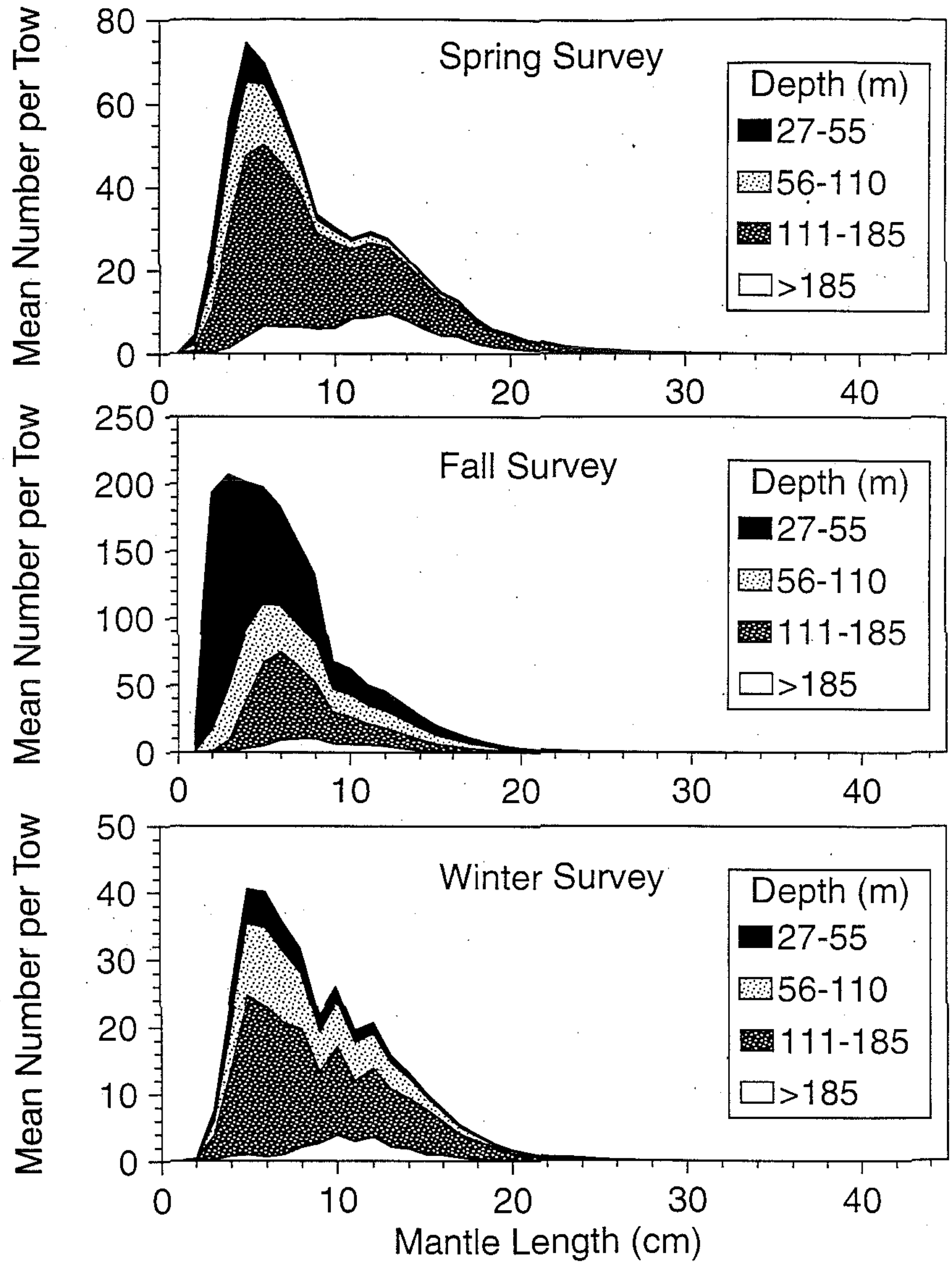
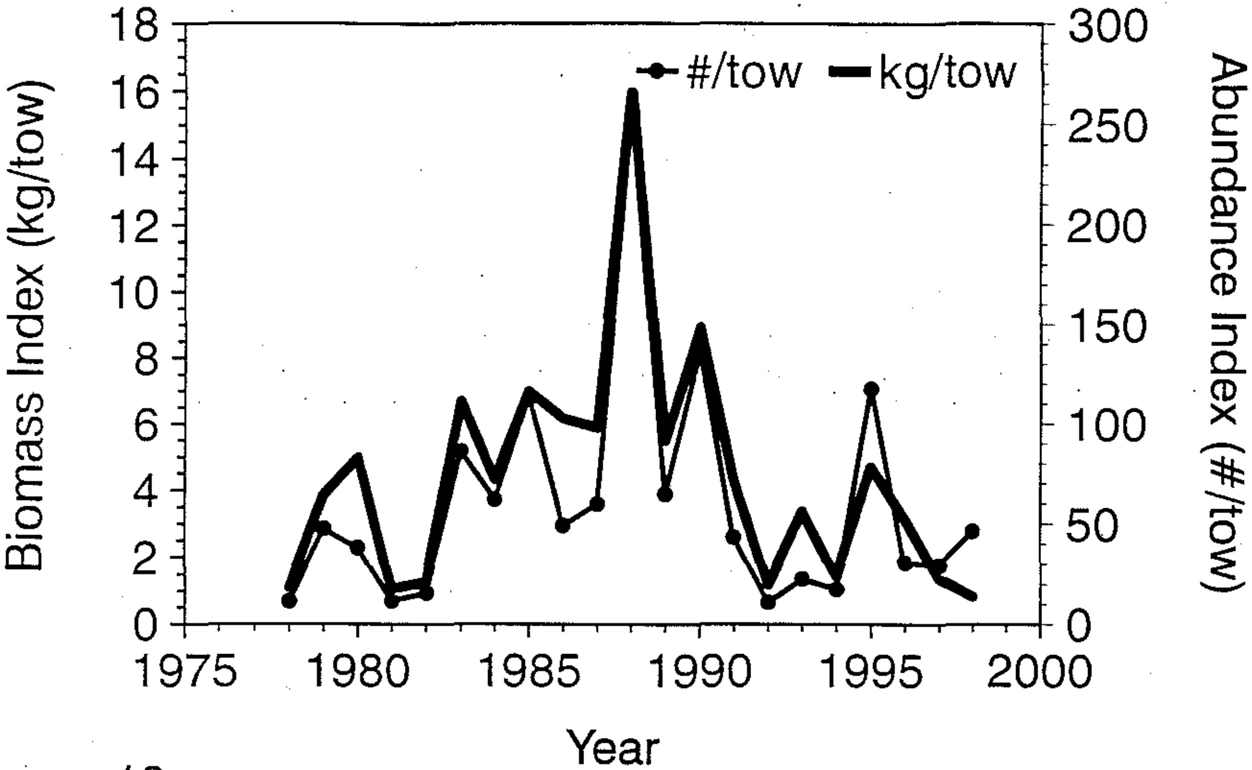



Figure C9b. Size distributions of *Loligo pealeii* from NEFSC surveys, by depth.



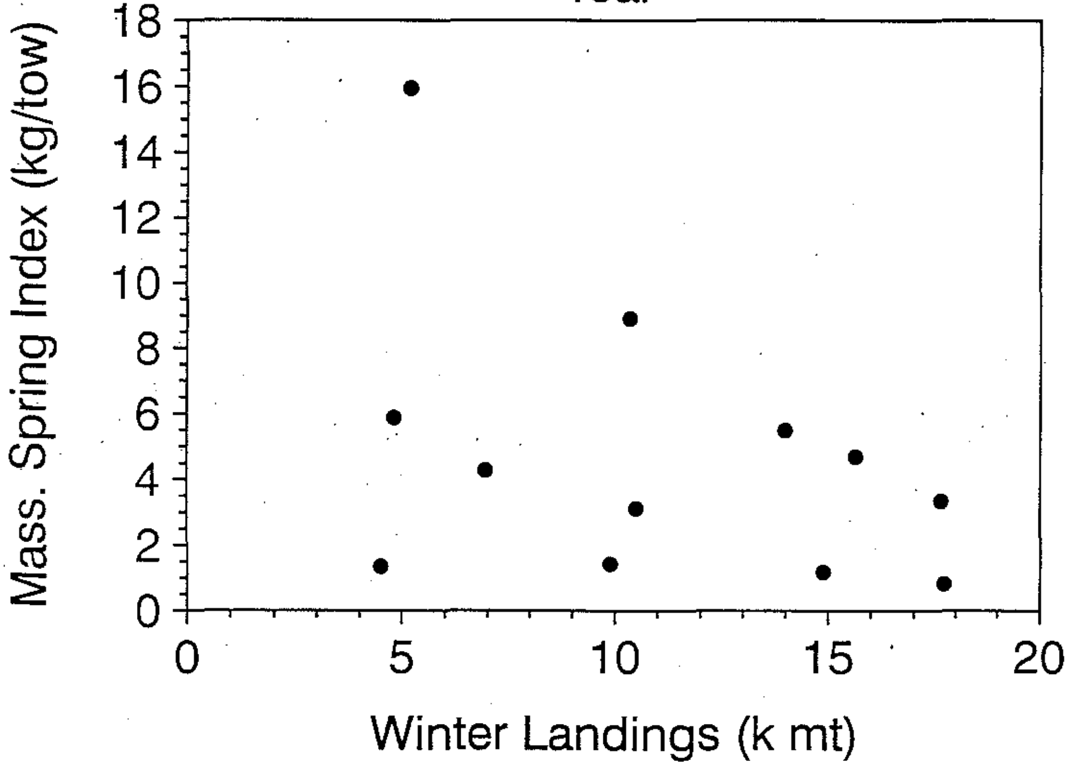




Figure C10. Indices of *Loligo pealeii* stock biomass and abundance from the Massachusets spring survey (above) and relationship between winter catch (Oct.-Mar.) and subsequent inshore biomass (below).

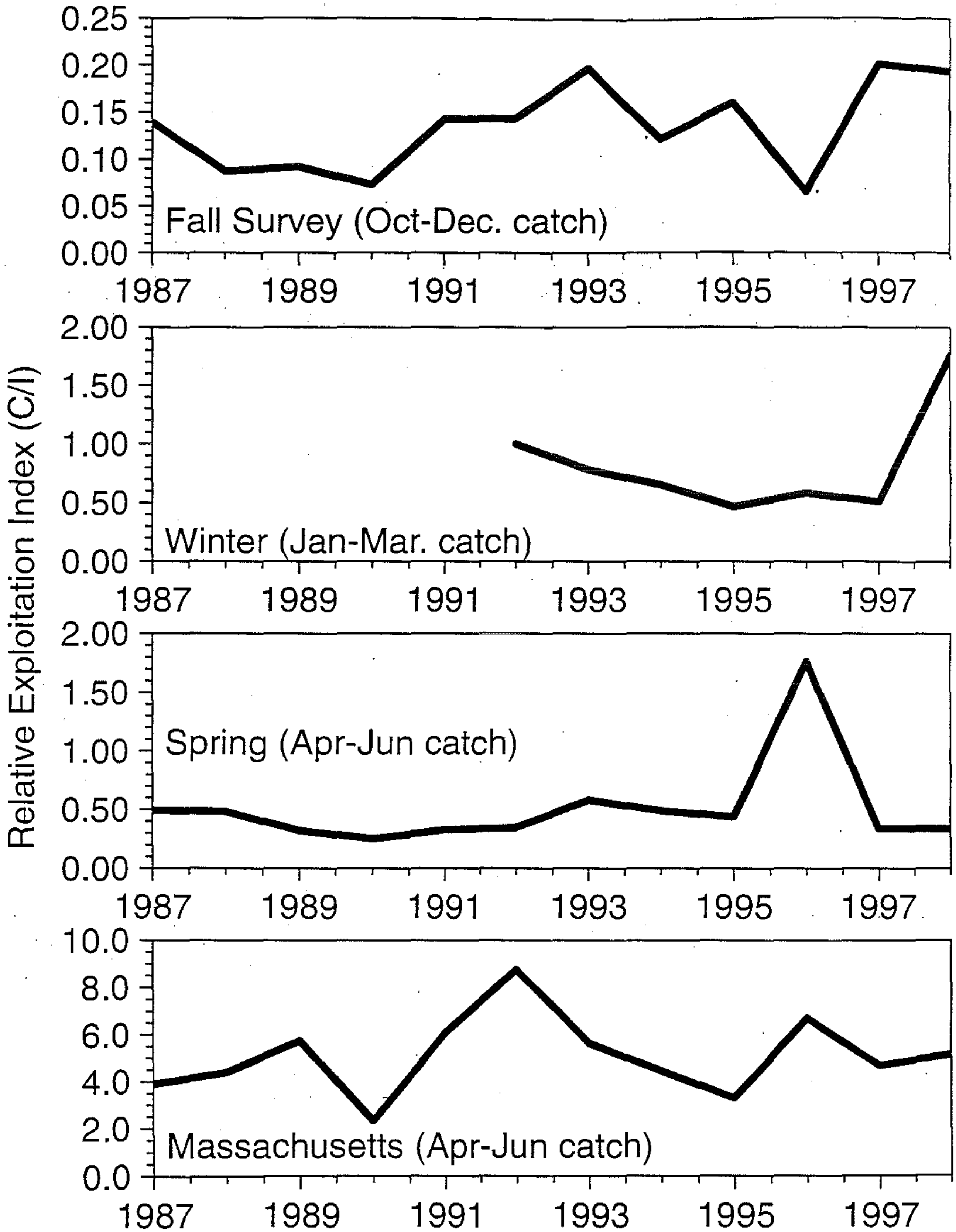



Figure C11. Survey indices of relative exploitation of *Loligo pealeii* derived as the quotient of quarterly catch and survey biomass index.

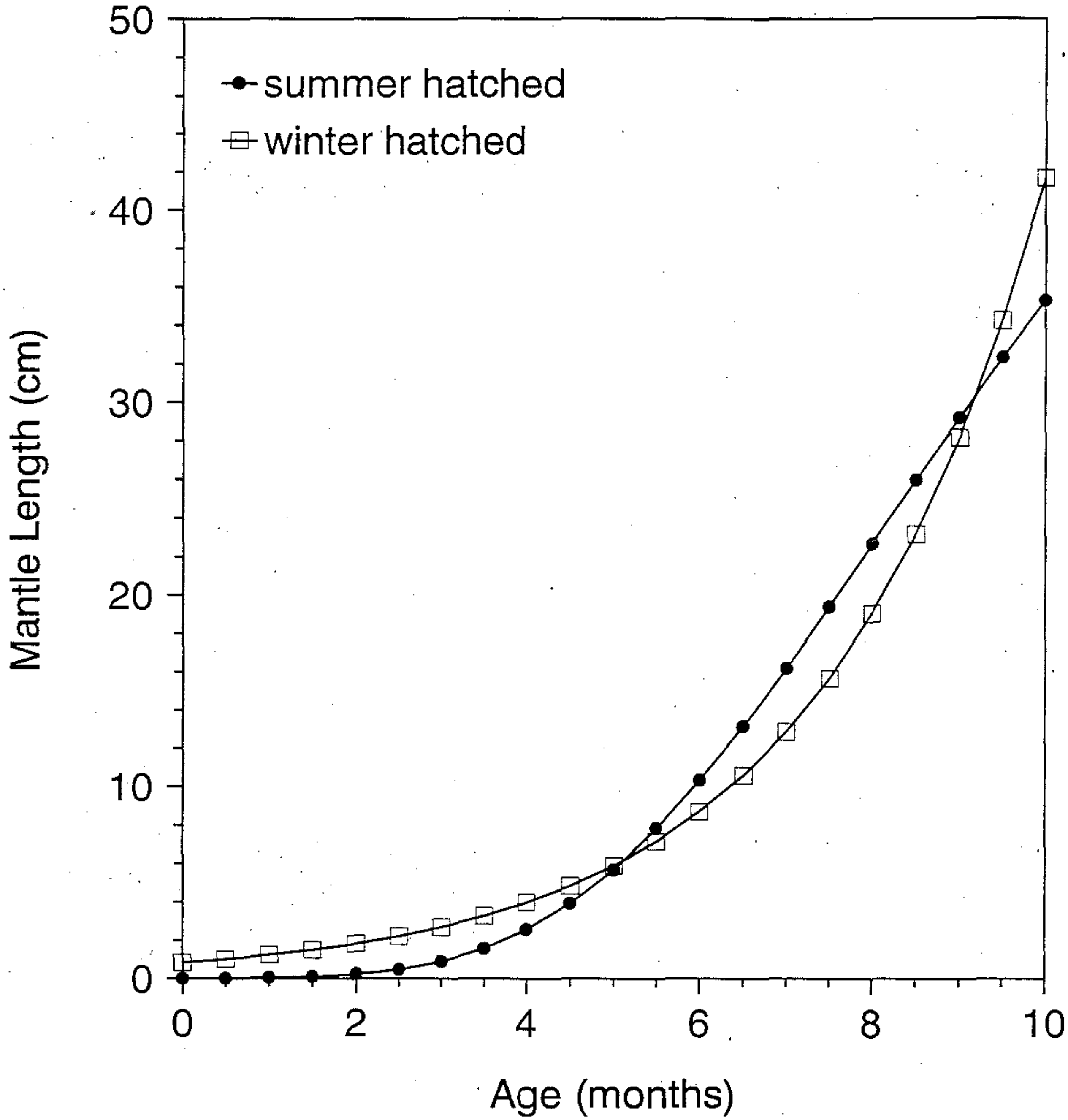



Figure C12. Estimated length at age of *Loligo pealeii* by hatch date (from Brodziak and Macy 1996).

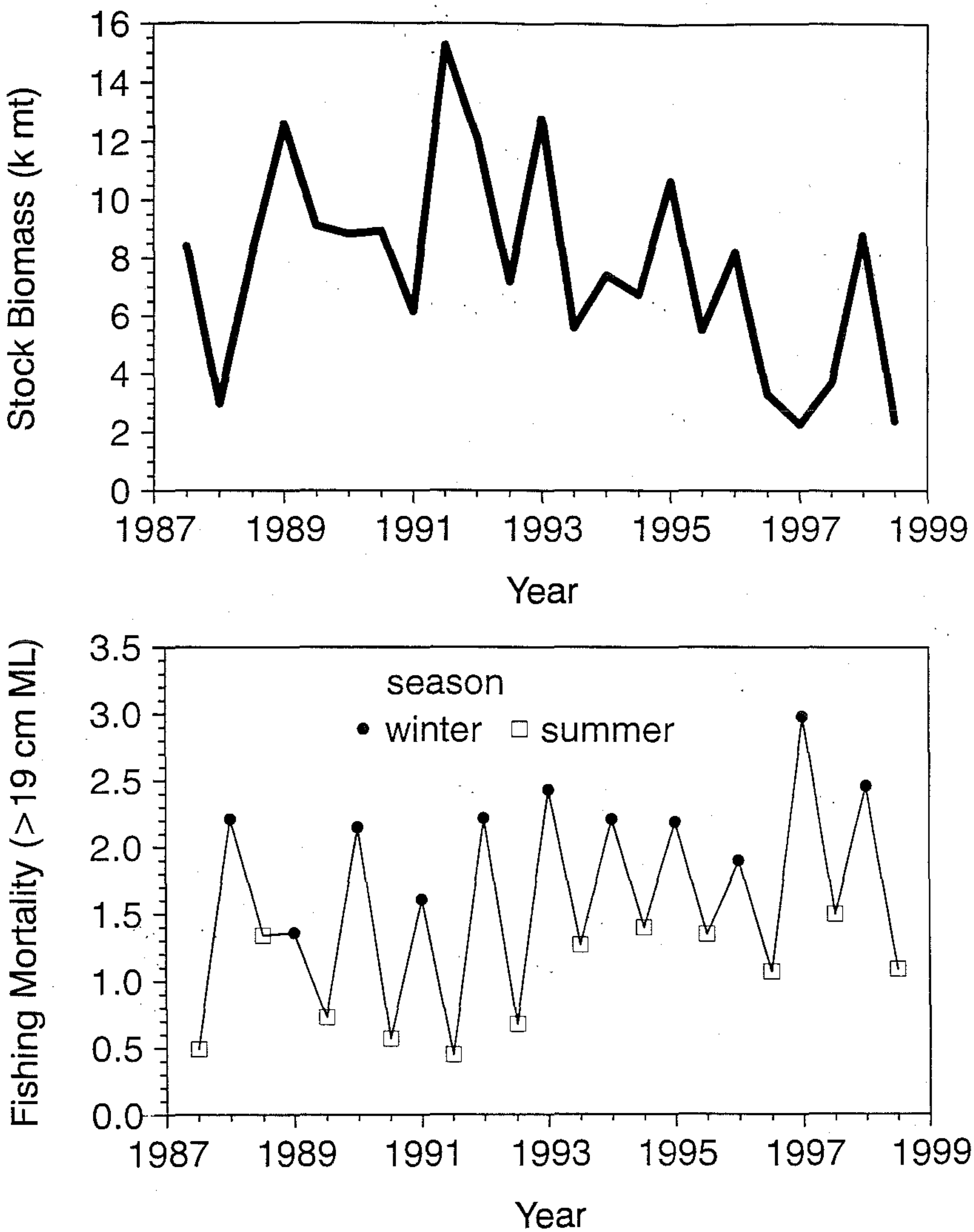



Figure C13. Stock biomass and fishing mortality of *Loligo pealeii* from LVPA.

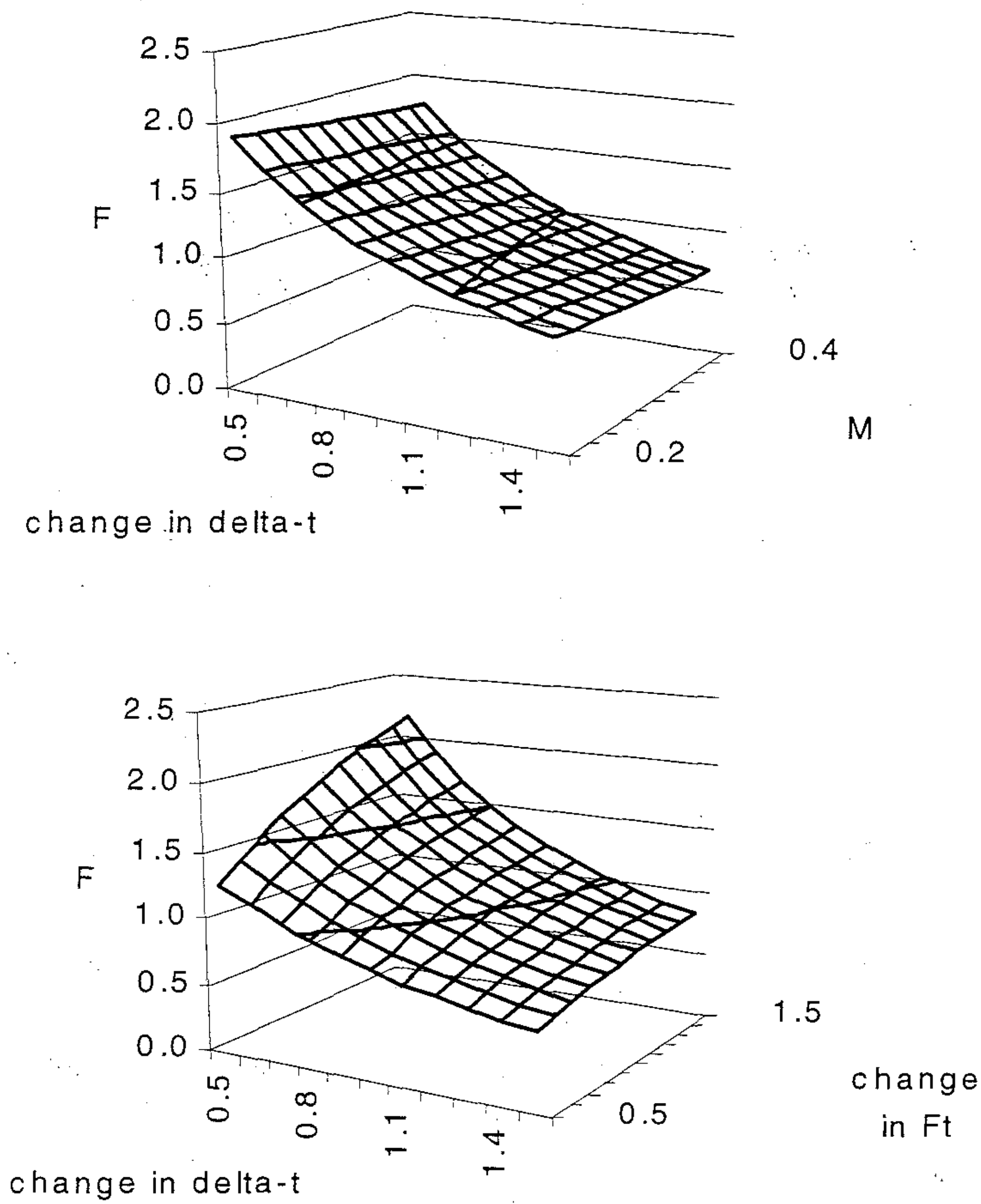



Figure C14. Sensitivity of fishing mortality estimates from LVPA of *Loligo pealeii* landings to relative change in delta-t and M (above) and relative change in delta-t and terminal F (below).

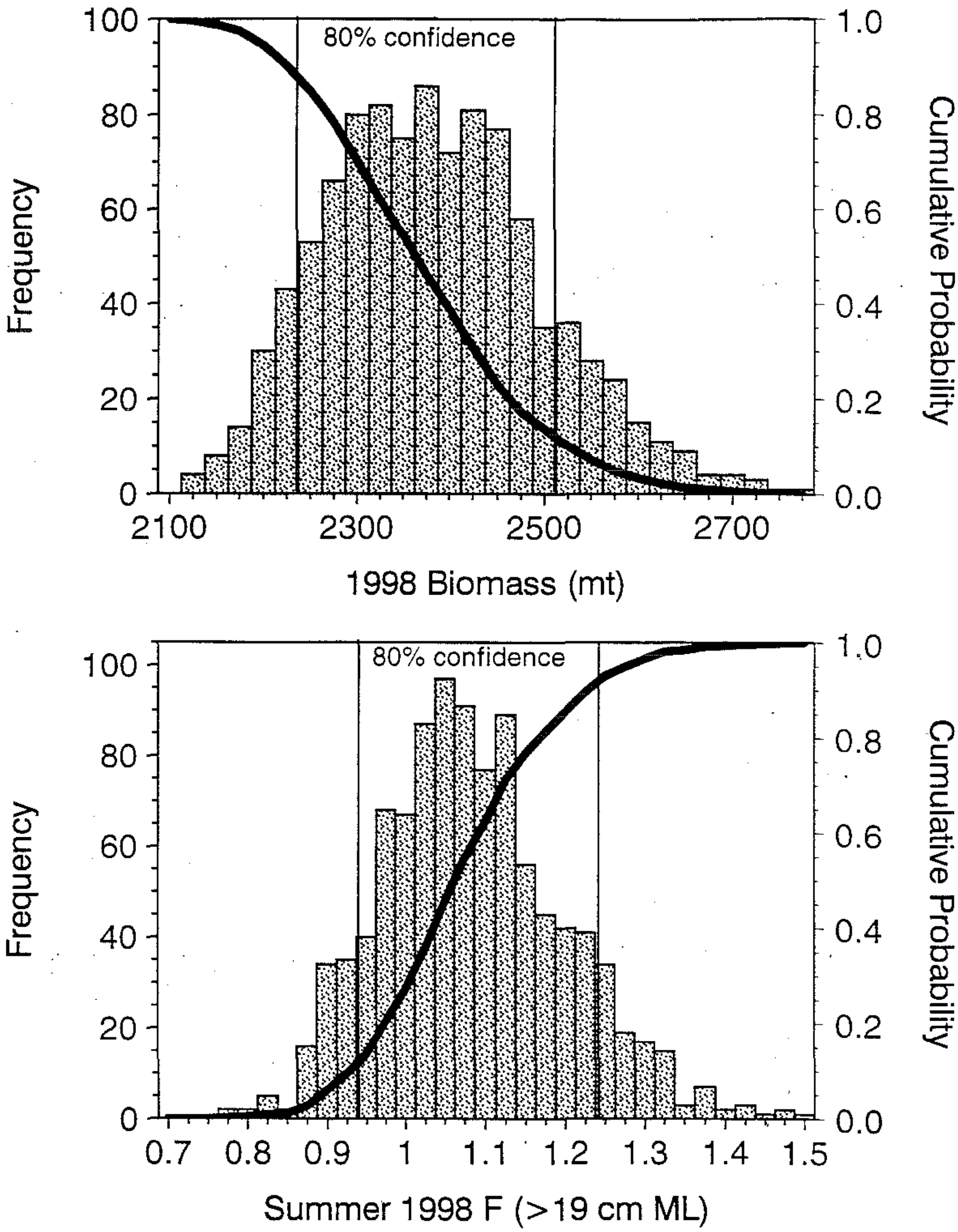
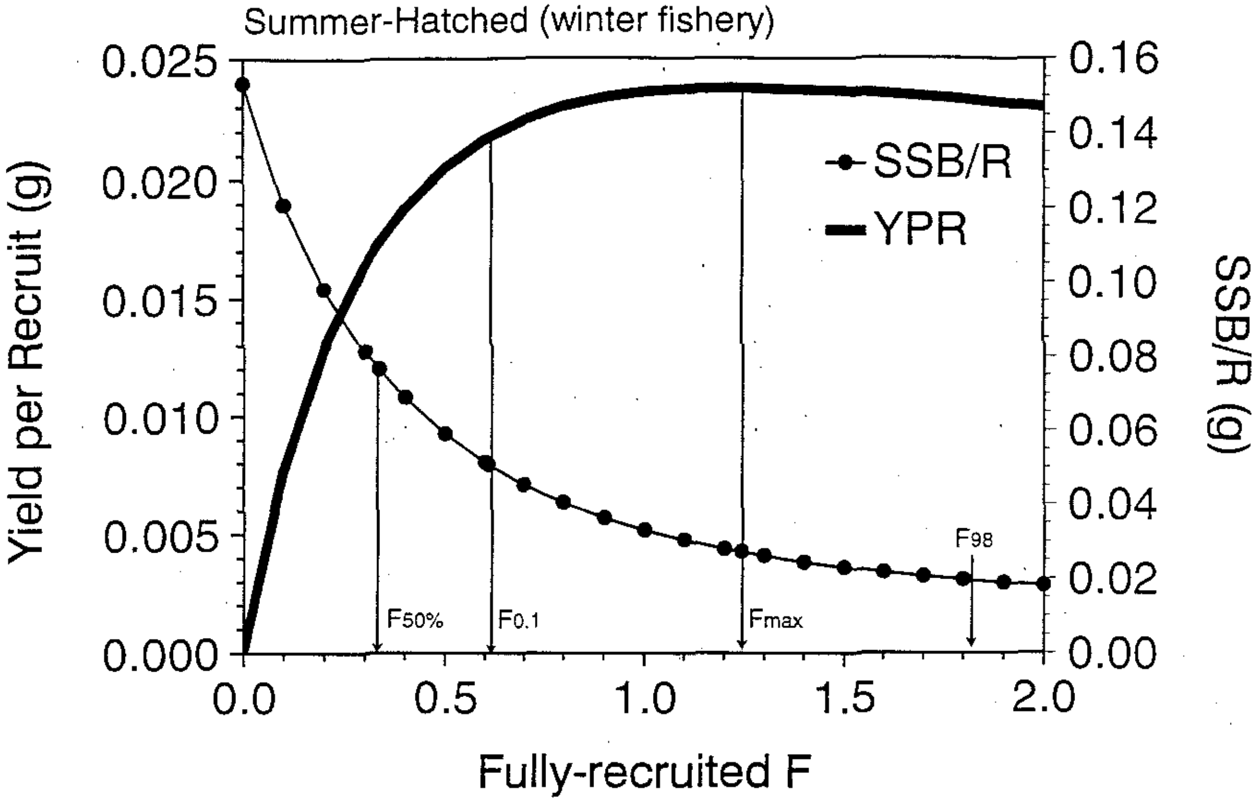



Figure C15. Monte Carlo estimates of stock biomass, and fishing mortality of *Loligo pealeii* from LVPA of 1998 summer landings with 80% confidence limits.



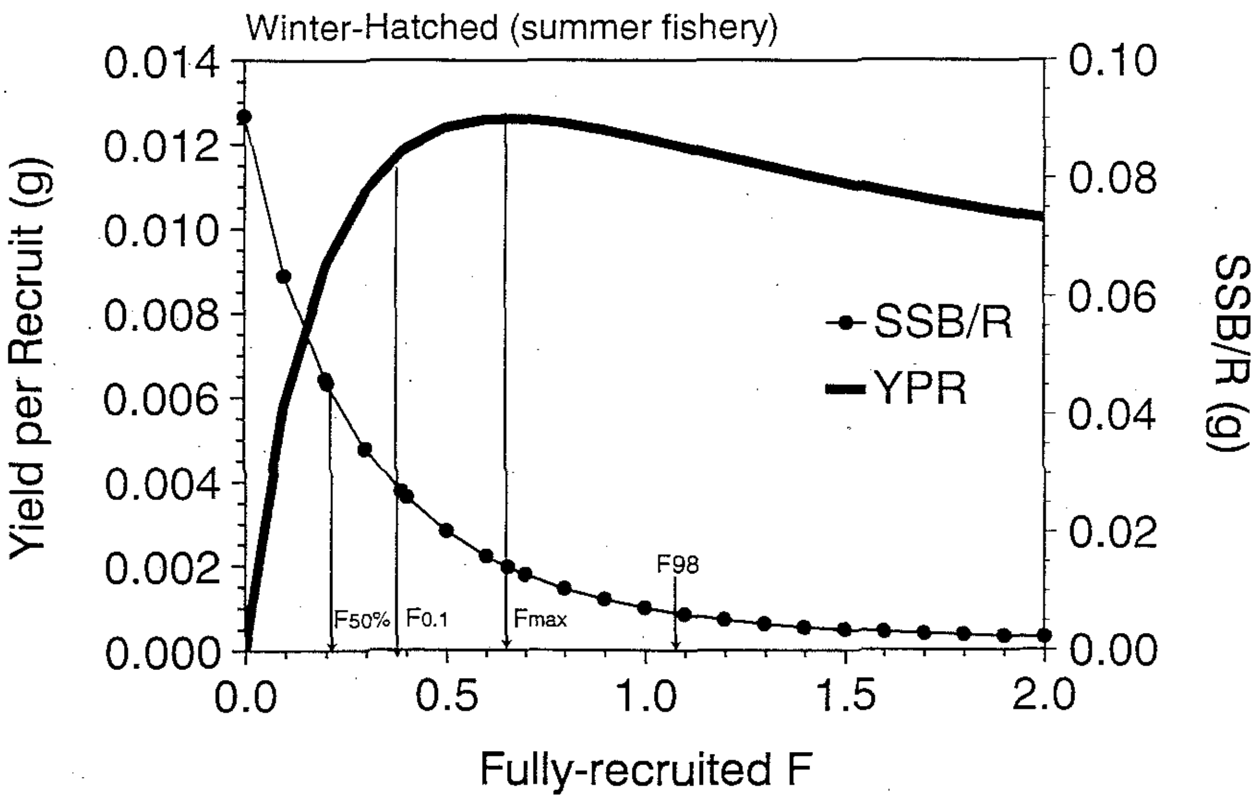




Figure C16. Yield and spawning biomass per recruit of *Loligo pealeii* by season.

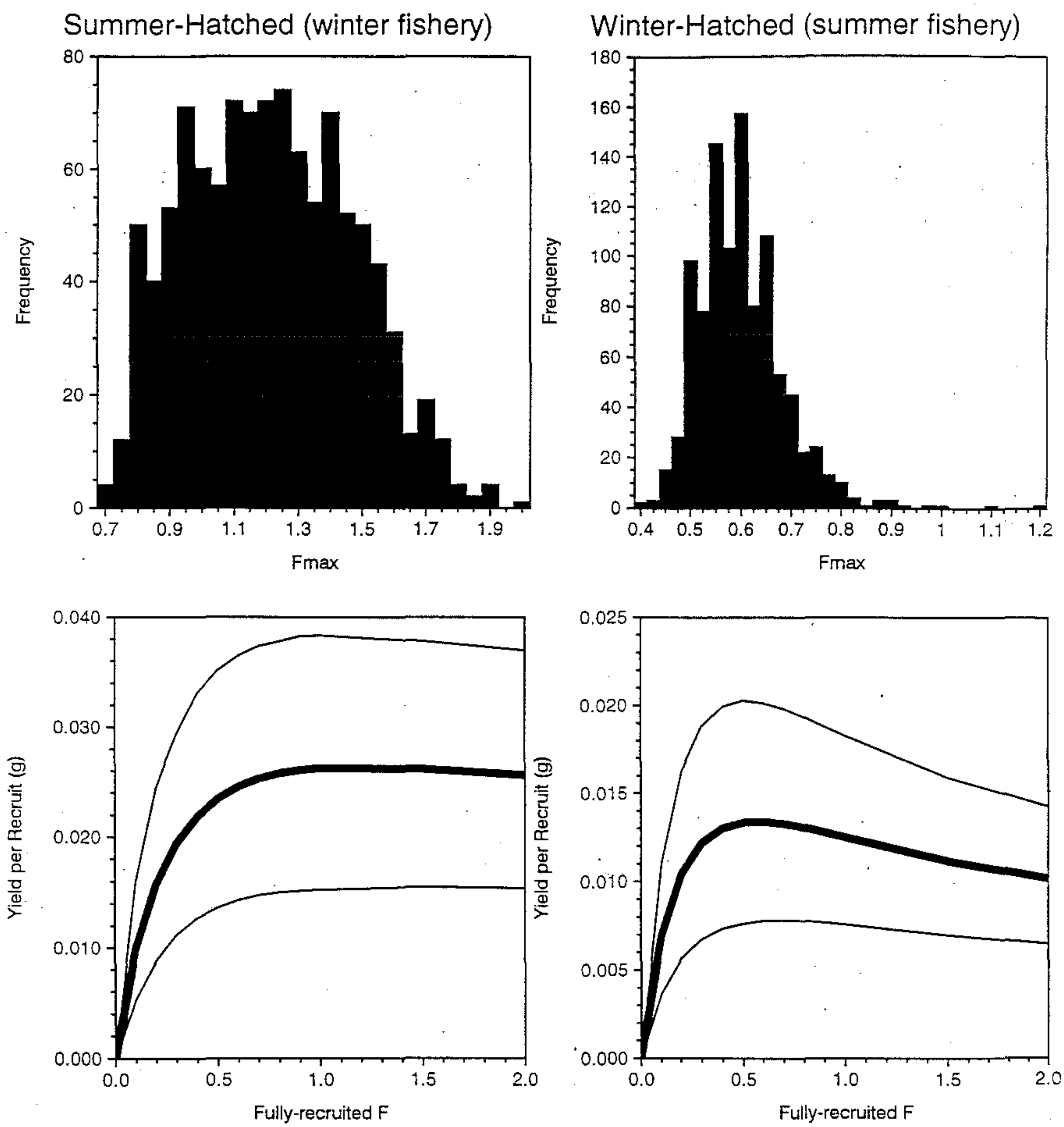



Figure C17. Monte Carlo estimates of Fmax (above) and yield per recruit (below, with 80% confidence limits) for the *Loligo pealeii* fishery, by season.

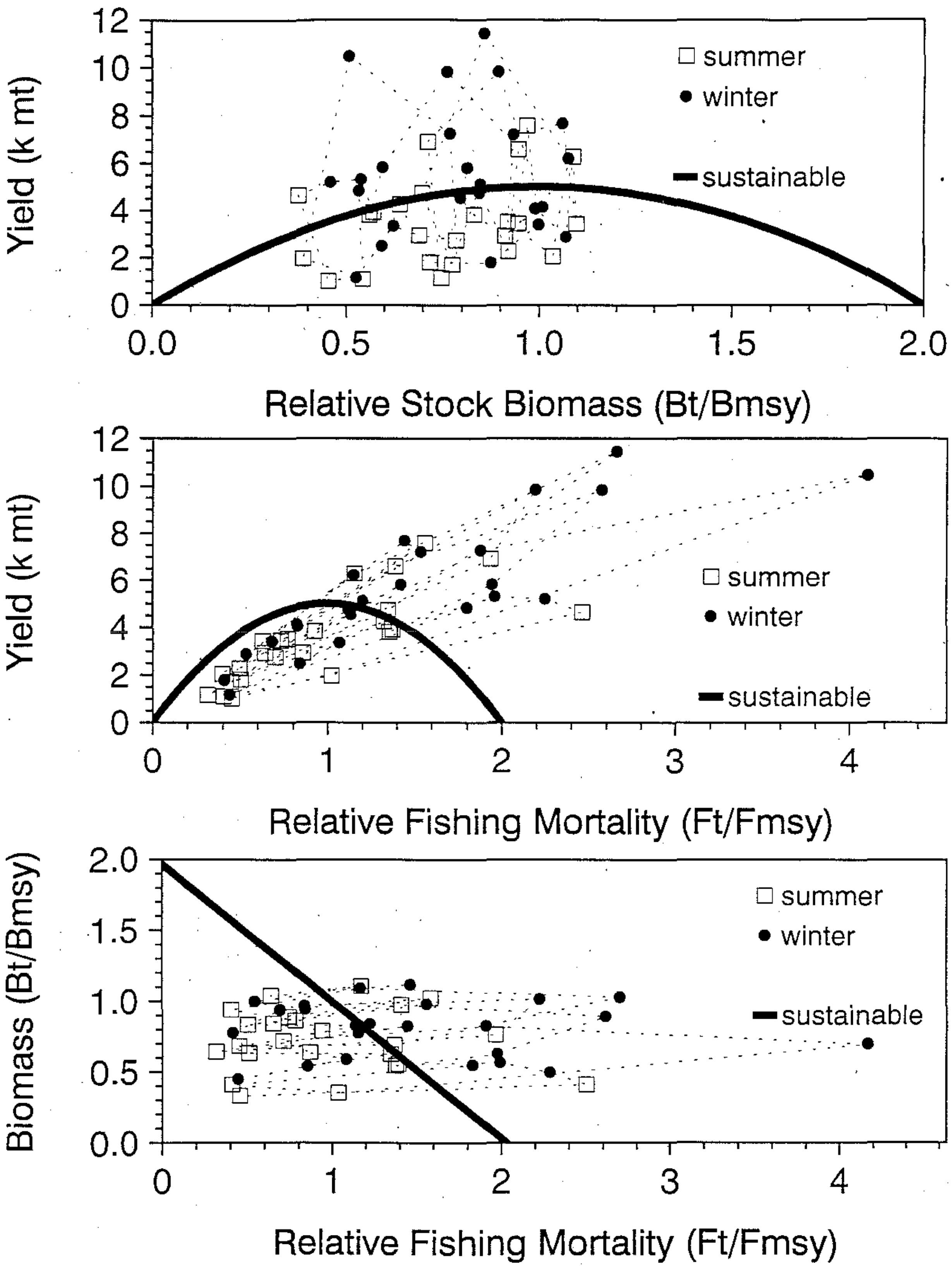



Figure C18. Biomass dynamics of *Loligo pealeii* from surplus production modeling.

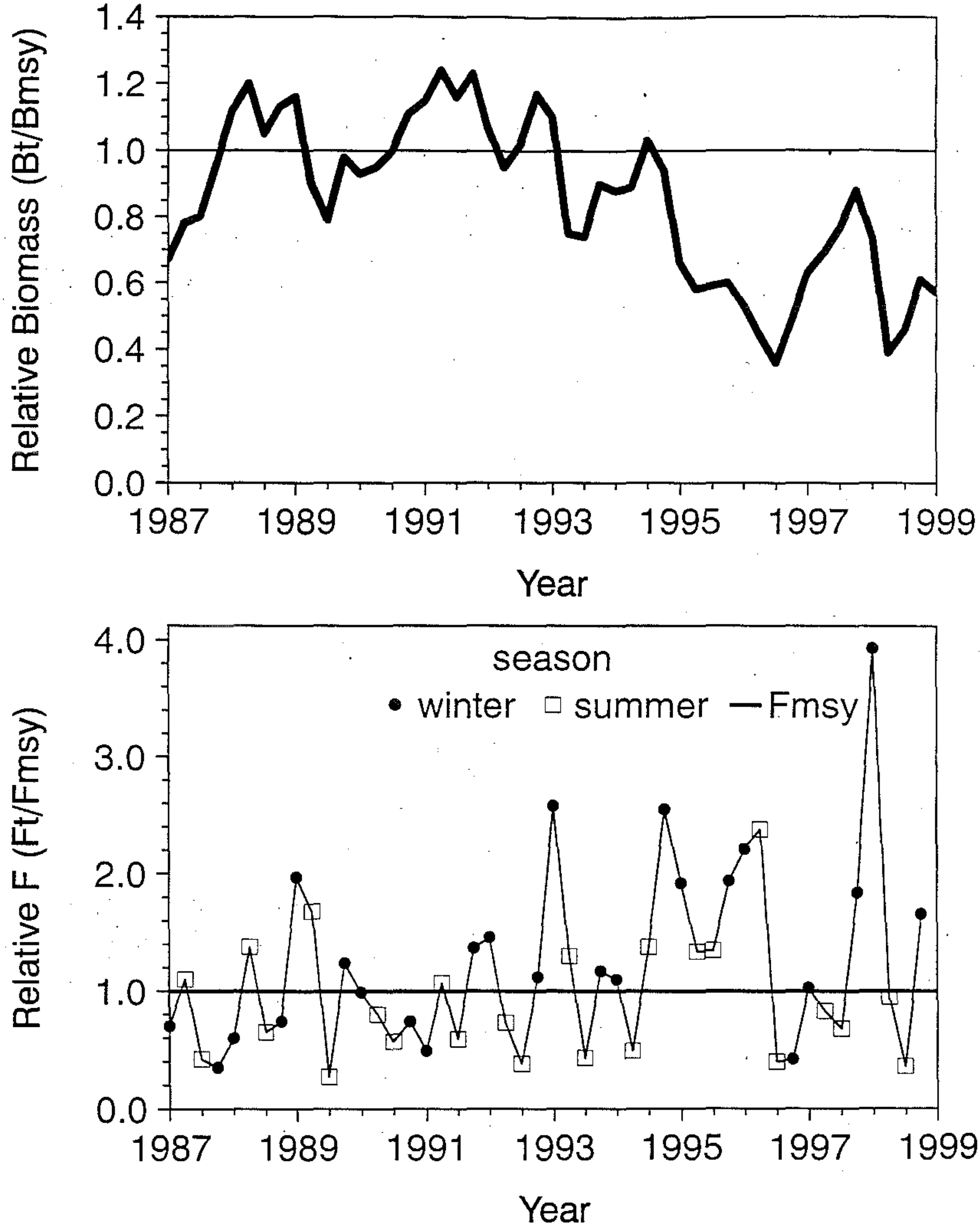



Figure C19. Stock biomass and fishing mortality of *Loligo pealeii* relative to MSY reference points from surplus production modeling.

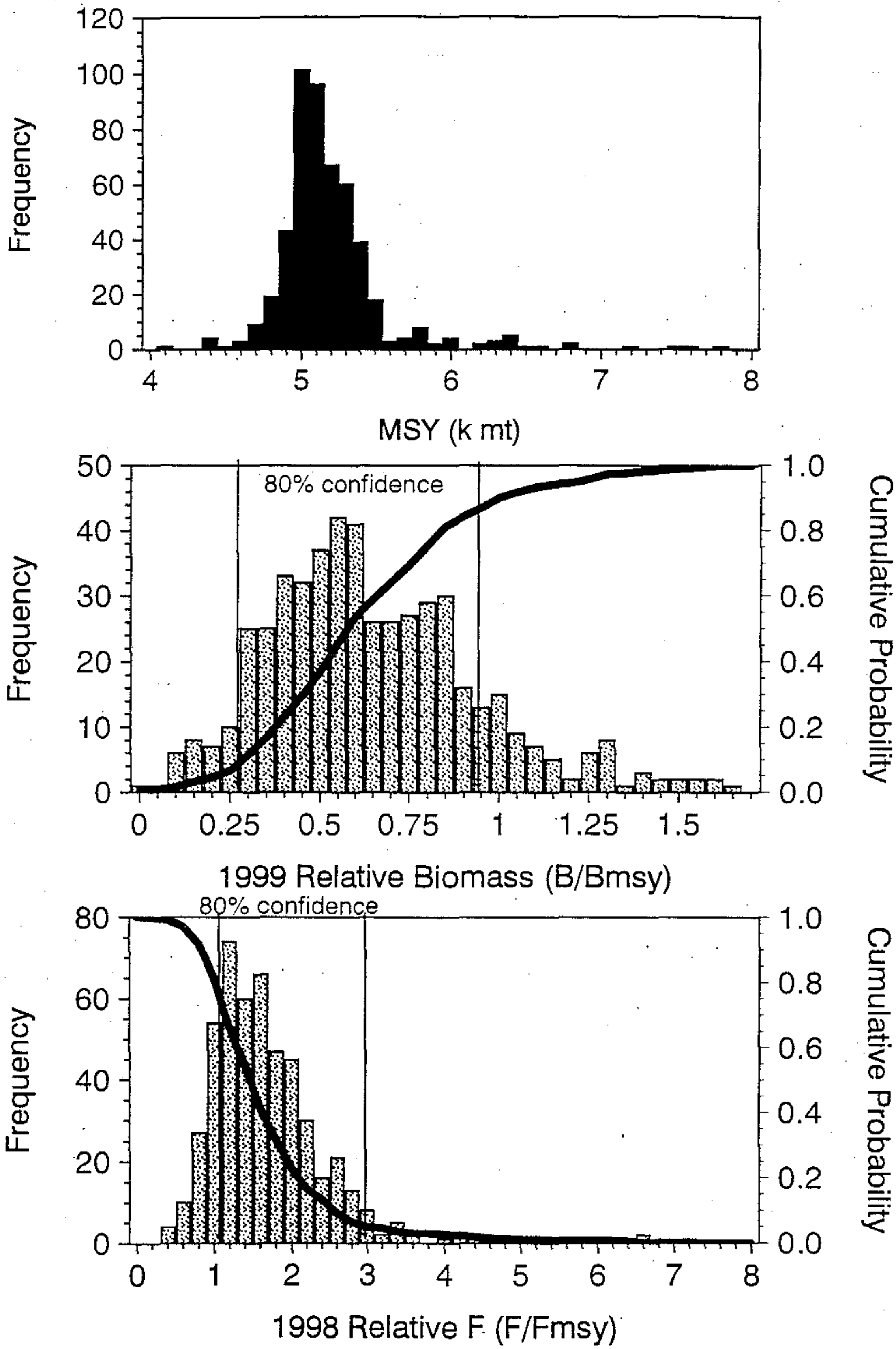



Figure C20. Bootstrap estimates of maximum sustainable yield, relative stock biomass, and fishing mortality of *Loligo pealeii* from surplus production modeling.

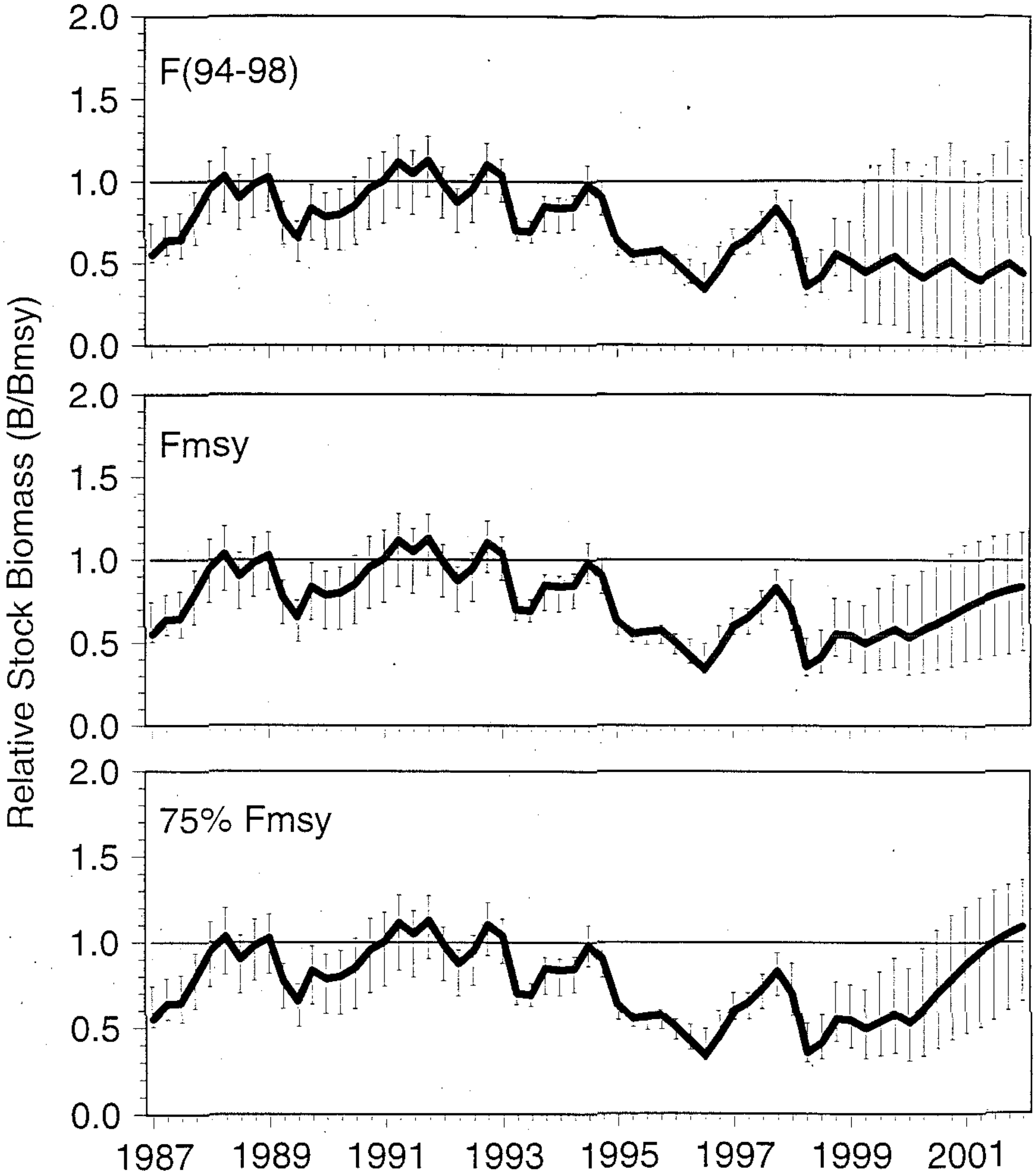



Figure C21a. Stochastic projections of relative stock biomass of *Loligo pealeii* at the overfishing definition (Fmsy) and the target F (75% Fmsy).

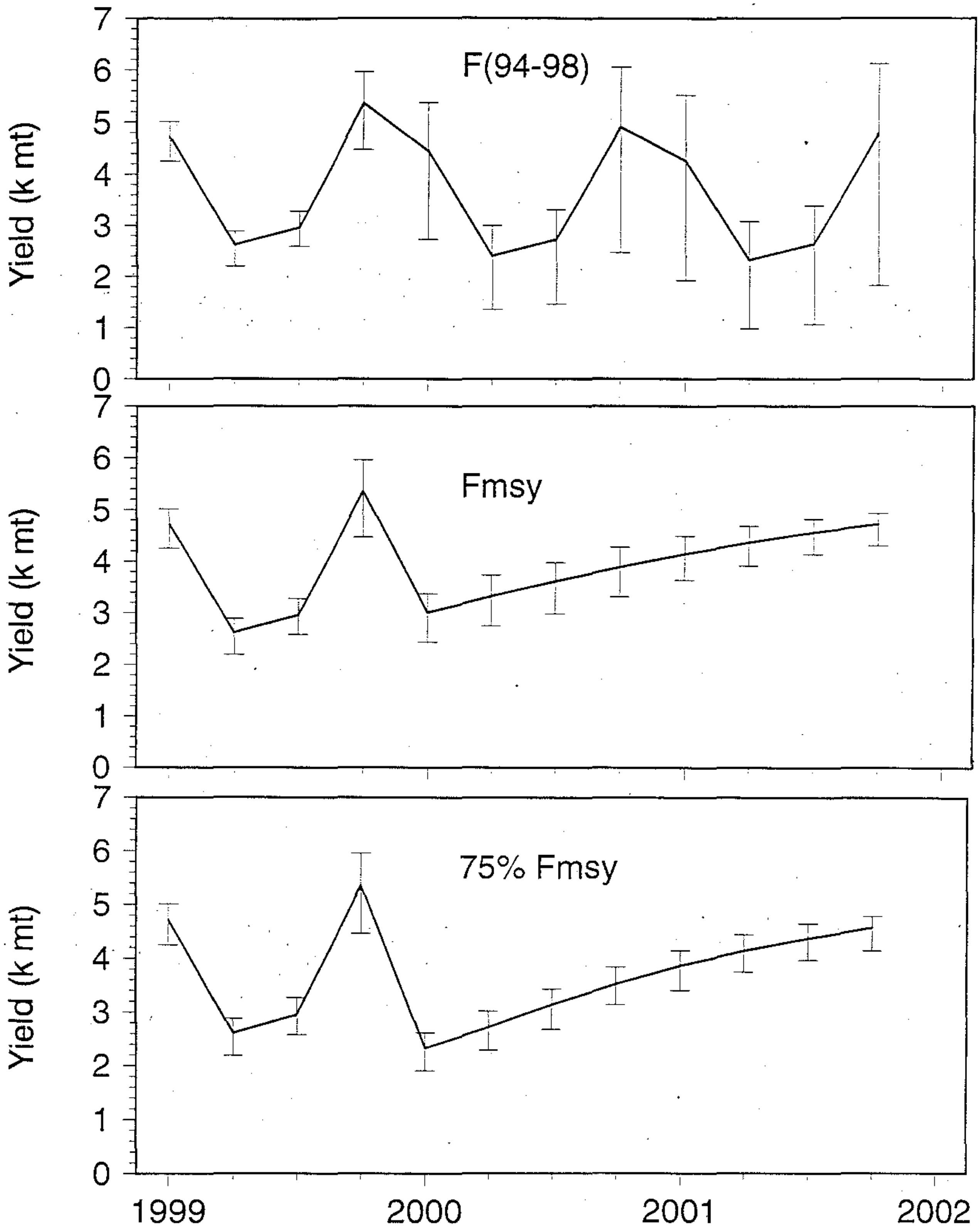



Figure C21b. Stochastic projections of *Loligo pealeii* yield at status quo F (1994-1998 seasonal averages), the overfishing definition ($F_{MSY}$), and the target F (75% $F_{MSY}$).

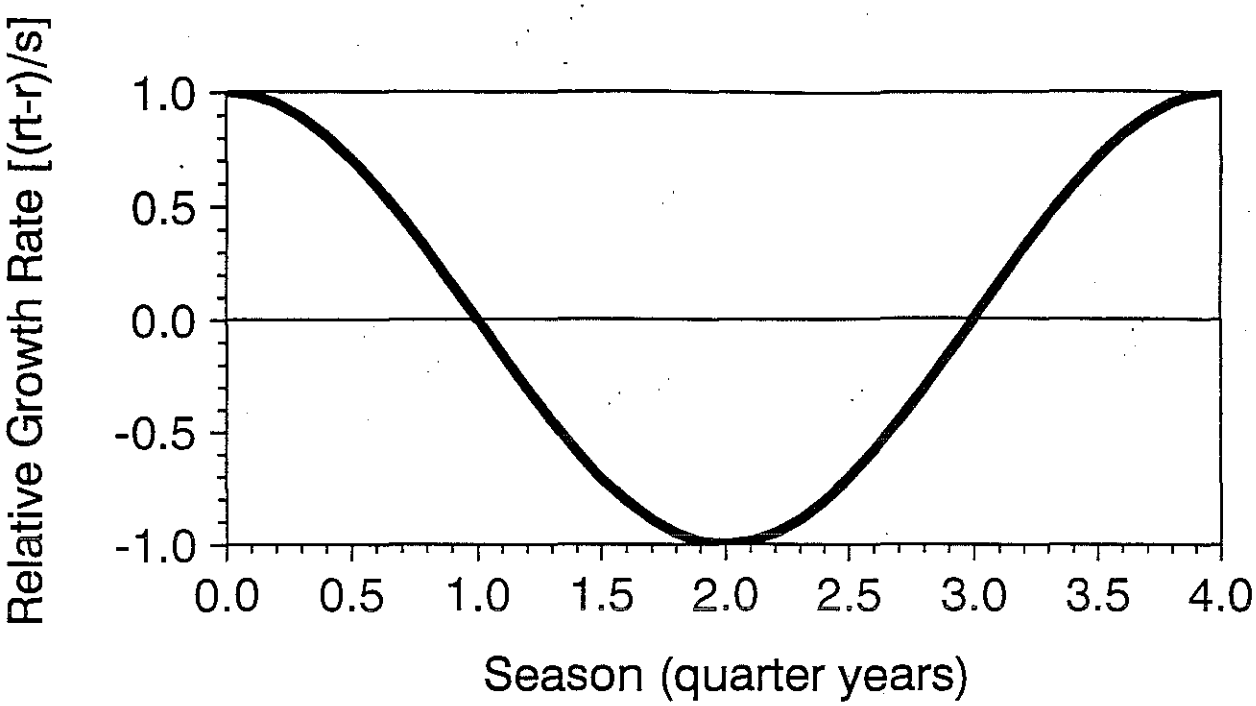



Figure C22. Hypothetical seasonal pattern of relative population growth rate [($r_t$-$r$)/s], where $r$ is the intrinsic rate of increase, $r_t$ is the seasonal growth rate, and s is the absolute seasonal deviation.

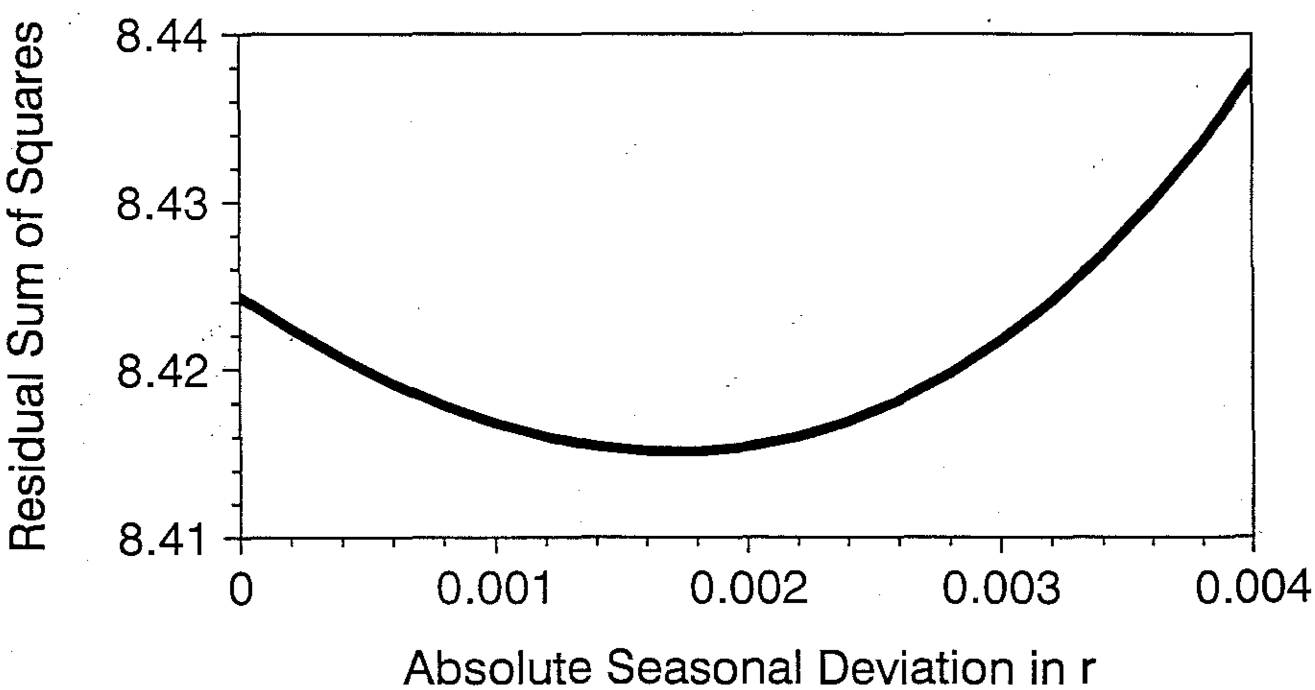



Figure C23. Response of objective function to estimates of s, the absolute seasonal deviation in $r$.

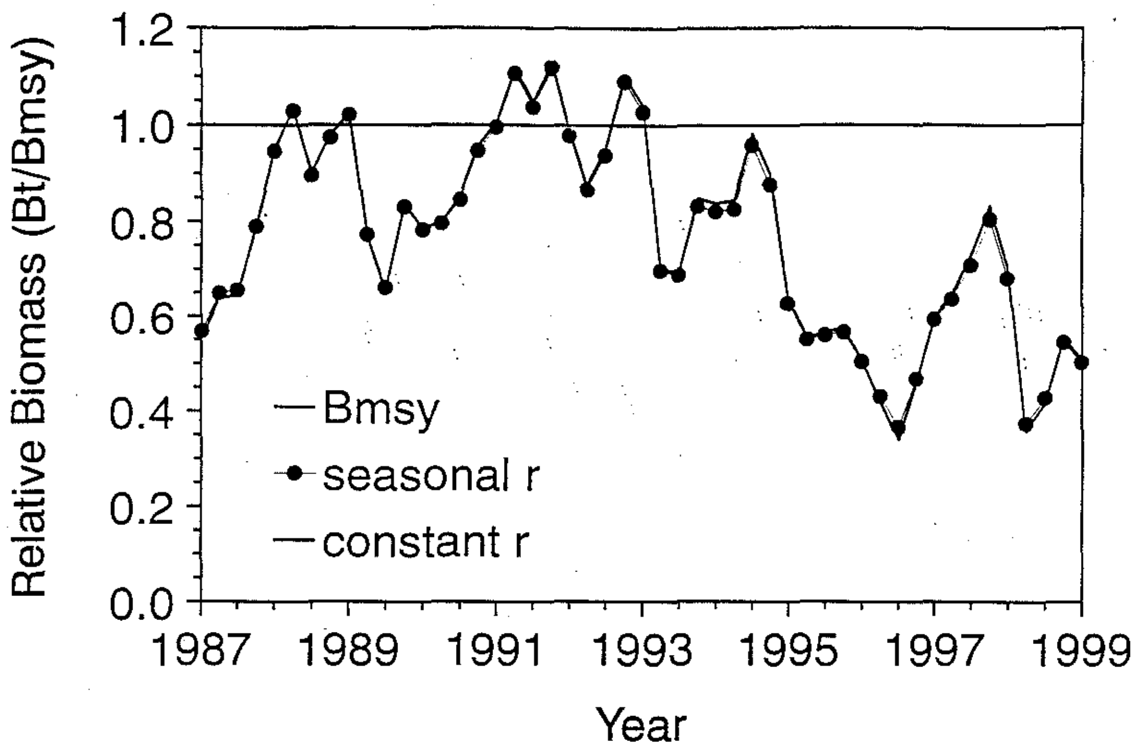



Figure C24. Comparison of relative biomass estimates from surplus production models that assume constant *r* and seasonally varying *r*.

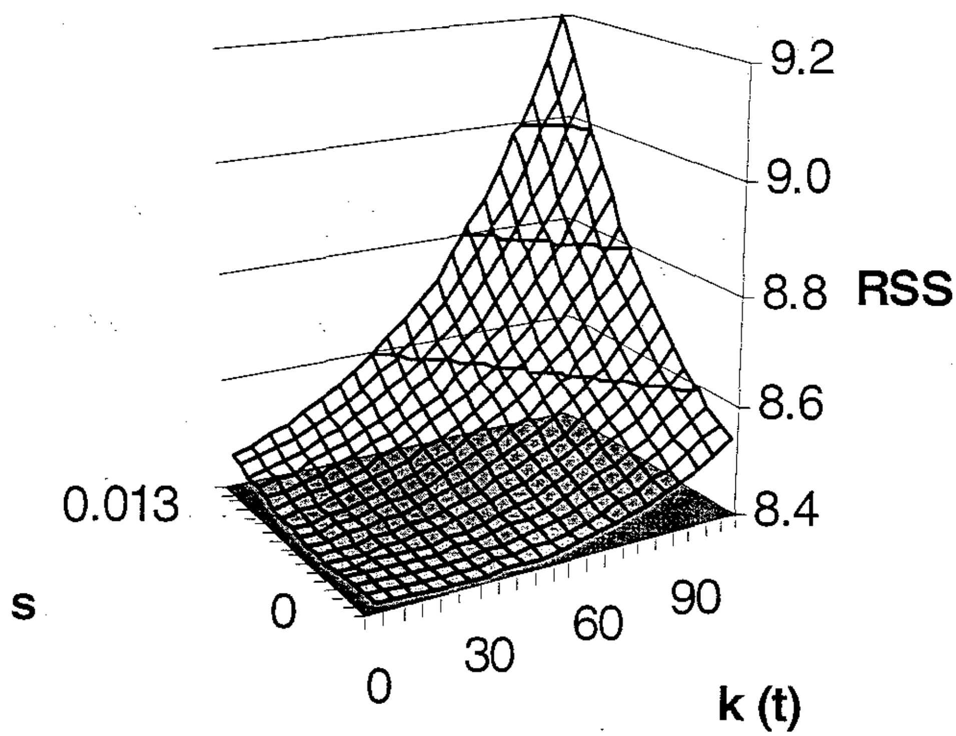



Figure C25. Response of objective function to simultaneous estimates of s (absolute seasonal deviation in *r*) and *k* (absolute seasonal deviation in *K*).

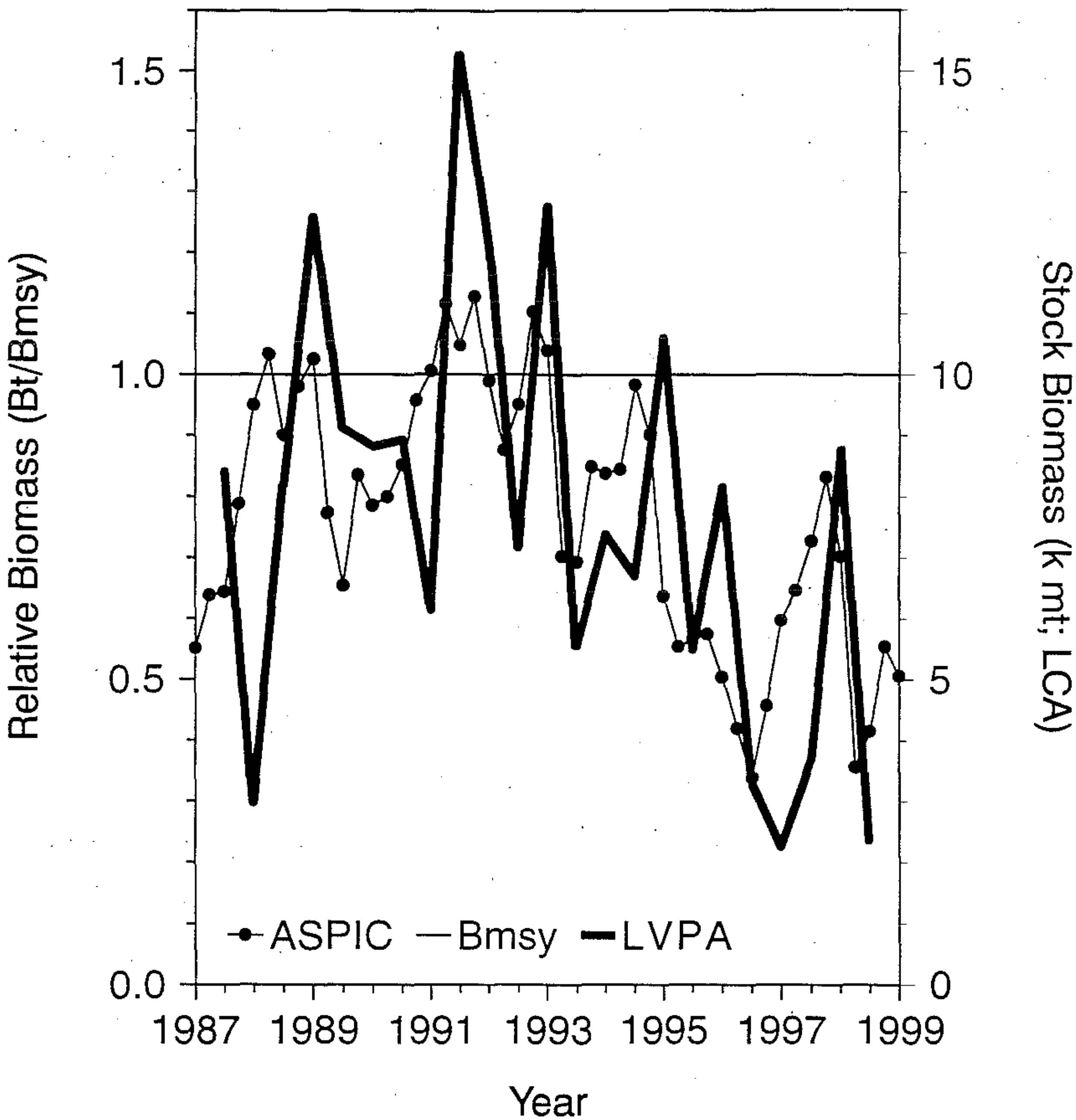



Figure C26. Comparison of relative biomass and F estimates from ASPIC with absolute biomass and F estimates from LVPA.

## D. NORTHERN SHORTFIN SQUID (*Illex*)

### TERMS OF REFERENCE

The following Terms of Reference were addressed:

a) update the status of the fishery and characterize uncertainty in stock size and fishing mortality rates;

b) update estimates of biological reference points based on new data, if available;

c) determine, with reference to the current overfishing definition, the status of northern shortfin squid stock;

d) determine whether overfishing is occurring and/or the likelihood of it occurring within the next two years, based on the SFA overfishing definition and biological reference points;

e) if stock biomass is less than $B_{target}$, determine rebuilding scenarios under current management measures; and

f) if practical, evaluate new management approaches such as real-time management.

### INTRODUCTION

The *Illex illecebrosus* stock was last assessed in 1995 at the 21st Stock Assessment Workshop (SAW), for the period 1982-1993, at which time annual biomass and fishing mortality rate estimates for the U.S. EEZ component were computed by fitting a biomass dynamics model to bottom trawl landings per unit of effort (LPUE) indices (NEFSC 1996, Hendrickson et. al. 1996). Based on that assessment, the U.S. EEZ portion of the stock was at a medium biomass level and was fully-exploited with regards to new biological reference points consisting of a $F_{20\%}$ threshold (equal to 0.28 per month) and a $F_{50\%}$ target (equal to 0.11 per month). The model estimates of MSY and $F_{MSY}$ were 24,000 mt and 1.22, respectively. However, the model provided imprecise estimates of initial and average stock biomass. As an improvement to the stock assessment and management of this annual species, the 21st Stock Assessment Review Committee (SARC) recommended real-time management (RTM), similar to the management of *Illex argentinus* in the Falkland Islands. The benefits of implementing RTM were presented as the minimization of recruitment overfishing and maximization of annual yield. This could be accomplished via an in-season adjustment of an effort or catch quota, based on an in-season estimation of stock size, in relation to a pre-determined target spawner escapement level which allows for sufficient recruitment during the following year. The components of a real-time management program for the *Illex illecebrosus* stock were described in the SAW 21 report (NEFSC 1996).

During late August in 1998, U.S. EEZ landings of *Illex* squid exceeded a 19,000 mt annual quota and the directed fishery was closed for the first time. This action initiated a request from the *Illex* squid fishing industry to assist the Invertebrate Subcommittee of the Stock Assessment Review Committee with the collection of data which would improve the stock assessment. Major issues addressed at three Subcommittee meetings, held during

October, November and December of 1998, were estimations of the fraction of the stock residing in waters outside the range of the fishery and improvement of the data set available for stock assessments.

Methods to estimate the offshore fraction of the stock were addressed at a squid hydroacoustics workshop, held in December of 1998, which was co-sponsored by the *Illex* squid industry and the Northeast Fisheries Science Center. A panel of international experts in this field offered insights into conducting a hydroacoustic survey of *Illex illecebrosus.* The primary workshop conclusion was that a qualitative feasibility study, both on and off the continental shelf, could be conducted by industry vessels outfitted with a digital data logger, scientific echosounder, computer and gear monitoring equipment. However, since *Illex* squid bottom trawl gear is limited to depths of approximately 250 fathoms, mid-water trawls would have to be used for deeper tows. Ground-truthing of acoustic signals would be required, during day and night tows, since target strength has not been estimated for this species and little is known about its behavior. In addition to equipment requirements, this feasibility study would require acousticians to direct the study and to process the large set of data which would be collected and scientific observers to record the catches at sea.

The Subcommittee addressed improving the data inputs to the stock assessment. *Illex illecebrosus* is a transboundary stock and is fished on the continental shelf from Newfoundland, Canada to Cape Hatteras, North Carolina. However, there are no stock-wide indices of relative abundance and biomass available for assessments. The limitations of utilizing the NEFSC bottom trawl survey indices of relative abundance and biomass in the *Illex* stock assessment were identified at SAW 21. In addition, a discontinuity in the LPUE time series utilized in the SAW 21 assessment occurred in 1994. At this time, the method for collecting fishing effort and location data changed from port agent interviews to self-reporting via logbooks. In addition, logbook reporting in the *Illex* fishery did not become mandatory until January1, 1997. Given this data gap, the Subcommittee discussed real-time management (RTM) as a potential long-term solution to improving data resolution and the assessment of this stock. Fishing industry members present at these meetings were in favor of investigating RTM and 17 captains have agreed to participate in a RTM feasibility study beginning on June 1, 1999. Each fishing vessel will report their catch, effort and fishing location on a daily basis. In addition, squid processors will be submitting weekly biological data reports and shipping samples to NEFSC for further biological data analysis. In the short-term, Subcommittee members noted that through Amendment 6, the MAFMC has the authority to regulate the length of the *Illex* fishing season. A delay in the start of the fishing season may result in an increase in fishery yields and the Subcommittee agreed that this possibility should be investigated as an intermediate step in the process of moving toward the implementation of real-time management. In an effort to make this analysis possible, the industry submitted a multi-year data set of *Illex* squid mantle lengths and body weights which were analyzed as part of the current stock assessment. Tow-based catch and effort data were also submitted, but these data were not extensive enough to incorporate into a quantitative model to estimate stock size.

The current assessment pertains to the U.S. EEZ portion of the stock and incorporates mean weights of squid caught in the U.S. bottom trawl fishery, provided by the fishing industry, and in-season trends in fishing effort and landings from Vessel Trip Reports during 1994-1998. Yield optimization, based on three different harvest policies involving a delay in the start week of the fishery, were evaluated as well as DeLury depletion model applicability for real-time management. A yield-per-recruit analysis was updated and new sexual maturity and age data for *Illex* squid caught in U.S. EEZ waters is also presented. Bottom trawl survey relative biomass and abundance indices, as well as landings, are presented for NAFO Subareas 3-6 to assess the overall status of the stock.

## BACKGROUND

A review of the biology, population dynamics and exploitation of the *Illex illecebrosus* stock in the northwest Atlantic Ocean in relation to the assessment and management of this resource is presented in Dawe and Hendrickson (1998). The northern shortfin squid is a highly-migratory ommastrephid that tends to school by sex and size and lives for up to one year (Dawe et al. 1985, Dawe and Beck 1997, O'Dor and Dawe 1998). The *Illex* population is assumed to constitute a unit stock throughout its range of commercial exploitation from Cape Hatteras to Newfoundland (Dawe and Hendrickson, 1998). Temporal and spatial distribution patterns are highly variable and are associated with environmental factors at the northern limit of this species' range (Dawe and Colburne 1998). Recruitment dynamics are complex and have not been elucidated for the U.S. EEZ component of the stock, inhibiting reliable predictions of annual recruitment levels. Coelho and O'Dor (1993) found that determination of *Illex* stock structure may be complicated by the overlap of seasonal cohorts. They found that mean size at sexual maturity varied between northern and southern geographic regions in some years. However, it was unknown whether these differences were due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal breeding patterns of the *Illex* population could have played a role in the collapse of the Canadian fishery during the early 1980's.

## MANAGEMENT

A commercial fishery for *Illex illecebrosus* occurs from Newfoundland to Cape Hatteras. The fishery is managed in the U.S. EEZ (NAFO Subareas 5 and 6) by the Mid-Atlantic Fishery Management Council (MAFMC) and by the Northwest Atlantic Fisheries Organization (NAFO) in NAFO Subareas 2, 3 and 4. Since 1980, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 has been 150,000 mt (NAFO 1995). This TAC was reduced by NAFO to 75,000 mt for the 1999 fishing season (NAFO 1998). Annual levels of allowable biological catch (ABC) and domestic annual harvest (DAH) in the U.S. EEZ are determined in accordance with the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan (SMB FMP) and are based on the best available information about the current status of the stock. During 1991-1995, the optimum yield (OY), ABC and DAH were 30,000 mt (MAFMC 1994). The DAH was reduced to 21,000 mt for 1996 (MAFMC 1995a) and 19,000 mt for the 1997-1999 fishing seasons (MAFMC 1996a, 1997a, 1998a).

Since the last *Illex* squid stock assessment, several FMP Amendments have been enacted. In recognition that the domestic resource was approaching full utilization and that expansion of the U.S. fleet may lead to overcapitalization, Amendment 5 was enacted (MAFMC 1995b, 196b). This Amendment established a permit moratorium to limit entry into the directed fishery, required mandatory logbook and dealer reporting as of January 1, 1997, and established 5,000-pound trip limits for incidental catches of *Illex* by non-moratorium vessels. Amendment 6 (MAFMC 1996c) allowed for the establishment of a seasonal closure of the *Illex* fishery and set a new overfishing definition as the catch associated with $F_{20\%}$ and the specification of annual quotas based on $F_{50\%}$. Amendment 7 (MAFMC 1998b) pertains to achieving consistency between FMPs regarding Limited Access Federal permits. Based on the requirements of the Sustainable Fisheries Act (SFA), Amendment 8 (MAFMC 1998c) defines a new overfishing definition and target for this stock; the catch associated with $F_{MSY}$ and 75% of $F_{MSY}$, respectively. In addition, a biomass target is specified as $B_{MSY}$ and the minimum biomass threshold is specified as ½ $B_{MSY}$. Amendment 8 also defines the essential habitat of this stock in the U.S. EEZ and establishes a framework adjustment process for specific management measures.

## THE FISHERY

### Temporal Distribution of Landings

The NAFO Subareas are shown in Figure 1. Landings (mt) of *Illex* squid during 1963-1998 are presented for NAFO Subareas 3+4 Subareas 5+6 (U.S. EEZ), and all Subareas combined in Table 1. Total allowable catches (TACs) established for NAFO Subareas 3+4 and Subareas 5+6 during 1974-1998 are also presented. Prior to 1976, U.S. EEZ landings of squid by distant water fleets were not consistently reported to species, so *Illex illecebrosus* and *Loligo pealeii* landings were combined. In addition, reporting of the purchase of squid, by species, did not occur in the NEFSC commercial fisheries Weighout database until 1979. Therefore, U.S. EEZ landings during 1963-1978 represent prorations based on the temporal and spatial landings patterns of *Illex illecebrosus* and *Loligo pealeii*, by country, from fisheries observer data (Lange and Sissenwine 1980). The source of U.S. EEZ landings during 1979-1998 is the NEFSC commercial fisheries Weighout database and includes landings from joint ventures which occurred during 1982-1990 between U.S. and foreign fishing vessels. Landings from NAFO Subareas 3 and 4, during 1973-1994, were taken from NAFO Scientific Council Summary reports (NAFO 1986, 1994a and 1994b). Landings from Subareas 3 and 4, during 1995-1997, were taken from Dawe and Hendrickson (1998), and during 1998, were reported by E. Dawe, Department of Fisheries and Oceans, Newfoundland (pers. comm. 1999) and Statistical Services of the Department of Fisheries and Oceans, Canada (pers. comm. 1999).

The magnitude of *Illex* landings varied considerably during 1963-1998 (Figure 2A) and consisted of two distinct levels. Prior to 1968, total landings were low, averaging 7,350 mt, and were primarily from the Subarea 3 hand jig fishery. Distant water fleets began fishing for *Illex* squid in Subareas 5+6, in 1968, and in Subarea 4 in 1970. Total landings during 1968-1974 averaged 13,470 mt and were primarily (75%) from Subareas 5+6. However, this trend was reversed during 1976-1981, when landings were predominately from the northern fishery areas (Subareas 3+4) and reached their highest levels since 1963; averaging 100,300 mt. Landings in Subareas 3+4 increased from

17,600 mt in 1975 to a peak of 162,000 mt in 1979, then decreased regularly to 426 mt in 1983. Since 1982, landings from Subareas 3+4 have remained low and total landings have been predominately from the U.S. EEZ. During 1982-1993, total landings averaged only 14,481 mt and landings from NAFO Subareas 3+4 averaged only 3,668 mt. Landings from Subarea 4 are taken as bycatch in the silver hake fishery (NAFO 1995) and the Subarea 3 landings are still taken by hand jigging. Combined landings from Subareas 3 and 4 during 1997 (15,485 mt) were at their highest levels since 1982 and exceeded U.S. EEZ landings (13,629 mt) for the first time since then. However, preliminary landings from these combined Subareas during 1998 totaled only 1,639 mt.

During 1968-1987 distant water fleets, consisting of automated jiggers, and bottom and midwater trawlers, fished in the U.S. EEZ. Landings from the U.S. EEZ reached a peak during this time period, in 1976, of 24,700 mt (Figure 2B). Total landings have been dominated primarily by the domestic bottom trawl fishery since its inception in 1982. During 1988-1993, landings from this fishery averaged 11,363 mt, comprising 71% of the average total landings, and averaged 17,142 mt during 1994-1998, comprising 72 % of the average total landings during this time. There has been no foreign participation permitted in the *Illex* fishery within the U.S. EEZ since 1987. Domestic fishing effort is greatly influenced by the global market demand for squid and is limited by onshore and at-sea freezer storage capacity (Lars Axelson, pers. comm., 1999) as well as the availability of this species to bottom trawl gear. The majority of the domestic landings are taken in bottom trawls; approximately 98 % of the 1998 landings. The Vessel Trip Report and NEFSC Sea Sampling databases indicate that the U.S. EEZ *Illex* fishery occurs primarily in the depth range of 70-200 fathoms. Gear limitations prevent consistent fishing in waters deeper than 250 fathoms (Glenn Goodwin, pers. comm). Domestic landings increased between 1988 and 1994, to 18,350 mt, then decreased to a range slightly below this level during 1995-1997. U.S. EEZ landings during 1998 (22,705 mt) reached the highest level on record since 1976, when the distant water fleets were fishing in U.S. waters, and exceeded the 1998 quota (19,000 mt), which led to a closure of the fishery in late August.

The monthly pattern of *Illex* landings during 1982-1996 is presented, by NAFO Subarea, in Figure 3 and Tables 2-4. Monthly landings for Subareas 3 and 4 were unavailable for 1997-1998. The temporal patterns of fisheries in U.S. and Canadian waters are determined primarily by the timing of this species' feeding migration onto and spawning migration off the continental shelf, although worldwide squid market conditions secondarily influence the timing of the fishing season in the U.S. EEZ. Inshore migration in Subarea 3 generally occurs during August, approximately three months later than it occurs on the continental shelf in Subareas 4, 5 and 6. This delay in the arrival of juveniles on the fishing grounds is a result of the Gulf Stream being located further from shore in this northern region. An unusually early inshore arrival of squid occurred in Subarea 3 during June of 1987, when 78% of the landings for that year were taken. This species also remains on the shelf longer in Subarea 3, where fishing extends into November, particularly since 1992. Since 1992, the U.S. EEZ fishery and the bycatch of *Illex* taken in the Subarea 4 silver hake fishery have begun in May or June. Although the silver hake fishery in Subarea 4 closes in July, it is apparent from the Canadian observer program that these vessels target *Illex* when it is available (Mark Showell, pers. comm. 1998). Since 1992, peak landings have occurred in Subareas 4, 5, and 6 during July and in Subarea 3 during September.

Since 1987, the U.S. fishery has occurred between May and November, but most of the landings (90%) have been taken between June and September (Table 2). Since 1994, the percentage of landings by month has generally exceeded the average percentage for the 1992-1998 period. Figure 4 shows the trends in landings by week of the year during 1994-1998. During 1994-1996, the fishery began during weeks 20-22, the length of the season increased from 18 weeks to 23 weeks during these three years. The 1996 season extended into November with an unusually large percentage (15%) of the landings occurring during October. However, landings during 1996 occurred at a consistently low level throughout the season. Landings during 1994, a shorter season, increased rapidly at the beginning of the season, reaching a peak at week 28, then rapidly declined. During 1997, the fishing industry voluntarily delayed the opening of the fishing season until June 21, resulting in only 25% of the 1992-1998 average percentage of landings being taken during June. However, the percentage of landings during July of 1997 was 10% higher (39%) than the 1992-1998 average for that month. During 1998, an unusually large percentage of the landings occurred during May (9%), since a market for small squid was available and the market squid, *Loligo opalescens*, was in short supply. Although the fishery closed during week 35 of 1998, the weekly landings pattern was one of gradual increase up to the point of closure.

Spatial Distribution of Landings

Since 1994, the Vessel Trip Reports (VTR) have become the sole source of fishing effort and location data. These data were used to discern the spatial distribution of the 1998 landings, by Statistical Area (Figure 5) since the VTR and Weighout database landings were similar during 1998. Spatially, the 1998 landings were similar to the average for previous years (Table 5), with a majority of the landings (68%) being taken from Statistical Area 622.

## STOCK ABUNDANCE AND BIOMASS INDICES

Research Vessel Survey Indices

There are no stock-wide indices of abundance or biomass for this stock. Figures 6A and 6B show the annual trends in research bottom trawl survey indices of relative abundance (stratified mean number per tow) and biomass (stratified mean weight per tow), respectively, for NAFO Subareas 4 (Gulf of St. Lawrence and Scotian Shelf) and Subareas 5+6 (U.S. EEZ), as well as standardized U.S. domestic landings per unit of effort (LPUE) indices (Hendrickson et al 1996). Figure 6C shows an additional relative abundance index; NEFSC autumn survey (1967-1998) trends in the percentage of tows, in all offshore strata between Georges Bank and Cape Hatteras, in which more than one individual was caught during the month of September. The Gulf of St. Lawrence survey occurs during September, similar to the U.S. survey, although the latter extends through October and into November during some years. The Scotian Shelf indices represent pre-fishery indices of abundance and biomass, whereas the U.S. and Gulf of St. Lawrence indices represent post-fishery indices. Trends in relative biomass indices are similar between the Subareas, but the abundance indices show more variability between Subareas.

Annual indices of *Illex* relative abundance (stratified mean catch per tow, in numbers) and biomass (stratified mean weight per tow, in kilograms), within the U.S. EEZ from Cape Hatteras to the Gulf of Maine, were computed from NEFSC autumn (1967-1998) bottom trawl surveys. Survey procedures and details of the stratified random sampling design are provided in Azarovitz (1981). Standard survey tows in offshore strata 1-40 and 61-76 (Figure 7) were used to compute these indices, which were adjusted for differences in research vessel effects (Table 6). A vessel conversion coefficient of 0.81 was applied to the *Delaware II* stratified mean weight per tow values, prior to computing the autumn survey indices, to standardize these tows to *Albatross IV* catches (Hendrickson et al. 1996).

As might be expected for an annual species if fluctuations in recruitment are substantial, the survey indices show a large degree of interannual variability. However, it should be noted that the outer shelf and continental slope are important *Illex* habitats (Lange 1981) that are not intensively sampled during NEFSC bottom trawl surveys. Furthermore, the survey bottom trawl gear is not likely to sample pelagic species efficiently.

Survey biomass indices for Subareas 5+6 and Subarea 4 (Scotian Shelf) indicate that the stock has been characterized by high (1976-1981) and low productivity regimes (Figure 8A). The low productivity regime began in 1982, following the peak period of high landings in Subareas 3+4 during 1976-1981(Figure 8B) and in addition to low biomass indices is characterized by a drastic drop in the mean weights of individuals, which reached the lowest levels on record during 1995-1997. The Subarea 5+6 mean number per tow and weight per tow indices indicate the occurrence of a second period of high abundance during 1987-1990. However, although the abundance indices from this latter period were comparable to those during 1976-1981, individual mean weights of animals from the latter period were less than half those from 1976-1981 (Figure 8C). This observed difference in mean weights may be due to differing contributions of seasonal breeding components or differing growth conditions during these periods. More recently, the 1998 Subarea 5+6 number per tow index (14.60) was the highest since 1990 and well above the 1967-1998 long-term average of (9.32 squid/tow). Figure 9 shows the stratified mean proportion at length (DML in cm) of *Illex* squid caught during the autumn bottom trawl surveys during 1967-1998. Dawe and Hendrickson (1998) noted a unimodal length composition for squid from inshore Newfoundland, whereas the length composition in subareas 5+6 is bimodal in some years. The bimodal trend exists mainly prior to the 1981 productivity regime shift.

U.S. Commercial Catch Rates

During the last stock assessment in 1996, a standardized LPUE time series for the domestic *Illex* fleet was incorporated into a stock production model as an index of relative biomass. However, the 1982-1993 LPUE time series was not extended through 1998 for several reasons. There are currently two breaks in the *Illex* LPUE time series. The 1982-1993 time series consists of fishing effort and location data collected by port agents from interview with fishing vessel captains. This data collection method was changed in May of 1994, when a self-reporting system, vessel trip reports (VTR), was implemented for some fisheries. However, logbook reporting for *Illex* squid moratorium permit holders did not become mandatory until January 1, 1997. Therefore, fishing effort and location data for this fishery are incomplete for the 1994-1996 fishing seasons. Figure 10 outlines the process required to merge fishing effort and location data from the VTR database with landings from the Weighout database to obtain the information required to derive standardized LPUE indices using the same GLM data subset used for the 1982-1993 LPUE indices. The resulting merged subset consists of only 19 directed trips during 1995. Table 7 summarizes the percentages of landings, trips and number of vessels which occurred in the merged data set. Merged landings percentages were much lower during 1994-1996 than during the mandatory reporting years of 1997 and 1998. During 1995, directed trips merged were only 6% of those in the Weighout database and landings were only 15% of the Weighout landings. As a result of the under-representation of directed landings and trips during some years, and the change in data collection methodology, the standardized LPUE time series was not extended for 1994-1998.

## LIFE HISTORY PARAMETERS

*Illex* squid collected during the 1997 NEFSC autumn (September 9 - October 30) bottom trawl survey (N=731) were weighed to the nearest 0.1 g and dorsal mantle length was measured to the nearest mm. Male sexual maturity stages for 376 individuals were subjectively determined according to the Mercer scale (1973) and female maturity stages for 352 individuals were quantitatively determined according to Durward et. al. (1979). There were only 3 immature squid caught in the autumn survey. Individuals from survey stations which overlapped spatially with the primary fishing grounds in the Mid-Atlantic Bight were also aged ($N_{females}$=63, $N_{males}$=75)(Figure 11); by back-calculating hatch dates from dates of capture based on statolith increment counts using the method of Dawe and Beck (1997). Since sampling occurred during a narrow time window (September 9-12, 1997) it is unlikely that migration into or out of the survey area occurred. Similar biological data were collected for female (N=163) and male (N=145) *Illex* squid from the inshore Newfoundland jig fishery, which were aged ($N_{females}$=71, $N_{males}$=59). Jigged squid samples were collected during a similar time window (August 30, September 11 and 25 , 1997) so length, age and sexual maturity data for these fishery samples were compared to those from the U.S. survey samples. The details of the age and sexual maturity analyses are presented in Working Paper D2 and are summarized below.

### Age and Growth

Age estimates were 134-292 days for squid from the MAB and were 154-320 days for Newfoundland squid. The previous estimate of maximum age for this species was 250 days (Dawe and Beck 1997). Model fits for exponential, linear and power models, used to describe mantle length at age and weight at age. were poor for males and females from Newfoundland samples as well as the MAB samples. For the MAB squid, the linear model gave the best fit for length at age data and the power model gave the best fit for weight at age data. A growth rate of 0.76 mm/day was estimated for females, however, the female linear regression for length at age resulted in a poor fit ($r^2$ = 0.34) and a unrealistic prediction of size at year 0. This is likely due to incomplete sampling of all size ranges. Mantle lengths of squid aged from the MAB were 101-238 mm and from Newfoundland were 154-278 mm. Since squid less than four months of age were not sampled in the current study, it was not possible to link the growth rate estimate to the early part of the life cycle, which has been shown to be exponential for other squid species (see review in Forsythe and van Heukelem 1987). In addition, length at age was found to be highly variable. For example, squid of 150 mm ML vary in age by up to 5 months (150 days). This variability was not explained by modeling the growth rates of each cohort (by hatch month). However, the female growth rate point estimate does lie within the range of previous estimates based on statolith age determination (0.71-1.29 mm/day) for Newfoundland jig fishery samples of this species (Dawe and Beck 1997).

The hatch date distribution (Figure 12) for squid sampled on September 11, 1997 shows a January peak, with a December through February predominance, for the Newfoundland samples and a February peak, with a January through March predominance, for squid sampled on September 9-12 in the MAB. Based on the age distribution of squid from the MAB, a summer spawning event was not evident in the U.S. EEZ in 1997, as had previously been inferred from length data to have occurred during 1974, 1975 and 1979 (Lange and Sissenwine 1981). The presence of a hatching peak one month earlier in Newfoundland than in the MAB, for squid sampled concurrently, suggests that the Newfoundland squid would had to have been spawned earlier than the MAB squid since they must be transported further north. Based on a maximum speed for the Gulf Stream core, 1 m/sec or 48 nautical miles per day, larval transport from Florida to Newfoundland (approximately 1,200 miles) is possible within 30 days. Therefore, it seems feasible that individuals from both populations could have been spawned off the Straits of Florida (Trites 1983; Rowell et. al. 1985), particularly since hatchlings have only been collected south of Cape Hatteras (see review by Dawe and Hendrickson 1998).

Sexual Maturity

Weekly monitoring of changes in squid mean size and length during the fishing season, in combination with the proportion of individuals at each maturity stage, would allow for a determination of whether the population is "closed" with respect to emigration and immigration through the fishing area (Agnew et. al. 1998). A "closed" population is one of the assumptions of the depletion model which would be used in real-time management of this stock.

The length frequency distribution of the 1997 Newfoundland jig fishery samples (Figure 13B) was similar to that of the 1997 U.S. bottom trawl fishery during the same week (week 34 in Figure 14) in that the size range for both is approximately 150-270 mm, with a mode in the 190-199 mm category. Fishery samples clearly lacked the smaller squid (70-149 mm) present in the 1997 autumn survey (Figure 13A). In addition, U.S. survey samples had lower percentages of squid larger than 230 mm, which appear to be primarily females since they are generally larger than males according to the Newfoundland fishery length frequency distributions by sex. Newfoundland squid were generally larger than U.S. EEZ squid of each sex and maturity stage, but they were not necessarily more mature. Although 5% of the females and 18% of the males from the U.S. survey samples were fully-mature, there were no fully-mature males or females in the Newfoundland sample. Since it is unknown whether squid smaller than 150 mm were present in inshore fishing areas when the Newfoundland samples were collected, jig selectivity is unknown. It is possible that male *Illex* squid caught in U.S. EEZ waters are maturing at smaller sizes. In the 1997 autumn research survey, the $L_{50\%}$ for male squid was 185 mm with an age at 50% maturity of 190 days. A 1980-1982 estimate for male squid from SA 5+6 was 200-215 mm (Coelho and O'Dor 1993). An $L_{50\%}$ for females could not be computed in the current study because only four fully-mature (Stage 5) females were captured in the NEFSC survey of the U.S. continental shelf. As indicated in Table 8, only nine fully-mature females have been recorded since 1968 (Dawe and Drew, 1981); of which four individuals had mated. However, the low sample sizes are, in part, due to low sampling intensity of *Illex* for maturity staging. All fully-mature and nearly mature (Stage 4) females were captured along the shelf edge in water deeper than 100 fathoms, with the exception of two animals which were captured inshore near the west coast of Newfoundland (Figure 15). Most captures occurred during late August through September and were south of 40° latitude. Furthermore, Subarea 5+6 survey densities of *Illex* squid in autumn are greatest in the deepest offshore survey strata. Larger squid show a preference for deeper water than smaller squid (Brodziak and Hendrickson 1999). In total, these factors suggest that mature squid migrate to the edge of the US continental shelf, in a "wave" pattern, and then move south to spawn, rather than migrating southward over the continental shelf. Likewise, Subarea 5+6 squid distribution maps of spring survey catches indicate that migration onto the continental shelf appears to occur in a "wave" pattern along a broad latitudinal expanse of the shelf edge (Hendrickson et. al. 1996). This "wave" pattern is also evident on the Grand Banks and Scotian Shelf in a series of monthly survey distribution maps, during 1970-1980 (Figure 16) (Black et. al. 1987). In addition, Dawe and Hendrickson (1998) point out that paralarvae have been caught in the Gulf Stream across a broad latitudinal range, from the Grand Banks (53° W) to south of Cape Hatteras (35° S). They also note that numerous surveys have shown a continuous distribution of juveniles along the axis of the Gulf Stream, across the same latitudinal range as the paralarval distribution, and that the spring onshore migration occurs later in Newfoundland than in US waters.

## STOCK SIZE AND FISHING MORTALITY RATES

### Overview

The short life cycles, rapid growth rates, highly variable population abundance, high natural mortality rates and generally semelparous breeding strategies of most cephalopod species render many of the traditional approaches to stock assessment inappropriate (Caddy 1983). This has certainly been true for the *Illex illecebrosus* stock, for which biomass dynamics models which have incorporated annual indices of relative biomass have been shown to result in imprecise estimates of stock size and fishing mortality rates (NEFSC 1996; Hendrickson et. al. 1996). At the 1998 NAFO Precautionary Approach NAFO Workshop, the ASPIC (A Surplus Production Model Including Covariates) (Prager 1994) biomass dynamics model was also applied to this stock. Various combinations of abundance indices and landings data were included in the model, but the resulting fit was also poor. Part of the problem with applying any model to this stock lies in the fact there is no single stock-based index of abundance or biomass. In addition, existing indices for the U.S. EEZ component of the stock are of inadequate temporal and spatial resolution for this annual species. Currently, logbook effort is recorded as the total number of tows within a large Statistical Area and the average tow time. The "search time" component of fishing effort is unaccounted for and is often a large fraction of fishing effort for pelagic species. Additional biological data and life history information is also needed for the U. S. component of the stock.

According to the ICES Working Group on Cephalopod Fisheries and Life History, depletion methods have been found to offer the most promise for assessing ommastrephid and loliginid squid stocks (Pierce and Guerra 1994, ICES 1998, Rosenberg et. al. 1990). Depletion estimation requires data consisting of: total catch, mean squid weights, an abundance index (catch and effort), a recruitment index proportional to the number of recruits, and an estimate of natural mortality. In addition, these data must be of appropriate temporal resolution, generally weekly, and available throughout the fishing season. Such data are currently unavailable for the *Illex illecebrosus* stock. Therefore, absolute estimates of stock size and fishing mortality rates cannot be provided at this time. However, data collected during the 1999 real-time management feasibility study may allow depletion estimation methods to be applied to this stock.

Given the lack of adequate data resolution for the current stock assessment, *Illex* length and body weight data from U.S. EEZ bottom trawl landings, during 1994-1998, were provided to NEFSC by squid processors. Individual body weight was measured to the nearest gram and dorsal mantle length (DML) was measured to the nearest centimeter. Samples from four freezer trawlers were used in the analysis, since date of capture was recorded for these samples and was used to assign each sample to a week of the year (Table 9). Similar trends between monthly sample sizes for the biological data and monthly landings from the Weighout database suggest that this data set was representative of the temporal landings pattern during each year included the analyses (Figure 17). Mean, minimum, and maximum values for body weights and dorsal mantle lengths are summarized, by week of the year, in Table 10. VTR data were used in the analysis to assess trends in CPUE, by assigning a week of the year to each trip based on date landed, and in establishing criteria used in evaluating various yield scenarios. VTR data and the length-weight data were also used to conduct a preliminary evaluation of the applicability of a depletion model to this stock and to estimate fishing mortality and stock size.

In-season trends in catch, effort and nominal CPUE were examined, by week of the year, for U.S. EEZ bottom trawl fishery data from the NEFSC Vessel Trip Report (VTR) database. Trends in the average body weight of *Illex* during the fishing season, supplied by the fishing industry, were used to conduct a preliminary evaluation of the applicability of a depletion model for this stock, to calculate preliminary estimates of stock size and fishing mortality rates, and to determine the effects on yield through delaying the start of the U.S. fishery. A geographic information system (GIS) was also used to examine the spatial distribution of catches during *Illex* squid trips. These tow-based data were either provided by fishing vessel captains or retrieved from the NEFSC Observer Program database. Figures 18 and 19 indicate that trips by large processor vessels (freezer trawlers) may occur in multiple Statistical Areas, but that the spatial distribution of individual tows for these vessels as well as trips of shorter duration, made by "fresh" or RSW vessels (Figures 20 and 21), tend to be aggregated within small, localized areas. These figures indicate that this spatial pattern is due to a feedback effect such that high catch rates lead to more tows in the same vicinity. Thus, fine-scale temporal and spatial resolution of fishery catch rates is necessary for real-time assessment of this stock.

Trends in Average Body Weight and Dorsal Mantle Length

Annual mean body weights (g) (Figure 22) and mean mantle lengths (Figure 23) were highest during 1994 and lowest during 1996. Summer bottom water temperature anomalies, as measured during the August sea scallop survey, indicate that bottom water temperatures were warmer during the summer of 1994 than 1995-1998. Figures 24-27 show the proportion at length by week of the year for 1994-1996 and 1998, respectively, and 1997 is shown in Figure 14. Figures 28-32 show the proportion at weight by week of the year for 1994-1998. Box plots of the average weight by week for all years combined revealed a steady increase in average size from 50-175 g between week 20 and 34 (mid July) (Figure 33). The Lowess-smoothed trend line of average weight in the landings subsumes processes of recruitment, emigration, natural mortality and fishing mortality. The apparent stability of average size in the fishery after week 34 may be driven in part by the recruitment of smaller individuals, but most likely reflects the migration of larger squid out of the fishing area. Further evidence that this asymptote represents the annual offshore spawning migration is that larger squid in advanced stages of maturity are present in the deepest survey strata at this time. However, comparisons among years show marked differences in the temporal occurrence of asymptotic size which may be due to environmental conditions (Brodziak and Hendrickson 1999). The Lowess smoothed time series of average weights (Figure 34) suggest that a maximum size range of 175-200 g is achieved at varying times during the season. In 1994 the asymptotic size was attained before week 35, whereas in 1996 the rate of change in average size was slow but continuous through week 48 (Figure 34).

Trends in Catch and Nominal Effort and CPUE

Median landings per unit effort (LPUE) for trips recorded in the Vessel Trip Report (VTR) database increased in 1997 and 1998 from lower levels in 1994-1996 but a wide range of variation was present (Figure 35). Additional work on effort standardization is necessary to evaluate underlying reasons for the apparent increase, but 1997 was the first year that logbooks were mandatory for this fishery. Partitioning of the data into trips greater than 3 days duration (Figure 36), generally made by freezer trawlers, and trips less than four days (Figure 37), made by "fresh" boats or RSW boats, demonstrated an overall decline in LPUE beginning in week 25. The pattern for trips less than four days may be confounded by mis-assigned trip durations in the VTR database. In some instances, longer duration trips are assigned a trip duration of one day when the date landed was not reported. Tables 11 and 12 summarize the total effort (hours fished) and landings (pounds), respectively, by week of the year for 1994-1998. For the purpose of modeling stock abundance, it was assumed that the seasonal distribution of fishery landings in the VTR data set adequately represented the total landings from the fleet. Average landings per unit effort (LPUE) was estimated using a ratio estimator of total landings divided by total effort (Table 13, Figure 38). The cumulative distributions of fishing effort and landings, depicted in Figure 39, illustrate marked shifts in the timing of median catch level and median cumulative effort.

Model for Estimation of Stock Size and Fishing Mortality Rates

As noted above, population and fishing mortality estimates for squid populations are problematic, owing to difficulties in aging, rapid growth rates, multiple within-year cohorts and lack of population closure. The migration of *Illex* squid into northern fishing areas in Newfoundland waters is thought to be controlled by oceanographic conditions (Rowell et al. 1985, Dawe and Warren 1992, Dawe et. al. 1998). Nonetheless, the fine-scale temporal resolution of the fishery biological data set, average weight and length by week, affords an extraordinary opportunity to examine the suite of population processes that govern population size in the fishing area. Moreover, comparable detail on the seasonal distribution of fishing effort provides insight into the fishery, and as will be demonstrated, a lower bound on population size and upper bound on fishing mortality rates.

The population biomass of *Illex* in the fishing area reflects the net flux of migrants into and out of the area, losses due to fishing and natural mortality, recruitment via reproduction, and growth of individuals. At present, none of these factors can be isolated unequivocally. Estimation of migration rates requires tagging and/or surveys of the fraction of the stock outside the fishing area. Quantification of migration rates would further require an understanding of the spatial distribution of the on-shelf movements of *Illex*. For example, simultaneous arrival of squid across a broad expanse of the shelf break would imply a much different migration rate than would a gauntlet process in which all of the population is funneled through the Mid-Atlantic Bight fishing area before moving to northern areas. These two hypotheses represent extremes of a continuum of possible migration patterns. Similarly, natural mortality rates are poorly known but are likely to be high relative to fishing mortality. Given the large number of potential predators it is unlikely that natural mortality rates are constant with time, age or location. Despite the considerable shortcomings of our biological knowledge, it is clear that *Illex* possess a broad range of life history mechanisms to ensure persistence. The following empirical model of *Illex* stock dynamics allows for examination of the potential importance of these factors.

The basic inputs to the model are summarized below:

1. Inputs: Observed Values
   Weekly average weight: $W_t$
   Relative seasonal distribution of Effort: $p(E_t)$
   Total Landings: $Y_{TOT}$
   Weekly Landings $Y_t$

2. Outputs: Parameter Estimates
   Total Fishing Mortality: $F_{TOT}$
   Initial Population Size $N_0$

Model variables for *Illex* in the fishing area are defined as follows:

$N_t$ = Number of squid alive at the beginning of week t

$R_t$ = New recruits and/or migrants into the fishing area during week t

$B_t$ = Total biomass of population in fishing area at start of week t

$W_t$ = Observed average weight of *Illex* in fishery in week t

$F_t$ = Fishing mortality rate in week t

M = weekly natural mortality rate (constant across weeks)

$X_t$ = Instantaneous Emigration rate in week t

$Z_t$ = total mortality on population in week t

$G_t$ = Instantaneous rate of true growth in week t

$C_t$ = Catch (in numbers) from fishery in week t

$Y_t$ = Yield (in weight) from fishery in week t
$E_t$ = Effort (hours fished) in week t

T = maximum duration of fishery (in weeks) t=s,s+1, s+2, ...,

s = starting week of fishery $1 \leq s \leq T$

The mass balance equation governing the abundance of squid in the fishing area can be written as

$$N_{t+1} = N_t \exp(-(F_t + M + X_t)) + R_t \qquad (1)$$

Recruitment into the fishing area is impossible to estimate if all of the migrants or recruits are the same size as the extant population. A pulse of smaller sized Illex would provide indirect evidence of delayed reproduction, but given the wide variation in growth rates, even this assertion cannot be confirmed without significant increases in sampling for age determination. Empirical analyses of the relationship between size and age suggests that weight increases as an exponential function of age such that

$$W_{t+1} = W_t \exp(G_t) \qquad (2)$$

Therefore the biomass at time t+1 can be expressed as

$$B_{t+1} = N_{t+1} W_{t+1} \qquad (3)$$

$$= N_t \exp(-(F_t + M + X_t) * W_t \exp(G_t) + R_t * W_t \exp(G_t)$$

If, for the moment, we ignore recruitment into the area, the biomass at week t can be expressed as

$$N_{t+1} W_{t+1} = N_t \exp(-(F_t + M) * W_t \exp(G_t - X_t) \qquad (4)$$

Since the estimate of average weight in week t is derived from landings samples, it is safe to assume that $F_t > 0$. Similarly, it is safe to assume that M>0. Therefore we know that $N_{t+1} \leq N_t$. We also believe that $G_t > 0$ for all weeks up to the time of mating, reproduction, or death, whichever comes first.

Therefore if $W_{t+1} \leq W_t$, then $G_t \leq X_t$. In words, the most likely factor that can effect such a change in average weight is the emigration ($X_t$) of larger animals from the population. Although this simple example does not incorporate size specific migation, it is conceptually equivalent (Eq. 4 ) to view $X_t$ as a decrease in the average growth rate. Moreover, we can exploit this relationship to "estimate" migration by noting

$$W_{t+1} = W_t \exp(G_t - X_t) \qquad (5)$$

or

$$X_t = \ln(W_{t+1} / W_t) + G_t$$

where $G_t$ is derived from known aged animals. Of course, weekly changes in M could also reduce average size, but M would have to increase with size which seems unlikely.

In order to relate Eq. 1-5 to estimates of initial population size and fishing mortality it is necessary to relate fishing mortality to fishing effort. If we assume that the effort reports from the VTR data sets are a representative sample of the effort in week t, and that the power of a unit period of fishing does not change over the season, then the seasonal distribution of fishing effort can be used to characterize the seasonal pattern of fishing mortality on the stock. Let $p(E_t)$ represent the fraction of fishing effort (hr fished) in week t and the sum of $p(E_t)$ equals 1.

$$1 = \sum_{t=1}^{T} p(E_t) \qquad (6)$$

It is now possible to generalize the recursive relation for numerical abundance as

$$\hat{N}_T = \hat{N}_0 \, e^{-\sum_{t=1}^{T} (\hat{F}_{TOT}\, p(E_t) + M)} \qquad (7)$$

where $F_{TOT}$ represents the total fishing mortality applied over the season of duration T and $p(E_t)$ represents the seasonal distribution of fishing effort. Eq. 7 implies that $F_t = F_{TOT}\, p(E_t)$. Note also that it is not necessary in this formulation to know total effort. The only assumption is that the VTR data adequately characterizes the overall seasonal pattern of the fishing effort $p(E_t)$. Eq. 7 has two unobservable entities, $N_0$ and $F_{TOT}$ that can be estimated only by relating them to some observable quantity, such as yield. To achieve this objective, we write a modified catch equation for yield (biomass) as

$$\hat{Y}_t = \left( \frac{\hat{F}_{TOT}\, p(E_t)}{\hat{F}_{TOT}\, p(E_t) + M} \right) \left(1 - e^{-(\hat{F}_{TOT}\, p(E_t) + M)}\right) \hat{N}_t \, W_t \qquad (8)$$

To solve for $F_{TOT}$ and $N_0$ it is sufficient to minimize the differences between the observed and predicted yields:

$$Minimize \sum_{t=1}^{T} \left( Y_t - \hat{Y}_t \right)^2 \qquad (9)$$

The only constraint necessary to solve Eq. 9 is that the total predicted yield is equal to the observed yield:

$$subject\ to: \qquad Y_{TOT} = \hat{Y}_{TOT}$$

where

$$Y_{TOT} = \sum_{t=s}^{T} Y_t$$

Therefore the only model parameters are the annual fishing mortality **F** and initial population size **N.**

The model was applied to the 1994-1998 fishery by substituting the average yield of 17,142 mt, an average weight change described in Figure 33, and an average weekly effort distribution (Figure 38). Results (Figure 40) suggest a high degree of correspondence between the observed and predicted distribution of landings and no significant outliers or temporal trends in residuals. Comparison of monthly moving averages of observed and predicted catches suggest strong agreement. The absence of significant outliers suggests that the initial hypothesis of negligible within-season recruitment to the fishery cannot be rejected. Perhaps it is more accurate to say that the weekly change in average weight is sufficient to adequately describe the complex of interacting processes affecting biomass. The basic model during 1994-1998 was supported by an initial cohort of 557 million squid based on a fishing mortality rate of 0.74. Under the assumed natural mortality of 0.06 per week and a 31-week season, the total natural mortality over the season is 1.86.

To test whether the seasonal distribution of fishing effort contributed significantly to the observed agreement, we assumed a uniform distribution of fishing effort over the fishing season (Figure 41). The residual sum of squares increased nearly ten-fold and the residuals showed a strong temporal trend.

Several important caveats to these model results should be noted.

1. The fishing mortality rate applies to the fraction of stock vulnerable to fishing mortality in the zone of the fishery and applies to the entire population if all squid pass through the zone of fishery; a "gauntlet" migration. If a fraction of the stock exists outside the zone of the fishery and is never affected by fishing mortality, then the derived estimate of F can be considered a maximum fishing mortality rate. As described in the "Sexual Maturity" section, a "wave" pattern of migration into and out of the U.S. fishing area seems most likely, so the derived estimate of F represents a maximum value for the U.S. fishing area.

2. A similar argument can be applied to the abundance estimate. If some fraction of the stock exists outside the zone of the fishery and is never affected by fishing mortality, then the derived population size can be considered a minimum population size.

3. Scaling of population size is controlled by constraining predicted total yield to observed yield

4. Seasonal fishing effort for fleet is assumed to be proportional to the pattern observed in the VTR subset.

5. Changes in average weight subsume changes attributable to growth, recruitment and emigration.

6. The current version of the model has not been cast as a likelihood estimator and it is not possible to make any inferential statements about the precision of these estimates.

Based on the assumption of a "wave" pattern of migration into and out of the U.S. fishing area, the model estimate of the fishing mortality rate (F = 0.74) represents a maximum value for the U.S. fishing area (Figure 42A). An imprecise estimate of a lower bound on fishing mortality, F = 0.24, was also computed by multiplying this maximum F value for the fishery area by the fraction of *Illex* habitat located along the 50 fathom line which it represents (32%). *Illex* squid habitat was identified based on a map of the density of squid caught during the 1982-1998 NEFSC autumn surveys (Figure 42B). During 1998, at least 91% of the landings occurred in Statistical Areas 622, 616, 626 and 632 (Table 5) and this landings pattern is consistent with that which occurred during 1991-1993 (Figure 42A). Thus, fishing mortality rate estimates in the U.S. EEZ during 1994-1998 ranged between 0.24 and 0.74. However, the precision of these estimates is unknown.

Relative Fishing Mortality Rates

Trends in stock-based relative fishing mortality rates, during 1983-1998, were computed as the ratio of the Subarea 3+6 landings to the average of the Subarea 4 (July) and Subarea 5+6 (autumn) survey biomass indices (Figure 43). Relative fishing mortality rates have generally increased since 1988 and have been at or above their 1983-1998 mean since 1994.

## BIOLOGICAL REFERENCE POINTS

During SAW-21, percent maximum spawning potential (% MSP) biological reference points were recommended as the most suitable for minimizing the risk of recruitment overfishing of this annual species. An overfishing definition for the U.S. EEZ portion of the *Illex illecebrosus* stock was promulgated in Amendment 6 as the catch associated with $F_{20\%}$, with a target defined as the catch associated with $F_{50\%}$. However, these reference points will be superceded when Amendment 8, which has recently received final approval, becomes a Final Rule. The Amendment 8 overfishing definition and target are defined as the catches associated with $F_{MSY}$ and 75% of $F_{MSY}$, respectively. These reference points were selected by the Overfishing Definition Review Panel (Applegate et. al. 1998) to comply with requirements of the Sustainable Fisheries Act (SFA).

A seasonal yield-per-recruit and spawning stock biomass-per-recruit analysis was conducted based on the 1994-1998 weekly exploitation pattern in the *Illex* squid bottom trawl fishery, which was determined from *Illex* squid trips contained in the NEFSC Vessel Trip Report database. Similar to SAW-21, full recruitment to the fishery was assumed to occur at week 42. A constant natural mortality rate equal to 0.06 per week was applied. Input data for these analyses are presented in Table 14. Average stock weight, or mean weights at age, were those determined for the SAW-21 assessment from an estimated growth curve based on squid from the Subarea 3 jig fishery. Average weights in the catch, by week, were Lowess-smoothed values for squid caught in the U.S. bottom trawl fishery during 1994-1998 which were provided from the squid industry (Figure 33). The results of the analysis are provided in Table 15 and Figure 44. Similar to SAW-21, values for $F_{0.1}$ and $F_{max}$ were 2.3 and 4.3, respectively. As recommended in SAW-21, maintaining the rate of fishing mortality above a minimum or threshold spawning stock biomass level is most appropriate for minimizing the risk of recruitment overfishing of this annual species. Thus, a %MSP reference point should be considered as an $F_{MSY}$ proxy. The results of the current analysis support the SAW-21 recommendation that $F_{50\%}$ may be an appropriate target fishing mortality rate. The estimated average fishing mortality rate during 1994-1998 ($F_{1994-1998}$ = 0.74) for the U.S. EEZ *Illex* squid fishery is below the value of $F_{0.1}$ and $F_{50\%}$.

## ESTIMATION OF POTENTIAL YIELD

Subareas 3+4

The potential yield for Subareas 3+4 was estimated at the 1998 Scientific Council meeting of the Northwest Atlantic Fisheries Organization (NAFO) in order to address a request for scientific advice on an appropriate Total Allowable Catch (TAC) for these northern Subareas. Estimates of relative fishing mortality rates were computed by dividing annual landings for Subareas 3+4 into the annual Subarea 4 July survey biomass indices (Table 16). The Subarea 4 survey indices were considered to represent a pre-fishery index of biomass in that the northern fisheries occur after the survey is conducted. A range of maximum yields (18,800-33,600 mt) was obtained by scaling the peak (1979) and average SA 4 survey biomass indices during 1983-1997 by the relative fishing mortality rates during these same time periods to account for yields during the high (1976-1981) versus the low (1983-1997) productivity periods (Figure 45) (Rivard et. al. 1998).

Yield Optimization through Delay of Fishing Season in Subareas 5+6

The model used to estimate the effects of a delayed opening on harvest policies is closely related to the model for estimation of population size and fishing mortality. The purpose of the optimization model was to evaluate the maximum potential benefit that might accrue to the fishery subject to vague but important notions of conservation equivalency. In addition, the analysis can be used to characterize the relative costs and degree of risk incurred by the fishing fleet by a delayed opening. In this section we describe the additional features necessary to optimize yield, the fitting procedures employed and examine three alternative policies. These can be considered as a: 1) Constant number harvest policy; 2) Constant escapement policy; and 3) Production bottleneck policy.

The only new feature necessary to implement the yield optimization model is the notion of rescaling effort. As before, let $p(E_t)$ represent the fraction of fishing effort (hr fished) in week t were the sum of $p(E_t)$ equals 1:

$$1 = \sum_{t=1}^{T} p(E_t)$$

When the season opening is delayed to week s it is assumed that the fishing effort pattern is rescaled such that

$$p'(E_t) = \frac{p(E_t)}{\sum_{t=s}^{T} p(E_t)}$$

Therefore, the sum of the $p'(E_t)$ is also equal to one.

The model calibration process was defined as follows:

1. Set M to constant value = 0.06 per week
2. Assume $F_t$ is proportional to $E_t$
3. Assume $F_t < M$ and $F_{TOT} = 0.5$
4. Distribute $F_t$ such that $F_t = F_{TOT}\, p(E_t)$ where $p(E_t)$ = proportion of average annual effort in week t
5. Use observed $W_t$ as adequate descriptor of population in fishery area
6. Find $N_1$ such that $Y_{TOT} = 16{,}600$ mt

The baseline results under conditions 1-6 are as follows:

1. Initial Cohort size is 7.25 x $10^8$
2. Residual Population size is 9.44% of initial cohort
3. Predicted LPUE at end of season is 29.5% of maximum LPUE (mt/ unit effort)
4. Total number killed by fishery is 137,690,189 squid

Therefore, relative changes in the fishery or Illex population are reported as percentages with respect to these baseline results.

Note that this calibration process uses different parameter values than those used for the estimation of population abundance and fishing mortality rates. In part, this reflects the fact that the optimization model was developed prior to the estimation model. However, it is also important to emphasize that the following results are indicative of the relative magnitude and likely direction of changes that might be achieved under various harvest policies. The absolute changes will ultimately depend on the state of the resource and the environment during the year in which such management changes might be implemented.

Simple nonlinear optimization methods were used to find the maximum yield subject to a specified opening week and other constraints. Many different scenarios can be implemented but for initial discussion purposes, three were evaluated

Scenario 1. Constant number harvested.

> In this option, the number of squid harvested is set equal to the total number killed in the baseline scenario. By delaying the season, the same number of squid can be landed but at a larger size. Redistribution of seasonal effort as described above, results in greater overall yields. Increases in yield come at a cost of increased effort per week, a factor that is important with respect to vessel operations and costs, onshore processing capacity and perhaps price structure of the product. The fraction of the initial population alive at the end of the fishery is reduced by about 50% compared to the baseline scenario (i.e., from 9.4% to 6.1% when the fishery is delayed by 16 weeks (Table 17 and Figure 46).

Scenario 2. Constant Escapement Policy

> Residual population size is fixed to calibrated value. Total fishing effort remains constant but weekly effort is rescaled without any constraints (Table 18 and Figure 47).

Scenario 3. Production bottleneck Policy

> Delays in season opening could imply an increase in average weekly fishing effort by the fleet. The ability to increase is ultimately limited by factors such as processing time for catch, hold capacity, distance to fishing grounds, and onshore processing capacity. In this scenario it was assumed that the maximum level of effort that could be exerted is twice the maximum average fishing time observed in a week for the period 1994-1998 (Table 19 and Figure 48).

Some general conclusions can be made from the scenarios examined thus far. First, Scenario 1 affords the greatest potential increase in yield (about 40%) while still maintaining some level of conservation (i.e., the total number killed is constant). The implications of harvesting larger, maturing animals late in the season on total reproductive potential are not known. The increase in yield comes at the expense of increase in total effort. For delays of up to 8 weeks, the relative increase in effort is about the same as the increase in yield (Table 17). Delays greater than 8 weeks would require up to twice as much total fishing effort in order to attain the benefits of increased yield. Moreover, the effort would be required late in the season when the availability of the squid becomes less certain. Second, if the objective is to maintain a constant residual population (in this example 9.4% for the "baseline" run) there is very little room for increase in yield (approximately 2%) (Table 18 and Figure 47). Although total effort would not change, the effort would be compressed into shorter periods and therefore require significant increases in average weekly effort. Finally, gains in yield of up to 50% would be possible if maximum average weekly effort could be increased up to 2-fold across all weeks. However such an increase would significantly increase the number of squid killed, reduce the size of the residual population and require major increases in fishing effort (Table 19 and Figure 48). Scenario 3 is probably the least realistic of scenarios examined but it does illustrate the importance of constraints on fishing effort.

Overall the scenarios are indicative of the magnitude of changes that might by attained by delay of the season. Complete formulation of more realistic scenarios will require additional guidance from scientists on the relevant biological constraints, from managers regarding the feasible options, and from industry regarding production constraints and other risks (e.g., influence of late season hurricanes on catch rates).

## DEPLETION MODEL APPLICABILITY FOR REAL-TIME MANAGEMENT

The potential applicability of the Delury depletion model was examined by evaluating the seasonal distribution of log LPUE versus week and log LPUE versus cumulative fishing effort for 1994 and 1996-1998. The analyses were primarily graphical and designed to highlight some of the potential problems of in-season estimation of abundance. As noted by Caddy (1991), the seasonal pattern of CPUE reflects the balance of immigration, fishing and natural mortality, and emigration from the fishing area. In Caddy's formulation, the boundaries between these processes are sharp and are assumed to induce point changes in the slope of log LPUE versus time. Graphical analyses of the log LPUE series for the pooled 1994, 1996-1998 period indicated general agreement with Caddy's hypotheses (Figure 49). Important differences were noted between years. The 1994 LPUE series revealed a steady decline commencing in week 25 (Figure 50). The 1996 fishery landings dropped sharply between weeks 25 and 30 but remained at the week 30 level for another 10 weeks (Figure 51). In 1997 the fishery peaked at about week 28, dropped consistently until week 38 but then picked up again in week 40 (Figure 52). The 1998 fishery was also very different since LPUE increased more or less continuously until the fishery was closed due to attainment of the quota (Figure 53).

Implementation of real-time management would require an ability to detect such point changes in the LPUE slope. Lowess smoothing was used to test this detection ability by successively truncating the observed LPUE series at week 33 and earlier. The objective was to determine if the long-term pattern, discernible from the entire series could be detected in the shortened time series. Results suggest that this was possible (Figures 49-53) in most years. These results suggest that important characteristics of the fishing season should be evident early in the season.

As a final level of analysis, the log LPUE was plotted against cumulative fishing time (Figures 54-59). Although the composite fishery for 1994-1998 appears reasonable, the individual year plots suggest that model results would either be imprecise or misleading. The 1994-1996 fisheries exhibited the expected declining trend in LPUE, but 1997 fishery showed a sharp increase in LPUE after a steep drop in catch rates. In 1998 there was no evidence of a decline in LPUE prior to the fishery closure at week. In these instances, biological data, spatial changes in fishing patterns and other ancillary information would be used to explain these LPUE trends.

## RESEARCH RECOMMENDATIONS

1. Develop a collaborative effort with the squid industry to determine the fraction of the stock residing in U.S. EEZ waters outside the fishing area, during the fishing season, by placing scientists on board industry vessels equipped with scientific echosounders and data loggers to qualitatively map the distribution and size of *Illex* squid schools.

2. Discern in-season migration patterns of *Illex* squid through tagging studies and/or the collection of weekly size at maturity data.

3. Improve knowledge about interannual variability in population age structure and growth rates by aging *Illex* squid caught in NEFSC autumn bottom trawl surveys and US bottom trawls.

4. Develop assessment methods to predict in-season catches of *Illex* squid and investigate reasons for the lack of progressive decline in fishery catch rates during the season.

5. Examine NEFSC Food Habits Database to develop alternative relative abundance indices and/or estimate natural mortality rates.

## SARC COMMENTS

The SARC reviewed the new model for estimating stock size and fishing mortality rates for *Illex*. Estimates from the model are average values for 1994-1998 and apply to squid in the US EEZ fishing areas, mainly between 70 and 200 F in the Mid-Atlantic Bight. Thus, these estimates do not cover all *Illex* habitat within the area of the stock, in the US EEZ, and in Canadian waters (NAFO Subareas 3+4). Therefore, the fishing mortality rate estimate represents an upper bound. An imprecise lower bound on F was also computed for the unfished portion of the stock in the US EEZ based on survey distribution maps which delineated *Illex* habitat. This approach is useful for bounding likely values of fishing mortality in this data poor situation. Performance and statistical properties of the estimator (including bias) need to be evaluated. Bias needs to be evaluated because the model likely tends to over estimate fishing mortality.

a. In reviewing upper bounds on fishing mortality, life history and survey information, the SARC decided the "wave" hypothesis, described in the assessment, and lower bounds on fishing mortality rates were most likely. The "gauntlet" hypothesis is that all or most individual squid in the *Illex* stock migrate through the area of the fishery during spawning and feeding migrations. Distribution maps, timing of US and Canadian fisheries and other data cast doubt on the gauntlet hypothesis.

b. The SARC endorsed the Stock Assessment Team's decision not to update the production model used in the last assessment because the model had proven difficult to use with gaps in the LPUE time series since 1994 and a methodological change in the data collection method and because there was no reliable abundance index for the *Illex* stock.

c. In lieu of a traditional stock assessment model, the SARC decided to update Y/R reference calculations based on a seasonal model and new biological data. Questions about appropriate growth and maturity curves were major uncertainties in this calculation.

d. Although the stock assessment gives a range of plausible values for fishing mortality and updated estimates of biological reference points, it is important to remember that the *Illex* stock assessment is data poor.

e. Based on largely qualitative considerations (mainly the relative areas of the fishery versus the stock and short seasonal nature of the fishery), it is unlikely that the *Illex* stock is overfished. However, given the current uncertainties and inadequate data resolution, it would be difficult to identify an overfishing condition if conditions in the fishery should change and overfishing becomes more likely; primarily because this is an annual species and fishing occurs in a small, localized area.

f. Management policies involving fishing mortality rates may not be useful for data-poor invertebrate stocks like *Illex* when it is not possible to estimate fishing mortality with any certainty. Another approach to harvest policy formulation and definition of overfishing should be considered for *Illex*. A constant escapement harvest policy should be considered for *Illex* if real time management procedures are implemented.


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Table D1. *Illex* landings (mt) in NAFO Subareas 5=6 (U.S. EEZ) and Subareas 3+4 during 1963-1998 [1,2,3,4,5] and TACs[6].

| Year | Cape Hatteras to the Gulf of Maine (Subareas 5+6) Domestic (mt) | Foreign (mt) | Total (mt) | Subarea 4 (mt) | Subarea 3 (mt) | All Subareas (3-6) Total (mt) | TAC (mt) 3+4 | TAC (mt) 5+6 |
|---|---|---|---|---|---|---|---|---|
| 1963 | 810 | | **810** | 103 | 2,119 | **3,032** | | |
| 1964 | 358 | 2 | **360** | 369 | 10,408 | **11,137** | | |
| 1965 | 444 | 78 | **522** | 433 | 7,831 | **8,786** | | |
| 1966 | 452 | 118 | **570** | 201 | 5.017 | **5,788** | | |
| 1967 | 707 | 288 | **995** | 126 | 6.907 | **8,028** | | |
| 1968 | 678 | 2593 | **3,271** | 47 | 9 | **3,327** | | |
| 1969 | 562 | 975 | **1,537** | 65 | 21 | **1,623** | | |
| 1970 | 408 | 2418 | **2,826** | 1.274 | 111 | **4,211** | | |
| 1971 | 455 | 6159 | **6,614** | 7.299 | 1.607 | **15,520** | | |
| 1972 | 472 | 17169 | **17,641** | 1.842 | 26 | **19,509** | | |
| 1973 | 530 | 18625 | **19,155** | 9,255 | 622 | **29,032** | | |
| 1974 | 148 | 20480 | **20,628** | 389 | 48 | **21,065** | | 71,000 |
| 1975 | 107 | 17819 | **17,926** | 13,945 | 3,751 | **35,622** | 25,000 | 71,000 |
| 1976 | 229 | 24707 | **24,936** | 30.510 | 11.257 | **66,703** | 25,000 | 30,000 |
| 1977 | 1.024 | 23771 | **24,795** | 50.726 | 32.754 | **108,275** | 25,000 | 35,000 |
| 1978 | 385 | 17207 | **17,592** | 52.688 | 41.376 | **111,656** | 100,000 | 30,000 |
| 1979 | 1.493 | 15748 | **17,241** | 73.259 | 88.833 | **179,333** | 120,000 | 30,000 |
| 1980 | 299 | 17529 | **17,828** | 34.826 | 34.780 | **87,434** | 150,000 | 30,000 |
| 1981 | 615 | 14956 | **15,571** | 14.801 | 18.061 | **48,433** | 150,000 | 30,000 |
| 1982 | 5.871 | 12762 | **18,633** | 1,744 | 11.164 | **31,541** | 150,000 | 30,000 |
| 1983 | 9.775 | 1809 | **11,584** | 421 | 5 | **12,010** | 150,000 | 30,000 |
| 1984 | 9.343 | 576 | **9,919** | 318 | 397 | **10,634** | 150,000 | 30,000 |
| 1985 | 5.033 | 1082 | **6,115** | 269 | 404 | **6,788** | 150,000 | 30,000 |
| 1986 | 6.493 | 977 | **7,470** | 110 | 1 | **7,581** | 150,000 | 30,000 |
| 1987 | 10.102 | 0 | **10,102** | 372 | 194 | **10,668** | 150,000 | 30,000 |
| 1988 | 1.958 | 0 | **1,958** | 528 | 272 | **2,758** | 150,000 | 30,000 |
| 1989 | 6.801 | 0 | **6,801** | 3.899 | 3.101 | **13,801** | 150,000 | 30,000 |
| 1990 | 11.670 | 0 | **11,670** | 6.560 | 4.440 | **22,670** | 150,000 | 30,000 |
| 1991 | 11.908 | 0 | **11,908** | 2.277 | 1,719 | **15,904** | 150,000 | 30,000 |
| 1992 | 17.827 | 0 | **17,827** | 1.076 | 924 | **19,827** | 150,000 | 30,000 |
| 1993 | 18.012 | 0 | **18,012** | 2.398 | 276 | **20,686** | 150,000 | 30,000 |
| 1994 | 18.350 | 0 | **18,350** | 4.016 | 1.954 | **24,320** | 150.000 | 30,000 |
| 1995 | 14.058 | 0 | **14,058** | 984 | 48 | **15,090** | 150,000 | 30,000 |
| 1996 | 16.969 | 0 | **16,969** | 445 | 8.285 | **25,699** | 150.000 | 21,000 |
| 1997 | 13.629 | 0 | **13,629** | 2.869 | 11.652 | **28,150** | 150,000 | 19,000 |
| 1998 | 22.705 | 0 | **22,705** | 1.118 | 800 | **24,623** | 150.000 | 19,000 |
| **AVERAGES** | | | | | | | | |
| 1976-1981 | 674 | 18,986 | 19,661 | | 37,844 | 100,306 | | |
| 1982-1987 | 7,770 | 2,868 | 10,637 | | 2,028 | 13,204 | | |
| 1988-1993 | 11,363 | 0 | 11,363 | | 1,789 | 15,941 | | |
| 1994-1998 | 17,142 | 0 | 17,142 | | 4,548 | 23,576 | | |

[1] Landings during 1963-1978 were not reported by species, but are proration-based estimates by Lange and Sissenwine (1980)

[2] Landings during 1979-1997 are from the NEFSC Weighout Database and the Joint Venture Database

[3] Domestic landings during 1982-1991 include Joint-Venture landings

[4] Includes landings from Subarea 2

[5] Landings during 1998 and 1999 are preliminary for all Subareas

[6] TACs for Subareas 5+6 during 1974 and 1975 include *Loligo pealeii*

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 0 | 0 | 0 | 0 | 9 | 20 | 21 | 14 | 30 | 4 | 1 | 0 |
| 1983 | 0 | 0 | 0 | 0 | 1 | 8 | 32 | 36 | 23 | 0 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 17 | 43 | 31 | 5 | 3 | 1 | 0 | 0 |
| 1985 | 0 | 0 | 0 | 0 | 2 | 23 | 36 | 20 | 16 | 4 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 2 | 3 | 24 | 33 | 37 | 1 | 0 | 0 |
| 1987 | 0 | 0 | 0 | 0 | 6 | 24 | 24 | 24 | 15 | 7 | 0 | 0 |
| 1988 | 0 | 0 | 0 | 0 | 1 | 2 | 13 | 34 | 41 | 8 | 0 | 0 |
| 1989 | 0 | 0 | 0 | 0 | 0 | 4 | 36 | 42 | 17 | 1 | 0 | 0 |
| 1990 | 0 | 0 | 0 | 0 | 2 | 9 | 25 | 21 | 26 | 14 | 3 | 0 |
| 1991 | 0 | 0 | 0 | 0 | 0 | 17 | 28 | 32 | 21 | 1 | 0 | 0 |
| 1992 | 0 | 0 | 0 | 0 | 4 | 22 | 22 | 25 | 14 | 11 | 1 | 0 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 9 | 29 | 32 | 23 | 6 | 1 | 0 |
| 1994 | 0 | 0 | 0 | 1 | 4 | 28 | 34 | 24 | 7 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 1 | 1 | 1 | 29 | 33 | 18 | 9 | 7 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 | 2 | 23 | 17 | 23 | 15 | 15 | 5 | 0 |
| 1997* | 0 | 0 | 0 | 0 | 0 | 5 | 39 | 29 | 16 | 9 | 1 | 0 |
| 1998** | 0 | 0 | 0 | 1 | 9 | 28 | 33 | 29 | 0 | 0 | 0 | 0 |

| AVG. % | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1982-86) | 0 | 0 | 0 | 0 | 6 | 19 | 29 | 22 | 22 | 2 | 0 | 0 |
| (1987-91) | 0 | 0 | 0 | 0 | 2 | 11 | 25 | 31 | 24 | 6 | 1 | 0 |
| (1992-98) | 0 | 0 | 0 | 0 | 3 | 21 | 30 | 26 | 12 | 7 | 1 | 0 |

* Opening of fishing season voluntarily delayed by industry until June 21, 1997
** Landings from CT and a portion of New York are not available yet

Table D2. Percent landings of *Illex illecebrosus*, by month, in Subareas 5+6 during 1982-1998.

Table D3. Percent landings of *Illex illecebrosus*, by month, in Subarea 4 during 1960-1996.

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | UNK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960 | 0 | 0 | 0 | 0 | 0 | 0 | 68 | 23 | 9 | 0 | 0 | 0 | 0 |
| 1961 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 27 | 8 | 8 | 4 | 0 | 0 |
| 1962 | 0 | 0 | 0 | 0 | 0 | 0 | 54 | 27 | 17 | 2 | 0 | 0 | 0 |
| 1963 | 0 | 0 | 0 | 0 | 0 | 1 | 22 | 56 | 3 | 18 | 0 | 0 | 0 |
| 1964 | 0 | 0 | 0 | 0 | 0 | 0 | 56 | 22 | 8 | 14 | 0 | 0 | 0 |
| 1965 | 0 | 0 | 0 | 0 | 1 | 3 | 41 | 40 | 8 | 4 | 2 | 1 | 0 |
| 1966 | 0 | 0 | 0 | 0 | 12 | 1 | 60 | 8 | 16 | 4 | 1 | 0 | 0 |
| 1967 | 0 | 0 | 0 | 0 | 0 | 5 | 4 | 75 | 13 | 4 | 0 | 0 | 0 |
| 1968 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 21 | 10 | 1 | 0 | 0 | 67 |
| 1969 | 23 | 14 | 42 | 0 | 0 | 0 | 0 | 11 | 5 | 6 | 0 | 0 | 0 |
| 1970 | 0 | 0 | 0 | 0 | 24 | 0 | 2 | 63 | 10 | 0 | 1 | 0 | 0 |
| 1971 | 0 | 1 | 0 | 0 | 2 | 11 | 24 | 28 | 29 | 2 | 3 | 0 | 0 |
| 1972 | 0 | 0 | 0 | 0 | 7 | 11 | 80 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1973 | 0 | 0 | 0 | 0 | 1 | 58 | 23 | 7 | 7 | 3 | 1 | 0 | 0 |
| 1974 | 0 | 33 | 36 | 0 | 0 | 3 | 12 | 14 | 1 | 1 | 0 | 0 | 0 |
| 1975 | 0 | 0 | 0 | 6 | 7 | 35 | 17 | 6 | 10 | 9 | 2 | 7 | 0 |
| 1976 | 0 | 0 | 0 | 1 | 7 | 22 | 34 | 28 | 5 | 4 | 1 | 0 | 0 |
| 1977 | 0 | 0 | 0 | 0 | 2 | 22 | 33 | 20 | 14 | 7 | 1 | 1 | 0 |
| 1978 | 0 | 0 | 0 | 0 | 0 | 1 | 22 | 12 | 23 | 24 | 18 | 0 | 0 |
| 1979 | 0 | 0 | 0 | 0 | 0 | 2 | 17 | 23 | 29 | 21 | 6 | 0 | 1 |
| 1980 | 0 | 0 | 0 | 0 | 1 | 3 | 14 | 28 | 25 | 21 | 9 | 0 | 0 |
| 1981 | 0 | 0 | 0 | 0 | 0 | 7 | 38 | 30 | 22 | 3 | 0 | 0 | 0 |
| 1982 | 0 | 0 | 0 | 0 | 0 | 2 | 41 | 47 | 7 | 1 | 2 | 0 | 0 |
| 1983 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 86 | 11 | 0 | 0 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 1 | 49 | 24 | 20 | 6 | 0 | 0 | 0 | 0 |
| 1985 | 0 | 0 | 0 | 0 | 1 | 3 | 73 | 21 | 2 | 0 | 0 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 0 | 37 | 21 | 16 | 26 | 0 | 0 | 0 | 0 |
| 1987 | 0 | 0 | 0 | 0 | 0 | 4 | 39 | 56 | 1 | 1 | 0 | 0 | 0 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 69 | 23 | 3 | 1 | 4 | 0 | 0 | 0 |
| 1989 | 0 | 0 | 0 | 0 | 2 | 24 | 72 | 0 | 0 | 0 | 2 | 0 | 0 |
| 1990 | 0 | 0 | 0 | 0 | 3 | 7 | 24 | 55 | 10 | 0 | 0 | 0 | 0 |
| 1991 | 0 | 0 | 0 | 0 | 5 | 20 | 48 | 12 | 0 | 0 | 15 | 0 | 0 |
| 1992 | 0 | 0 | 0 | 1 | 9 | 8 | 4 | 78 | 0 | 0 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 0 | 0 | 2 | 45 | 28 | 24 | 1 | 0 | 0 | 0 | |
| 1994 | 0 | 0 | 0 | 0 | 1 | 49 | 50 | 0 | 0 | 0 | 0 | 0 | |
| 1995 | 0 | 0 | 0 | 0 | 5 | 38 | 51 | 5 | 1 | 1 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 | 0 | 5 | 68 | 26 | 2 | 0 | 0 | 0 | 0 |

| AVG % | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | UNK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1982-1986) | 0 | 0 | 0 | 0 | 1 | 19 | 32 | 38 | 10 | 0 | 0 | 0 | 0 |
| (1987-1991) | 0 | 0 | 0 | 0 | 2 | 25 | 41 | 25 | 3 | 1 | 3 | 0 | 0 |
| (1992-1996) | 0 | 0 | 0 | 0 | 3 | 29 | 40 | 27 | 1 | 0 | 0 | 0 | 0 |

Table D4. Percent landings of *Illex illecebrosus*, by month, in Subarea 3 during 1960-1996.

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | UNK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |
| 1961 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 34 | 27 | 28 | 6 | 0 | 0 |
| 1962 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 24 | 52 | 21 | 2 | 0 | 0 |
| 1963 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 33 | 31 | 18 | 0 | 0 |
| 1964 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 50 | 23 | 20 | 3 | 0 | 0 |
| 1965 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 32 | 27 | 33 | 4 | 0 | 0 |
| 1966 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 25 | 37 | 37 | 1 | 0 | 0 |
| 1967 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 28 | 12 | 40 | 17 | 0 | 0 |
| 1968 | 0 | 0 | 0 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| 1969 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 77 | 5 | 0 | 0 | 0 |
| 1970 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 32 | 37 | 23 | 5 | 0 | 0 |
| 1971 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 46 | 30 | 13 | 1 | 0 | 0 |
| 1972 | 0 | 0 | 0 | 0 | 8 | 19 | 0 | 23 | 42 | 8 | 0 | 0 | 0 |
| 1973 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 41 | 39 | 16 | 2 | 0 | 0 |
| 1974 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 47 | 0 | 0 | 0 |
| 1975 | 0 | 0 | 0 | 1 | 1 | 5 | 13 | 56 | 17 | 6 | 0 | 1 | 0 |
| 1976 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 20 | 42 | 28 | 3 | 0 | 0 |
| 1977 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 19 | 20 | 33 | 18 | 0 | 0 |
| 1978 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 30 | 48 | 14 | 0 | 0 | 0 |
| 1979 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 25 | 38 | 24 | 4 | 0 | 0 |
| 1980 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 43 | 43 | 1 | 0 | 0 |
| 1981 | 0 | 0 | 0 | 0 | 0 | 1 | 36 | 47 | 13 | 2 | 1 | 0 | 0 |
| 1982 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 51 | 31 | 8 | 2 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 45 | 17 | 1 | 0 | 0 |
| 1985 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 54 | 34 | 3 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| 1987 | 0 | 0 | 0 | 0 | 0 | 78 | 7 | 7 | 4 | 3 | 1 | 0 | 0 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 39 | 39 | 19 | 2 | 0 | 0 |
| 1989 | 0 | 0 | 0 | 1 | 0 | 32 | 4 | 20 | 30 | 12 | 2 | 0 | 0 |
| 1990 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 10 | 36 | 38 | 11 | 0 | 0 |
| 1991 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 24 | 60 | 11 | 1 | 0 | 0 |
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 45 | 35 | 18 | 0 | 0 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 15 | 58 | 26 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 | 43 | 8 | 2 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 44 | 45 | 9 | 1 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 40 | 40 | 0 | 0 |

| AVG. % | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | UNK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1982-1986) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 49 | 33 | 15 | 2 | 0 | 0 |
| (1987-1991) | 0 | 0 | 0 | 0 | 0 | 23 | 4 | 20 | 34 | 16 | 3 | 0 | 0 |
| (1992-1996) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 34 | 30 | 17 | 0 | 0 |

Table D5. Vessel Trip Report preliminary landings (mt) of *Illex illecebrosus*, by 3-digit US statistical area and month, during 1998.

| | MONTH | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL | AVG % 1998 | AVG % 1982-93 |
| 500 | - | - | - | - | - | - | 174.6 | - | - | - | - | - | 174.6 | <1 | |
| 513 | - | - | - | - | - | - | - | 0.1 | 0.1 | 0.7 | 0.1 | - | 1.0 | | <1 |
| 514 | - | - | - | - | - | - | - | - | - | - | 0.8 | - | 0.8 | | <1 |
| 522 | - | - | - | - | - | - | 0.3 | 0.1 | 1.2 | - | - | - | 1.6 | | <1 |
| 525 | - | - | - | - | - | - | - | - | - | - | - | 2.5 | 2.5 | | |
| 526 | - | - | - | - | - | - | 290.2 | 40.8 | - | - | 4.7 | 4.9 | 340.6 | 2 | 4 |
| 530 | - | - | - | - | - | - | - | - | 0.7 | - | - | - | 0.7 | | |
| 537 | 5.2 | 10.2 | 1.9 | 0.3 | 233.6 | 22.4 | 0.2 | 0.3 | 9.9 | 3.1 | 4.3 | 2.3 | 293.7 | 1 | <1 |
| 538 | - | - | - | - | 0.4 | 0.2 | - | - | - | - | - | - | 0.6 | | <1 |
| 539 | - | - | 1.7 | 0.2 | 0.1 | - | 0.1 | - | - | - | 1.0 | 0.3 | 3.4 | | |
| 561 | - | - | - | - | - | - | 0.3 | 0.1 | - | 0.1 | - | - | 0.5 | | <1 |
| 600 | - | - | - | - | 0.6 | - | 117.9 | 220.0 | - | - | - | - | 338.5 | 2 | |
| 610 | 0.7 | - | - | - | - | - | - | - | - | - | - | - | 0.7 | | - |
| 611 | - | - | - | - | - | - | - | 31.5 | - | - | - | - | 31.5 | <1 | |
| 612 | 0.1 | - | - | - | - | 30.4 | 0.1 | - | - | 0.1 | 1.7 | 1.4 | 33.8 | <1 | - |
| 613 | - | - | - | - | - | - | - | - | - | 10.5 | 0.8 | - | 11.3 | | |
| 614 | - | - | - | 2.4 | - | - | - | - | - | - | - | - | 2.4 | | |
| 615 | - | - | - | - | - | 0.5 | 20.4 | - | - | - | - | - | 20.9 | <1 | |
| 616 | 0.8 | 4.5 | 16.6 | 65.7 | 411.9 | 308.5 | 1330.0 | 363.7 | - | - | - | - | 2501.7 | 12 | 4 |
| 620 | - | - | - | - | - | - | 49.2 | - | - | - | - | - | 49.2 | <1 | |
| 621 | 0.1 | 0.2 | - | - | - | - | - | - | - | - | - | - | 0.3 | | <1 |
| 622 | 3.4 | 5.9 | 14.0 | 1.4 | 1514.7 | 4830.6 | 4396.1 | 3917.6 | 0.6 | 0.6 | 1.8 | 6.5 | 14693.2 | 68 | 74 |
| 623 | - | - | - | - | 90.7 | 237.5 | 249.1 | 122.5 | - | - | - | - | 699.8 | 3 | 1 |
| 624 | - | - | - | 63.0 | - | - | - | - | - | - | - | | 63.0 | <1 | |
| 626 | - | 0.1 | - | 27.5 | - | 405.4 | 750.2 | 455.5 | - | - | - | - | 1638.7 | 8 | 9 |
| 627 | - | - | - | 1.0 | - | - | 99.7 | 154.7 | - | - | - | - | 255.4 | 1 | 1 |
| 628 | - | - | - | 8.6 | - | - | - | - | - | - | - | - | 8.6 | | |
| 629 | - | - | - | - | - | - | - | - | - | - | - | 1.6 | 1.6 | | |
| 631 | - | - | - | - | - | - | - | - | - | - | 0.1 | - | 0.1 | | <1 |
| 632 | - | - | - | 5.0 | - | 42.5 | 132.7 | 335.4 | 1.5 | 2.5 | 27.2 | - | 546.8 | 3 | 4 |
| 635 | 0.2 | 0.1 | - | - | - | - | - | - | 1.4 | - | - | 0.6 | 2.3 | | |
| 700 | 0.1 | - | - | - | - | - | - | - | - | - | - | - | 0.1 | | |
| TOTAL | 10.6 | 21.0 | 34.2 | 175.11 | 2252.0 | 5878.0 | 7611.1 | 5642.3 | 15.4 | 17.6 | 42.5 | 20.1 | 21,719.9 | | |
| AVG % | <1 | <1 | <1 | <1 | 10 | 27 | 35 | 26 | <1 | <1 | <1 | <1 | | | |
| AVG % 1989-93 | <1 | <1 | <1 | <1 | 1 | 12 | 28 | 30 | 20 | 7 | 1 | <1 | | | |
| AVG % 1982-93 | <1 | <1 | <1 | <1 | 4 | 15 | 27 | 27 | 22 | 5 | <1 | <1 | | | |

Table D6. Standardized, stratified mean catch per tow (delta-transformed) in numbers, and weight (kg) of *Illex illecebrosus*, pre-recruits (<11 cm) and recruits (>10 cm), caught during autumn research bottom trawl surveys in offshore strata 1-40 and 61-76 from Cape Hatteras to the Gulf of Maine during 1967-1998.

| Year | All sizes (no./tow) | CV (%) | All sizes (kg/tow) | CV (%) | Individual Mean Weight (g) | Pre-recruits (no./tow) | Recruits (no./tow) |
|---|---|---|---|---|---|---|---|
| 1967 | 1.57 | 17 | 0.242 | 17 | 147 | 0.04 | 1.53 |
| 1968 | 1.64 | 21 | 0.307 | 17 | 186 | 0.10 | 1.54 |
| 1969 | 0.59 | 23 | 0.073 | 26 | 121 | 0.09 | 0.50 |
| 1970 | 2.26 | 21 | 0.268 | 15 | 110 | 0.85 | 1.41 |
| 1971 | 1.68 | 12 | 0.337 | 14 | 206 | 0.20 | 1.48 |
| 1972 | 2.19 | 25 | 0.292 | 15 | 123 | 0.48 | 1.71 |
| 1973 | 1.47 | 24 | 0.353 | 25 | 242 | 0.04 | 1.43 |
| 1974 | 2.82 | 40 | 0.392 | 30 | 145 | 1.20 | 1.62 |
| 1975 | 8.74 | 36 | 1.417 | 18 | 143 | 3.98 | 4.76 |
| 1976 | 20.55 | 16 | 7.018 | 19 | 317 | 0.42 | 20.13 |
| 1977 | 12.62 | 18 | 3.740 | 18 | 299 | 0.72 | 11.90 |
| 1978 | 19.25 | 21 | 4.529 | 26 | 219 | 3.29 | 15.96 |
| 1979 | 19.42 | 11 | 6.053 | 11 | 305 | 1.31 | 18.11 |
| 1980 | 13.81 | 15 | 3.285 | 18 | 238 | 0.43 | 13.38 |
| 1981 | 27.10 | 32 | 9.340 | 40 | 327 | 0.22 | 26.88 |
| 1982 | 3.94 | 15 | 0.602 | 13 | 155 | 0.71 | 3.23 |
| 1983 | 1.73 | 14 | 0.233 | 13 | 134 | 0.16 | 1.57 |
| 1984 | 4.54 | 17 | 0.519 | 19 | 113 | 0.32 | 4.22 |
| 1985 | 2.38 | 17 | 0.355 | 18 | 147 | 0.19 | 2.19 |
| 1986 | 2.10 | 15 | 0.257 | 17 | 119 | 0.26 | 1.84 |
| 1987 | 15.83 | 31 | 1.527 | 29 | 92 | 0.84 | 14.99 |
| 1988 | 23.22 | 25 | 2.997 | 24 | 121 | 0.41 | 22.81 |
| 1989 | 22.43 | 45 | 3.307 | 57 | 118 | 1.05 | 21.38 |
| 1990 | 16.61 | 12 | 2.401 | 13 | 141 | 0.61 | 16.00 |
| 1991 | 5.21 | 17 | 0.691 | 18 | 129 | 0.22 | 4.99 |
| 1992 | 8.24 | 15 | 0.804 | 16 | 98 | 1.79 | 6.45 |
| 1993 | 10.42 | 19 | 1.595 | 20. | 159 | 0.15 | 10.27 |
| 1994 | 6.83 | 24 | 0.860 | 25 | 128 | 0.22 | 6.61 |
| 1995 | 8.01 | 30 | 0.700 | 39 | 84 | 0.82 | 7.19 |
| 1996 | 10.76 | 22 | 0.926 | 19 | 87 | 0.60 | 10.16 |
| 1997 | 5.83 | 24 | 0.521 | 17 | 89 | 0.74 | 5.09 |
| 1998 | 14.60 | 51 | 1.400 | 50 | 94 | 1.18 | 13.42 |
| Averages | | | | | | | |
| 1967-1981 | 9.05 | 22 | 2.510 | 21 | 209 | 0.89 | 8.16 |
| 1982-1998 | 9.57 | 23 | 1.159 | 24 | 118 | 0.60 | 8.97 |
| 1967-1998 | 9.32 | 23 | 1.792 | 22 | 161 | 0.74 | 8.59 |

Table D7. Summary of directed *Illex* squid trips and landings, (May-November with *Illex* landings >26% of trip weight landed) and the number of vessels in the Weighout database, during 1994-1998, in comparison to the percentage of each when merged with the Vessel Trip Report data.

### Directed *Illex* trips

| | Weighout | Merged w/VTR | Percent Merged |
|---|---|---|---|
| 1994 | 402 | 204 | 50.7 |
| 1995 | 359 | 22 | 6.1 |
| 1996 | 400 | 212 | 53.0 |
| 1997 | 197 | 108 | 54.8 |
| 1998 | 448 | 304 | 67.9 |

### Directed *Illex* landings (mt)

| | Weighout | Merged w/VTR | Percent Merged |
|---|---|---|---|
| 1994 | 17,961 | 6,798 | 37.8 |
| 1995 | 13,574 | 2,056 | 15.1 |
| 1996 | 16,244 | 7,533 | 46.4 |
| 1997 | 13,015 | 8,031 | 61.7 |
| 1998 | 22,239 | 13,632 | 61.3 |

### *Illex* vessels

| | Weighout | Merged w/VTR | Percent Merged |
|---|---|---|---|
| 1994 | 48 | 35 | 72.9 |
| 1995 | 44 | 13 | 29.5 |
| 1996 | 43 | 38 | 88.4 |
| 1997 | 32 | 21 | 65.6 |
| 1998 | 41 | 36 | 87.8 |

Table D8. Time and location of historical captures of female short-finned squid in advanced stages of maturity. Maturity stages are assigned based on NGL/ML relationship. (An asterisk indicates females which had mated.)

| Time of Capture Year | Date | Mantle length (mm) | Nidamental gland length (mm) | NGL/ML | Stage of Maturity[a] | [b]Age (days) |
|---|---|---|---|---|---|---|
| 1997 | Sept 26 | 222 | 60 | 0.27 | IV | |
| 1980 | Sept 26 | 244 | 115 | 0.47 | V | |
| 1997 | Sept 12 | 191 | 88 | 0.46 | V | 181 |
| 1997 | Sept 12 | 211 | 76 | 0.36 | V | 249 |
| 1997 | Sept 12 | 220 | 87 | 0.39 | V | 270 |
| 1997 | Sept 9 | 167 | 84 | 0.50 | V | |
| 1997 | Sept 7 | 220 | 95 | 0.43 | V* | |
| 1997 | Aug 15 | 210 | 50 | 0.24 | IV | |
| 1978 | June 7 | 235 | 77 | 0.33 | IV | |
| 1973 | May 12 | 305 | 132 | 0.43 | V* | |
| 1969 | Aug 19 | 205 | 63 | 0.31 | IV | |
| 1968 | Sept 6 | 255 | 105 | 0.41 | V* | |
| 1968 | Aug 28 | 235 | 89 | 0.38 | V* | |
| 1968 | Aug 28 | 260 | 62 | 0.24 | IV | |

[a] as proposed by Durward et al. (1979)
[b] age based on count of statolith increments

Table D9. Number of *Illex* squid sampled from U.S. EEZ bottom trawl landings, by year and week of capture, for body weight 9g) and dorsal mantle length 9cm) during 1994-1998. Data source: *Illex* squid processor data.

| year of capture | week of capture | # of squid sampled |
|---|---|---|
| 1994 | 22 | 1572 |
| | 23 | 1385 |
| | 24 | 1731 |
| | 25 | 1173 |
| | 26 | 601 |
| | 27 | 2532 |
| | 28 | 2813 |
| | 29 | 3264 |
| | 30 | 2980 |
| | 31 | 2295 |
| | 32 | 3945 |
| | 33 | 2269 |
| | 34 | 5060 |
| | 35 | 2523 |
| | 36 | 569 |
| | 37 | 2229 |
| | 38 | 284 |
| | 39 | 248 |
| | 44 | 256 |
| | 46 | 88 |
| Total | | 37,817 |

| year of capture | week of capture | # of squid sampled |
|---|---|---|
| 1995 | 22 | 30 |
| | 25 | 30 |
| | 26 | 30 |
| | 28 | 1163 |
| | 29 | 82 |
| | 30 | 1571 |
| | 31 | 35 |
| | 32 | 1144 |
| | 34 | 1125 |
| | 35 | 620 |
| Total | | 5,830 |

| year of capture | week of capture | # of squid sampled |
|---|---|---|
| 1996 | 4 | 173 |
| | 5 | 167 |
| | 6 | 270 |
| | 23 | 2347 |
| | 24 | 1422 |
| | 25 | 3551 |
| | 26 | 1399 |
| | 27 | 4002 |
| | 29 | 2448 |
| | 30 | 1610 |
| | 31 | 772 |
| | 32 | 2584 |
| | 33 | 35 |
| | 34 | 1802 |
| | 35 | 661 |
| | 36 | 2252 |
| | 37 | 2764 |
| | 39 | 2147 |
| | 40 | 741 |
| | 41 | 3687 |
| | 42 | 85 |
| | 43 | 867 |
| | 44 | 2140 |
| | 45 | 226 |
| | 46 | 1090 |
| Total | | 39,242 |

| year of capture | week of capture | # of squid sampled |
|---|---|---|
| 1997 | 20 | 757 |
| | 21 | 800 |
| | 24 | 30 |
| | 26 | 3179 |
| | 27 | 2415 |
| | 28 | 5598 |
| | 29 | 4162 |
| | 30 | 2612 |
| | 31 | 3269 |
| | 32 | 4359 |
| | 33 | 1669 |
| | 34 | 3819 |
| | 35 | 298 |
| | 36 | 2740 |
| | 37 | 900 |
| | 38 | 3883 |
| | 39 | 552 |
| | 40 | 3005 |
| | 41 | 2385 |
| | 42 | 1784 |
| | 43 | 1988 |
| Total | | 50,204 |

| year of capture | week of capture | # of squid sampled |
|---|---|---|
| 1998 | 20 | 1675 |
| | 21 | 2131 |
| | 22 | 3690 |
| | 23 | 2487 |
| | 24 | 5327 |
| | 25 | 3398 |
| | 26 | 5247 |
| | 27 | 7022 |
| | 28 | 8054 |
| | 29 | 4133 |
| | 30 | 4904 |
| | 31 | 6879 |
| | 32 | 4541 |
| | 33 | 4945 |
| | 34 | 7399 |
| | 35 | 649 |
| Total | | 72,481 |

Table D10. Summary of *Illex* squid body weight (g) and dorsal mantle length (DML) (cm) data from U.S. EEZ bottom trawl landings during 1994-1998. Data source: *Illex* squid processor data. Rivard et. al. (1998).

| Year of Capture | Week of the Year | Minimum Body Weight (g) | Maximum Body Weight (g) | Mean Body Weight (g) | Minimum DML (cm) | Maximum DML (cm) | Mean DML (cm) |
|---|---|---|---|---|---|---|---|
| 1994 | 22 | 34 | 424 | 131 | 12 | 26 | 18 |
| | 23 | 56 | 268 | 111 | 14 | 22 | 17 |
| | 24 | 42 | 344 | 119 | 11 | 26 | 17 |
| | 25 | 62 | 508 | 147 | 13 | 28 | 18 |
| | 26 | 52 | 410 | 145 | 13 | 25 | 18 |
| | 27 | 42 | 434 | 153 | 9 | 28 | 19 |
| | 28 | 56 | 444 | 181 | 14 | 26 | 20 |
| | 29 | 78 | 430 | 191 | 15 | 27 | 20 |
| | 30 | 88 | 584 | 190 | 14 | 28 | 20 |
| | 31 | 70 | 494 | 203 | 15 | 28 | 21 |
| | 32 | 108 | 424 | 202 | 14 | 26 | 21 |
| | 33 | 110 | 508 | 226 | 17 | 28 | 21 |
| | 34 | 104 | 510 | 214 | 14 | 36 | 22 |
| | 35 | 108 | 462 | 219 | 17 | 28 | 22 |
| | 36 | 56 | 462 | 182 | 14 | 26 | 20 |
| | 37 | 52 | 480 | 205 | 13 | 29 | 21 |
| | 38 | 118 | 336 | 210 | 9 | 25 | 21 |
| | 39 | 134 | 412 | 230 | 18 | 27 | 22 |
| | 44 | 86 | 320 | 194 | 13 | 25 | 21 |
| | 46 | 72 | 328 | 189 | 15 | 25 | 20 |
| All weeks | | 34 | 584 | 182 | 9 | 36 | 20 |
| 1995 | 22 | 62 | 82 | 70 | 15 | 17 | 16 |
| | 25 | 68 | 81 | 74 | 15 | 18 | 16 |
| | 26 | 78 | 85 | 81 | 17 | 19 | 18 |
| | 28 | 56 | 318 | 135 | 12 | 23 | 19 |
| | 29 | 110 | 224 | 151 | 17 | 22 | 19 |
| | 30 | 56 | 304 | 142 | 13 | 24 | 19 |
| | 31 | 98 | 288 | 145 | 15 | 24 | 18 |
| | 32 | 24 | 300 | 141 | 6 | 26 | 18 |
| | 34 | 36 | 290 | 144 | 13 | 25 | 19 |
| | 35 | 24 | 218 | 126 | 3 | 22 | 16 |
| All weeks | | 24 | 318 | 121 | 3 | 26 | 18 |
| 1996 | 23 | 17 | 214 | 75 | 12 | 21 | 15 |
| | 24 | 15 | 225 | 73 | 12 | 20 | 15 |
| | 25 | 15 | 250 | 72 | 12 | 22 | 16 |
| | 26 | 21 | 327 | 92 | 12 | 23 | 16 |
| | 27 | 53 | 325 | 132 | 12 | 23 | 18 |
| | 29 | 9 | 293 | 123 | 10 | 25 | 18 |
| | 30 | 60 | 207 | 107 | 15 | 21 | 18 |
| | 31 | 22 | 244 | 106 | 8 | 23 | 17 |
| | 32 | 21 | 270 | 114 | 7 | 24 | 17 |
| | 33 | 74 | 201 | 139 | 14 | 21 | 19 |
| | 34 | 34 | 276 | 119 | 9 | 27 | 18 |
| | 35 | 61 | 184 | 110 | 14 | 25 | 18 |
| | 36 | 47 | 416 | 143 | 15 | 27 | 19 |
| | 37 | 54 | 295 | 134 | 12 | 25 | 19 |
| | 39 | 56 | 385 | 169 | 14 | 26 | 20 |
| | 40 | 84 | 338 | 154 | 13 | 25 | 19 |
| | 41 | 63 | 432 | 178 | 11 | 26 | 20 |
| | 42 | 114 | 222 | 155 | 15 | 23 | 18 |
| | 43 | 68 | 420 | 189 | 12 | 27 | 21 |
| | 44 | 39 | 329 | 164 | 12 | 26 | 20 |
| | 45 | 18 | 367 | 188 | 8 | 29 | 20 |
| | 46 | 17 | 359 | 151 | 7 | 27 | 19 |
| All weeks | | 9 | 432 | 131 | 7 | 29 | 18 |
| 1997 | 20 | 23 | 185 | 61 | 10 | 21 | 14 |
| | 21 | 34 | 128 | 58 | 12 | 19 | 14 |
| | 24 | 47 | 72 | 59 | 11 | 13 | 12 |
| | 26 | 20 | 252 | 99 | 8 | 24 | 16 |
| | 27 | 21 | 305 | 118 | 11 | 23 | 17 |
| | 28 | 21 | 279 | 89 | 10 | 23 | 16 |
| | 29 | 19 | 311 | 130 | 9 | 25 | 18 |
| | 30 | 33 | 436 | 157 | 13 | 27 | 19 |
| | 31 | 31 | 420 | 147 | 11 | 27 | 19 |
| | 32 | 42 | 372 | 144 | 13 | 25 | 19 |
| | 33 | 30 | 403 | 166 | 10 | 34 | 20 |
| | 34 | 49 | 369 | 169 | 10 | 27 | 21 |
| | 35 | 104 | 315 | 168 | 17 | 26 | 19 |
| | 36 | 90 | 490 | 186 | 17 | 27 | 21 |
| | 37 | 46 | 371 | 178 | 11 | 26 | 21 |
| | 38 | 47 | 425 | 174 | 10 | 28 | 21 |
| | 39 | 62 | 286 | 154 | 15 | 27 | 20 |
| | 40 | 53 | 464 | 182 | 12 | 30 | 21 |
| | 41 | 68 | 344 | 145 | 13 | 28 | 19 |
| | 42 | 66 | 437 | 203 | 13 | 27 | 21 |
| | 43 | 29 | 377 | 175 | 8 | 28 | 20 |
| All weeks | | 19 | 490 | 141 | 8 | 34 | 18 |
| 1998 | 20 | 22 | 146 | 59 | 10 | 20 | 14 |
| | 21 | 23 | 145 | 62 | 11 | 20 | 15 |
| | 22 | 24 | 214 | 75 | 9 | 23 | 16 |
| | 23 | 18 | 235 | 92 | 10 | 24 | 17 |
| | 24 | 41 | 251 | 107 | 11 | 23 | 17 |
| | 25 | 34 | 301 | 106 | 9 | 25 | 17 |
| | 26 | 26 | 327 | 104 | 11 | 25 | 17 |
| | 27 | 37 | 330 | 111 | 11 | 25 | 17 |
| | 28 | 41 | 328 | 134 | 12 | 27 | 19 |
| | 29 | 47 | 357 | 142 | 11 | 24 | 19 |
| | 30 | 51 | 470 | 150 | 13 | 25 | 19 |
| | 31 | 54 | 406 | 159 | 11 | 26 | 19 |
| | 32 | 40 | 391 | 158 | 10 | 29 | 19 |
| | 33 | 59 | 426 | 171 | 11 | 29 | 19 |
| | 34 | 84 | 451 | 181 | 12 | 27 | 20 |
| | 35 | 102 | 442 | 183 | 16 | 25 | 20 |
| All weeks | | 18 | 470 | 125 | 9 | 29 | 18 |

Table D11. Sum of hours fished by year and week. Estimate from Vessel Trip Reports.

| Sum of HrsFishe | YR | | | | | |
|---|---|---|---|---|---|---|
| Week | 1994 | 1995 | 1996 | 1997 | 1998 | Grand Total |
| 18 | 39 | | | | 197 | 235 |
| 19 | 67 | 132 | 77 | 120 | 126 | 522 |
| 20 | 108 | 143 | | 91 | 63 | 404 |
| 21 | 87 | 72 | 66 | | 369 | 594 |
| 22 | 366 | 105 | 134 | 20 | 497 | 1121 |
| 23 | 593 | 127 | 357 | | 496 | 1572 |
| 24 | 591 | | 280 | 151 | 516 | 1537 |
| 25 | 504 | 60 | 505 | 32 | 408 | 1507 |
| 26 | 498 | 57 | 161 | 228 | 588 | 1530 |
| 27 | 513 | 54 | 856 | 537 | 603 | 2562 |
| 28 | 631 | | 263 | 272 | 595 | 1761 |
| 29 | 753 | 147 | 263 | 305 | 601 | 2069 |
| 30 | 689 | 16 | 901 | 436 | 612 | 2654 |
| 31 | 627 | 87 | 432 | 497 | 501 | 2143 |
| 32 | 880 | | 805 | 247 | 461 | 2392 |
| 33 | 335 | 224 | 697 | 590 | 431 | 2276 |
| 34 | 451 | | 569 | 198 | 646 | 1865 |
| 35 | 280 | 201 | 552 | 307 | 310 | 1650 |
| 36 | 201 | 80 | 450 | 417 | 83 | 1231 |
| 37 | 130 | | 390 | 319 | 70 | 908 |
| 38 | 191 | 116 | 333 | 307 | 227 | 1174 |
| 39 | 121 | | 619 | 572 | 99 | 1411 |
| 40 | 69 | 0 | 656 | 152 | 75 | 951 |
| 41 | 68 | | 288 | 163 | 48 | 567 |
| 42 | | 111 | 779 | 168 | 213 | 1269 |
| 43 | 209 | | 511 | 42 | 48 | 810 |
| 44 | 88 | | 192 | 165 | 119 | 564 |
| 45 | 166 | | 437 | 20 | 21 | 644 |
| 46 | 46 | | 101 | 39 | 486 | 672 |
| 47 | 45 | | 314 | 57 | 186 | 601 |
| 48 | 28 | | | 41 | 126 | 194 |
| Grand Total | 9368.12 | 1731.59 | 11985.19 | 6489.4 | 9815.49 | 39389.79 |

Table D12. Sum of total landings reported in Vessel Trip Reports by year and week.

| Sum of Landings | YR | | | | | |
|---|---|---|---|---|---|---|
| Week | 1994 | 1995 | 1996 | 1997 | 1998 | Grand Total |
| 18 | 8500 | | | | 306496 | 314996 |
| 19 | 63025 | 31000 | 10000 | 11306 | 225740 | 341071 |
| 20 | 188495 | 15406 | | 1630 | 391156 | 596687 |
| 21 | 151200 | 15917 | 258794 | | 2154179 | 2580090 |
| 22 | 601837 | 405578 | 412995 | 7630 | 1886322 | 3314362 |
| 23 | 1548436 | 555295 | 1534873 | | 2907474 | 6546078 |
| 24 | 1572363 | | 1337304 | 436664 | 3102314 | 6448645 |
| 25 | 1350948 | 380000 | 1862468 | 200000 | 2801280 | 6594696 |
| 26 | 1152339 | 350000 | 366454 | 701672 | 3664616 | 6235081 |
| 27 | 1592587 | 370000 | 1387095 | 2933204 | 3620307 | 9903193 |
| 28 | 1516960 | | 426137 | 2575556 | 2852245 | 7370898 |
| 29 | 1398184 | 429975 | 522234 | 1253054 | 4737643 | 8341090 |
| 30 | 1483567 | 23000 | 1511514 | 2860913 | 4593774 | 10472768 |
| 31 | 862488 | 300000 | 588340 | 3004752 | 3010286 | 7765866 |
| 32 | 1134650 | | 1797725 | 772246 | 3300154 | 7004775 |
| 33 | 436681 | 801000 | 1911599 | 2315042 | 3145158 | 8609480 |
| 34 | 719162 | | 751863 | 405610 | 3431815 | 5308450 |
| 35 | 140091 | 488729 | 784891 | 1223430 | 1005980 | 3643121 |
| 36 | 119766 | 11150 | 1094123 | 243700 | 5000 | 1473739 |
| 37 | 108350 | | 304862 | 1642281 | 4488 | 2059981 |
| 38 | 80190 | 211000 | 828043 | 108067 | 9748 | 1237048 |
| 39 | 112000 | | 1221456 | 2362852 | 11800 | 3708108 |
| 40 | 31173 | 588310 | 1845452 | 1269000 | 2000 | 3735935 |
| 41 | 21900 | | 406983 | 95040 | 8133 | 532056 |
| 42 | | 73000 | 777468 | 1234287 | 16006 | 2100761 |
| 43 | 36460 | | 1104307 | 95000 | 7027 | 1242794 |
| 44 | 13170 | | 162756 | 144864 | 2541 | 323331 |
| 45 | 48444 | | 700967 | 2000 | 1000 | 752411 |
| 46 | 7400 | | 4200 | 15610 | 22081 | 49291 |
| 47 | 20000 | | 306509 | 199560 | 6000 | 532069 |
| 48 | 8540 | | | 6783 | 46500 | 61823 |
| Grand Total | 16528906 | 5049360 | 24221412 | 26121753 | 47279263 | 119200694 |

Table D13. Ratio Estimator of Landings per unit Effort (mt/hr fished).

| Week | 1994 | 1995 | 1996 | 1997 | 1998 | Composite |
|---|---|---|---|---|---|---|
| 18 | 221 | | | | 1560 | 1340 |
| 19 | 941 | 235 | 130 | 95 | 1792 | 654 |
| 20 | 1753 | 108 | | 18 | 6209 | 1476 |
| 21 | 1738 | 220 | 3921 | | 5838 | 4342 |
| 22 | 1647 | 3863 | 3094 | 382 | 3795 | 2957 |
| 23 | 2613 | 4378 | 4298 | | 5868 | 4164 |
| 24 | 2662 | | 4785 | 2901 | 6010 | 4196 |
| 25 | 2683 | 6333 | 3690 | 6349 | 6874 | 4375 |
| 26 | 2315 | 6140 | 2283 | 3084 | 6237 | 4075 |
| 27 | 3105 | 6852 | 1620 | 5462 | 6009 | 3865 |
| 28 | 2403 | | 1622 | 9457 | 4798 | 4186 |
| 29 | 1857 | 2925 | 1984 | 4108 | 7888 | 4032 |
| 30 | 2153 | 1438 | 1678 | 6562 | 7506 | 3946 |
| 31 | 1376 | 3448 | 1363 | 6046 | 6009 | 3623 |
| 32 | 1290 | | 2234 | 3127 | 7163 | 2928 |
| 33 | 1304 | 3573 | 2743 | 3927 | 7300 | 3782 |
| 34 | 1595 | | 1320 | 2049 | 5309 | 2847 |
| 35 | 501 | 2434 | 1422 | 3985 | 3242 | 2208 |
| 36 | 595 | 139 | 2430 | 585 | 61 | 1198 |
| 37 | 837 | | 782 | 5144 | 64 | 2268 |
| 38 | 420 | 1816 | 2485 | 352 | 43 | 1054 |
| 39 | 926 | | 1973 | 4132 | 119 | 2628 |
| 40 | 455 | | 2812 | 8372 | 27 | 3927 |
| 41 | 322 | | 1414 | 582 | 169 | 938 |
| 42 | | 661 | 998 | 7369 | 75 | 1655 |
| 43 | 174 | | 2161 | 2262 | 146 | 1534 |
| 44 | 149 | | 848 | 878 | 21 | 573 |
| 45 | 293 | | 1604 | 100 | 48 | 1169 |
| 46 | 161 | | 42 | 400 | 45 | 73 |
| 47 | 448 | | 978 | 3501 | 32 | 885 |
| 48 | 305 | | | 167 | 370 | 318 |

Table D14. Input data for yield-per-recruit and spawning stock biomass-per-recruit analyses based on the weekly exploitation pattern in the U.S. EEZ *Illex illecebrosus* bottom trawl fishery.

| Week of Year | Fishing Mortality Pattern | Natural Mortality | Proportion Mature | Average Stock Weight (kg) | Average Weight in Catch (kg) |
|---|---|---|---|---|---|
| 18 | 0.004433 | 0.06 | 0 | 0.0355 | 0.035 |
| 19 | 0.009838 | 0.06 | 0 | 0.0391 | 0.044 |
| 20 | 0.007627 | 0.06 | 0 | 0.0430 | 0.053 |
| 21 | 0.011210 | 0.06 | 0 | 0.0473 | 0.062 |
| 22 | 0.021147 | 0.06 | 0 | 0.0520 | 0.071 |
| 23 | 0.029653 | 0.06 | 0 | 0.0572 | 0.080 |
| 24 | 0.028993 | 0.06 | 0 | 0.0629 | 0.089 |
| 25 | 0.028433 | 0.06 | 0 | 0.0692 | 0.098 |
| 26 | 0.028867 | 0.06 | 0 | 0.0762 | 0.107 |
| 27 | 0.048337 | 0.06 | 0 | 0.0838 | 0.116 |
| 28 | 0.033219 | 0.06 | 0 | 0.0922 | 0.125 |
| 29 | 0.039027 | 0.06 | 0 | 0.1015 | 0.134 |
| 30 | 0.050063 | 0.06 | 0 | 0.1117 | 0.143 |
| 31 | 0.040431 | 0.06 | 0 | 0.1229 | 0.152 |
| 32 | 0.045124 | 0.06 | 0 | 0.1352 | 0.161 |
| 33 | 0.042938 | 0.06 | 0 | 0.1487 | 0.170 |
| 34 | 0.035177 | 0.06 | 0 | 0.1636 | 0.171 |
| 35 | 0.031122 | 0.06 | 0 | 0.1800 | 0.171 |
| 36 | 0.023213 | 0.06 | 0 | 0.1980 | 0.172 |
| 37 | 0.017137 | 0.06 | 0 | 0.2178 | 0.172 |
| 38 | 0.022139 | 0.06 | 0.5 | 0.2398 | 0.173 |
| 39 | 0.026619 | 0.06 | 0.6 | 0.2638 | 0.173 |
| 40 | 0.017946 | 0.06 | 0.8 | 0.2902 | 0.174 |
| 41 | 0.010698 | 0.06 | 0.9 | 0.3193 | 0.174 |
| 42 | 0.023943 | 0.06 | 1.0 | 0.3514 | 0.175 |
| 43 | 0.015280 | 0.06 | 1.0 | 0.3866 | 0.175 |
| 44 | 0.010638 | 0.06 | 1.0 | 0.4253 | 0.175 |
| 45 | 0.012139 | 0.06 | 1.0 | 0.4679 | 0.175 |
| 46 | 0.012667 | 0.06 | 1.0 | 0.5149 | 0.175 |

Table D15. Results of yield-per-recruit and spawning stock biomass-per-recruit analyses based on the weekly exploitation pattern in the U.S. EEZ *Illex illecebrosus* bottom trawl fishery.

| FMORT | TOTCTHN | TOTCTHW | TOTSTKN | TOTSTKW | SPNSTKN | SPNSTKW | % MSP |
|---|---|---|---|---|---|---|---|
| 0.00 | 0.0000 | 0.0000 | 14.4985 | 0.0697 | 1.8028 | 0.6588 | 100.00 |
| 0.05 | 0.0224 | 0.0028 | 14.2553 | 0.0683 | 1.7249 | 0.6299 | 95.62 |
| 0.10 | 0.0440 | 0.0055 | 14.0199 | 0.0670 | 1.6504 | 0.6023 | 91.43 |
| 0.15 | 0.0647 | 0.0081 | 13.7921 | 0.0658 | 1.5791 | 0.5759 | 87.42 |
| 0.20 | 0.0847 | 0.0105 | 13.5715 | 0.0647 | 1.5110 | 0.5507 | 83.59 |
| 0.25 | 0.1039 | 0.0128 | 13.3579 | 0.0638 | 1.4457 | 0.5266 | 79.93 |
| 0.30 | 0.1225 | 0.0151 | 13.1511 | 0.0631 | 1.3833 | 0.5035 | 76.43 |
| 0.35 | 0.1403 | 0.0172 | 12.9508 | 0.0624 | 1.3236 | 0.4815 | 73.09 |
| 0.40 | 0.1574 | 0.0192 | 12.7567 | 0.0617 | 1.2665 | 0.4604 | 69.89 |
| 0.45 | 0.1740 | 0.0211 | 12.5686 | 0.0610 | 1.2119 | 0.4402 | 66.83 |
| 0.50 | 0.1899 | 0.0230 | 12.3863 | 0.0603 | 1.1596 | 0.4210 | 63.90 |
| 0.55 | 0.2053 | 0.0247 | 12.2096 | 0.0596 | 1.1096 | 0.4025 | 61.11 |
| 0.60 | 0.2201 | 0.0264 | 12.0383 | 0.0591 | 1.0617 | 0.3849 | 58.43 |
| 0.65 | 0.2343 | 0.0280 | 11.8722 | 0.0585 | 1.0160 | 0.3681 | 55.88 |
| 0.70 | 0.2481 | 0.0295 | 11.7110 | 0.0580 | 0.9722 | 0.3520 | 53.43 |
| 0.75 | 0.2614 | 0.0310 | 11.5547 | 0.0575 | 0.9303 | 0.3366 | 51.10 |
| 0.80 | 0.2742 | 0.0324 | 11.4030 | 0.0570 | 0.8902 | 0.3219 | 48.86 |
| 0.85 | 0.2865 | 0.0337 | 11.2558 | 0.0566 | 0.8519 | 0.3078 | 46.73 |
| 0.90 | 0.2985 | 0.0349 | 11.1129 | 0.0562 | 0.8152 | 0.2944 | 44.69 |
| 0.95 | 0.3100 | 0.0361 | 10.9741 | 0.0558 | 0.7801 | 0.2815 | 42.73 |
| 1.00 | 0.3211 | 0.0373 | 10.8394 | 0.0555 | 0.7465 | 0.2692 | 40.87 |
| 1.05 | 0.3318 | 0.0384 | 10.7085 | 0.0552 | 0.7144 | 0.2575 | 39.08 |
| 1.10 | 0.3422 | 0.0394 | 10.5814 | 0.0548 | 0.6836 | 0.2462 | 37.38 |
| 1.15 | 0.3522 | 0.0404 | 10.4578 | 0.0545 | 0.6542 | 0.2355 | 35.74 |
| 1.20 | 0.3619 | 0.0413 | 10.3377 | 0.0543 | 0.6260 | 0.2252 | 34.18 |
| 1.25 | 0.3713 | 0.0422 | 10.2210 | 0.0541 | 0.5991 | 0.2154 | 32.69 |
| 1.30 | 0.3804 | 0.0431 | 10.1075 | 0.0539 | 0.5734 | 0.2060 | 31.26 |
| 1.35 | 0.3891 | 0.0439 | 9.9971 | 0.0537 | 0.5487 | 0.1970 | 29.90 |
| 1.40 | 0.3976 | 0.0446 | 9.8898 | 0.0535 | 0.5251 | 0.1884 | 28.60 |
| 1.45 | 0.4058 | 0.0454 | 9.7853 | 0.0533 | 0.5025 | 0.1802 | 27.35 |
| 1.50 | 0.4137 | 0.0461 | 9.6837 | 0.0531 | 0.4809 | 0.1723 | 26.16 |
| 1.55 | 0.4214 | 0.0467 | 9.5847 | 0.0529 | 0.4603 | 0.1648 | 25.02 |
| 1.60 | 0.4289 | 0.0474 | 9.4884 | 0.0527 | 0.4405 | 0.1576 | 23.92 |
| 1.65 | 0.4361 | 0.0480 | 9.3946 | 0.0525 | 0.4216 | 0.1507 | 22.88 |
| 1.70 | 0.4431 | 0.0485 | 9.3033 | 0.0523 | 0.4035 | 0.1442 | 21.88 |
| 1.75 | 0.4499 | 0.0491 | 9.2143 | 0.0522 | 0.3862 | 0.1379 | 20.93 |
| 1.80 | 0.4564 | 0.0496 | 9.1276 | 0.0520 | 0.3696 | 0.1319 | 20.02 |
| 1.85 | 0.4628 | 0.0501 | 9.0431 | 0.0518 | 0.3537 | 0.1261 | 19.15 |
| 1.90 | 0.4690 | 0.0505 | 8.9607 | 0.0516 | 0.3386 | 0.1206 | 18.31 |
| 1.95 | 0.4750 | 0.0510 | 8.8804 | 0.0514 | 0.3240 | 0.1154 | 17.52 |
| 2.00 | 0.4808 | 0.0514 | 8.8021 | 0.0512 | 0.3101 | 0.1104 | 16.75 |

Table D16. Data summary for *Illex illecebrosus* in NAFO Subarea 3 and 4. Annual landings and research vessel indices are from SCR98/59. Relative F (fishing mortality) is the ratio of landings to survey index, divided by 10,000 to scale the values.

| Year | Landings (tons) | SA 4 Survey Index (kg/tow) | Relative F |
|---|---|---|---|
| 1970 | 1385 | 0.4 | 0.35 |
| 1971 | 8906 | 2.8 | 0.32 |
| 1972 | 1868 | 0.7 | 0.27 |
| 1973 | 9877 | 1.5 | 0.66 |
| 1974 | 437 | 1.8 | 0.02 |
| 1975 | 17696 | 5.0 | 0.35 |
| 1976 | 41767 | 42.7 | 0.10 |
| 1977 | 83480 | 9.5 | 0.88 |
| 1978 | 94064 | 2.3 | 4.09 |
| 1979 | 162092 | 14.2 | 1.14 |
| 1980 | 69606 | 2.2 | 3.16 |
| 1981 | 32862 | 4.9 | 0.67 |
| 1982 | 12908 | 2.1 | 0.61 |
| 1983 | 426 | 2.1 | 0.02 |
| 1984 | 715 | 1.5 | 0.05 |
| 1985 | 673 | 2.7 | 0.02 |
| 1986 | 111 | 0.4 | 0.03 |
| 1987 | 566 | 0.4 | 0.14 |
| 1988 | 800 | 2.7 | 0.03 |
| 1989 | 7000 | 2.7 | 0.26 |
| 1990 | 11000 | 4.8 | 0.23 |
| 1991 | 3996 | 1.8 | 0.22 |
| 1992 | 2000 | 7.3 | 0.03 |
| 1993 | 2674 | 5.4 | 0.05 |
| 1994 | 5970 | 4.2 | 0.14 |
| 1995 | 1032 | 2.4 | 0.04 |
| 1996 | 8730 | 0.9 | 0.97 |
| 1997 | 15485 | 4.8 | 0.32 |
| Mean | | | |
| 1970-1997 | 21362 | 4.79 | 0.54 |
| 1976-1981 | 80645 | 12.63 | 1.67 |
| 1983-1997 | 4079 | 2.94 | 0.17 |
| Maximum | 162092 | 42.7 | 4.09 |
| Minimum | 111 | 0.40 | 0.02 |

Table D17. Scenario 1:

Constant Harvest Number relative to "Average" fishery pattern, 1994-1998. Economic Factors

| Open Week | F_opt | Yield (mt) | Fraction of Initial Pop. | Fraction of Max CPUE | Avg Rel Effort /Week | Ave Yld/Wk (mt) | Relative Profit | % Change in Yield | % Change in Rel Cost | % Change in Avg Weekly Effort |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.5000 | 16665 | 0.094 | 0.2946 | 0.017 | 555.5 | 11664.8 | 0.000 | 0.000 | 0.000 |
| 2 | 0.5045 | 16838 | 0.094 | 0.2929 | 0.017 | 580.6 | 11792.3 | 1.037 | 0.908 | 4.388 |
| 3 | 0.5139 | 17176 | 0.093 | 0.2891 | 0.018 | 613.4 | 12037.0 | 3.067 | 2.779 | 10.120 |
| 4 | 0.5206 | 17407 | 0.092 | 0.2863 | 0.019 | 644.7 | 12200.5 | 4.453 | 4.129 | 15.699 |
| 5 | 0.5206 | 17464 | 0.092 | 0.2844 | 0.020 | 671.7 | 12257.7 | 4.797 | 4.129 | 20.149 |
| 6 | 0.5463 | 18199 | 0.090 | 0.2746 | 0.022 | 728.0 | 12735.7 | 9.205 | 9.261 | 31.113 |
| 7 | 0.5695 | 18845 | 0.088 | 0.2634 | 0.024 | 785.2 | 13149.8 | 13.083 | 13.905 | 42.381 |
| 8 | 0.5928 | 19439 | 0.086 | 0.2519 | 0.026 | 845.2 | 13511.5 | 16.648 | 18.552 | 54.633 |
| 9 | 0.6158 | 19977 | 0.084 | 0.2399 | 0.028 | 908.1 | 13818.8 | 19.876 | 23.167 | 67.954 |
| 10 | 0.6393 | 20471 | 0.082 | 0.2324 | 0.030 | 974.8 | 14077.7 | 22.838 | 27.860 | 82.658 |
| 11 | 0.6812 | 21249 | 0.079 | 0.2185 | 0.034 | 1062.5 | 14437.0 | 27.511 | 36.247 | 104.371 |
| 12 | 0.6812 | 21054 | 0.079 | 0.2176 | 0.036 | 1108.1 | 14241.4 | 26.336 | 36.247 | 115.127 |
| 13 | 0.7515 | 22283 | 0.073 | 0.2048 | 0.042 | 1237.9 | 14768.0 | 33.713 | 50.300 | 150.500 |
| 14 | 0.8082 | 22892 | 0.069 | 0.1933 | 0.048 | 1346.6 | 14810.1 | 37.366 | 61.632 | 185.234 |
| 15 | 0.8620 | 23312 | 0.066 | 0.1861 | 0.054 | 1457.0 | 14691.8 | 39.886 | 72.401 | 223.251 |
| 16 | 0.9337 | 23633 | 0.061 | 0.1760 | 0.062 | 1575.6 | 14295.9 | 41.815 | 86.748 | 273.496 |

Table D18. Scenario 2:

| Open Week | F_opt | Yield (mt) | Fraction of Initial Pop. | Fraction of Max CPUE | Avg Rel Effort /Week | Ave Yld/Wk (mt) | Relative Profit | % Change in Yield | % Change in Rel Cost | % Change in Avg Weekly Effort |
|---|---|---|---|---|---|---|---|---|---|---|
| Constant Residual Population: 9.4% of original (F=0.50, wk#1) | | | | | | | | Economic Factors | | |
| 1 | 0.5000 | 16665 | 0.094 | 0.2946 | 0.017 | 555.5 | 11664.8 | 0.000 | 0.000 | 0.000 |
| 2 | 0.5000 | 16719 | 0.094 | 0.2939 | 0.017 | 576.5 | 11719.2 | 0.326 | 0.000 | 3.448 |
| 4 | 0.5000 | 16866 | 0.094 | 0.2911 | 0.019 | 624.7 | 11865.7 | 1.205 | 0.000 | 11.111 |
| 4 | 0.5000 | 16866 | 0.094 | 0.2911 | 0.019 | 624.7 | 11865.7 | 1.205 | 0.000 | 11.111 |
| 5 | 0.5000 | 16920 | 0.094 | 0.2892 | 0.019 | 650.8 | 11920.4 | 1.533 | 0.000 | 15.385 |
| 6 | 0.5000 | 16986 | 0.094 | 0.2856 | 0.020 | 679.4 | 11985.8 | 1.926 | 0.000 | 20.000 |
| 7 | 0.5000 | 17033 | 0.094 | 0.2802 | 0.021 | 709.7 | 12032.6 | 2.207 | 0.000 | 25.000 |
| 8 | 0.5000 | 17039 | 0.094 | 0.2745 | 0.022 | 740.8 | 12038.7 | 2.244 | 0.000 | 30.435 |
| 9 | 0.5000 | 17008 | 0.094 | 0.2686 | 0.023 | 773.1 | 12008.3 | 2.061 | 0.000 | 36.364 |
| 10 | 0.5000 | 16943 | 0.094 | 0.2654 | 0.024 | 806.8 | 11942.6 | 1.667 | 0.000 | 42.857 |
| 11 | 0.5000 | 16771 | 0.094 | 0.2602 | 0.025 | 838.5 | 11770.6 | 0.635 | 0.000 | 50.000 |
| 12 | 0.5000 | 16608 | 0.094 | 0.2588 | 0.026 | 874.1 | 11607.7 | -0.343 | 0.000 | 57.895 |
| 13 | 0.5000 | 16363 | 0.094 | 0.2596 | 0.028 | 909.0 | 11362.6 | -1.813 | 0.000 | 66.667 |
| 14 | 0.5000 | 15955 | 0.094 | 0.2587 | 0.029 | 938.5 | 10954.6 | -4.262 | 0.000 | 76.471 |
| 15 | 0.5000 | 15528 | 0.094 | 0.2610 | 0.031 | 970.5 | 10528.5 | -6.819 | 0.000 | 87.500 |
| 16 | 0.5000 | 14913 | 0.094 | 0.2632 | 0.033 | 994.2 | 9912.7 | -10.514 | 0.000 | 100.000 |

Table 19. Scenario 3:

Assume maximum weekly effort is constrained to 2X max ave weekly effort — Economic Factors

| Open Week | F_opt | Yield (mt) | Fraction of Initial Pop. | Fraction of Max CPUE | Avg Rel Effort /Week | Ave Yld/Wk (mt) | Relative Profit | % Change in Yield | % Change in Rel Cost | % Change in Avg Weekly Effort |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0443 | 24851 | 0.055 | 0.2070 | 0.035 | 1035.5 | 24503.0 | 49.123 | 108.859 | 108.859 |
| 2 | 1.0106 | 24859 | 0.057 | 0.2070 | 0.035 | 1080.8 | 24510.1 | 49.168 | 102.122 | 109.091 |
| 3 | 0.9769 | 24711 | 0.059 | 0.2070 | 0.035 | 1123.2 | 24362.2 | 48.283 | 95.384 | 109.340 |
| 4 | 0.9432 | 24424 | 0.061 | 0.2070 | 0.035 | 1163.1 | 24074.9 | 46.562 | 88.647 | 109.608 |
| 5 | 0.9095 | 24012 | 0.063 | 0.2070 | 0.035 | 1200.6 | 23662.5 | 44.090 | 81.909 | 109.896 |
| 6 | 0.8759 | 23488 | 0.065 | 0.2070 | 0.035 | 1236.2 | 23138.0 | 40.946 | 75.172 | 110.206 |
| 7 | 0.8422 | 22864 | 0.067 | 0.2070 | 0.035 | 1270.2 | 22513.1 | 37.199 | 68.435 | 110.543 |
| 8 | 0.8085 | 22150 | 0.069 | 0.2070 | 0.035 | 1302.9 | 21798.6 | 32.915 | 61.697 | 110.910 |
| 10 | 0.7411 | 20492 | 0.074 | 0.2109 | 0.035 | 1366.1 | 20138.7 | 22.963 | 48.223 | 111.746 |
| 11 | 0.7074 | 19564 | 0.077 | 0.2150 | 0.035 | 1397.4 | 19209.9 | 17.395 | 41.485 | 112.228 |
| 12 | 0.6737 | 18580 | 0.079 | 0.2202 | 0.035 | 1429.2 | 18225.1 | 11.491 | 34.748 | 112.760 |
| 13 | 0.6401 | 17546 | 0.082 | 0.2266 | 0.036 | 1462.2 | 17190.7 | 5.290 | 28.010 | 113.351 |
| 14 | 0.6064 | 16469 | 0.085 | 0.2342 | 0.036 | 1497.2 | 16112.4 | -1.175 | 21.273 | 114.011 |
| 15 | 0.5727 | 15353 | 0.088 | 0.2428 | 0.036 | 1535.3 | 14995.3 | -7.870 | 14.536 | 114.754 |
| 16 | 0.5390 | 14203 | 0.091 | 0.2525 | 0.036 | 1578.1 | 13843.9 | -14.771 | 7.798 | 115.596 |

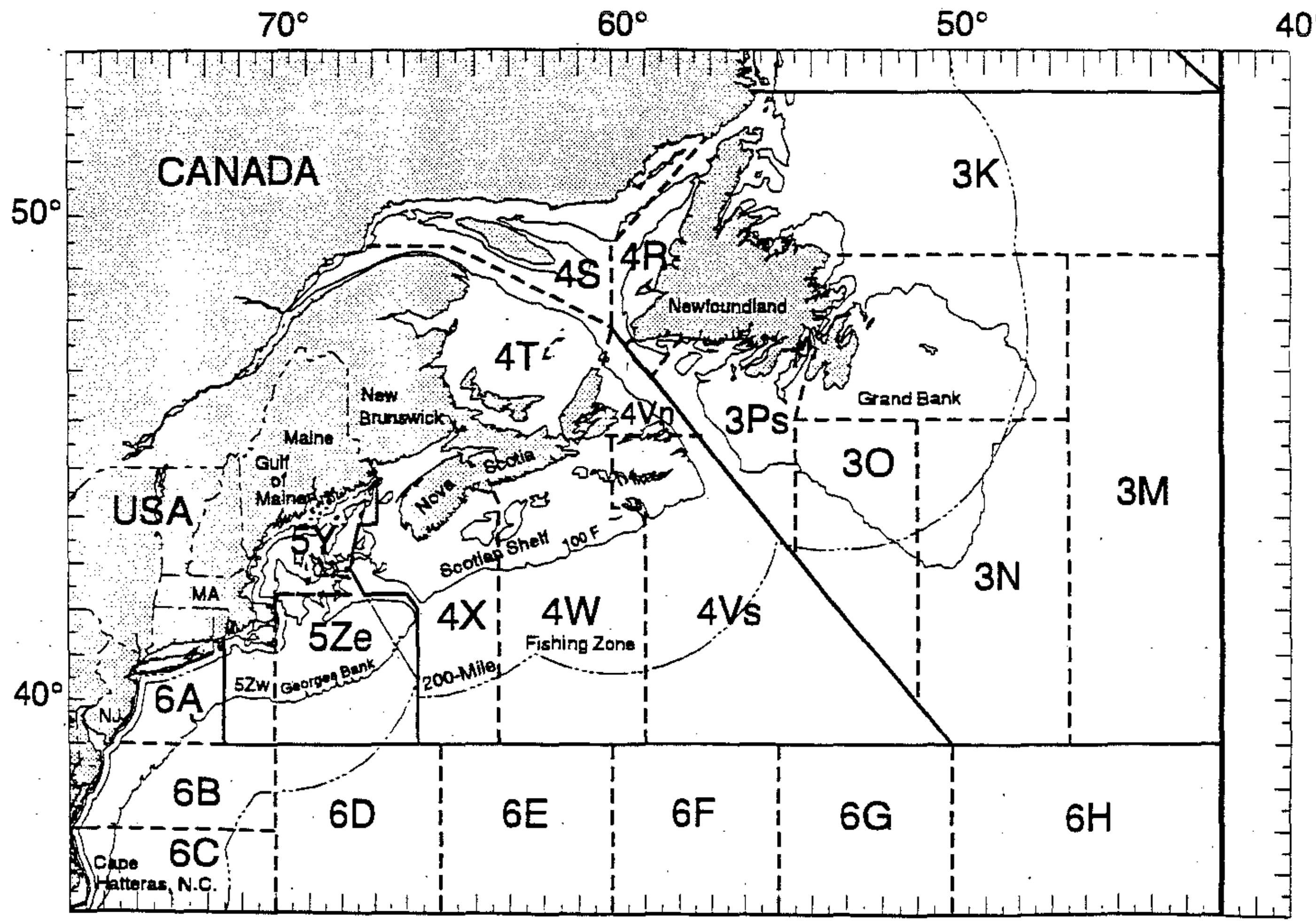



Figure D1. NAFO Subareas 3-6 and Divisions in the Northwest Atlantic Ocean.

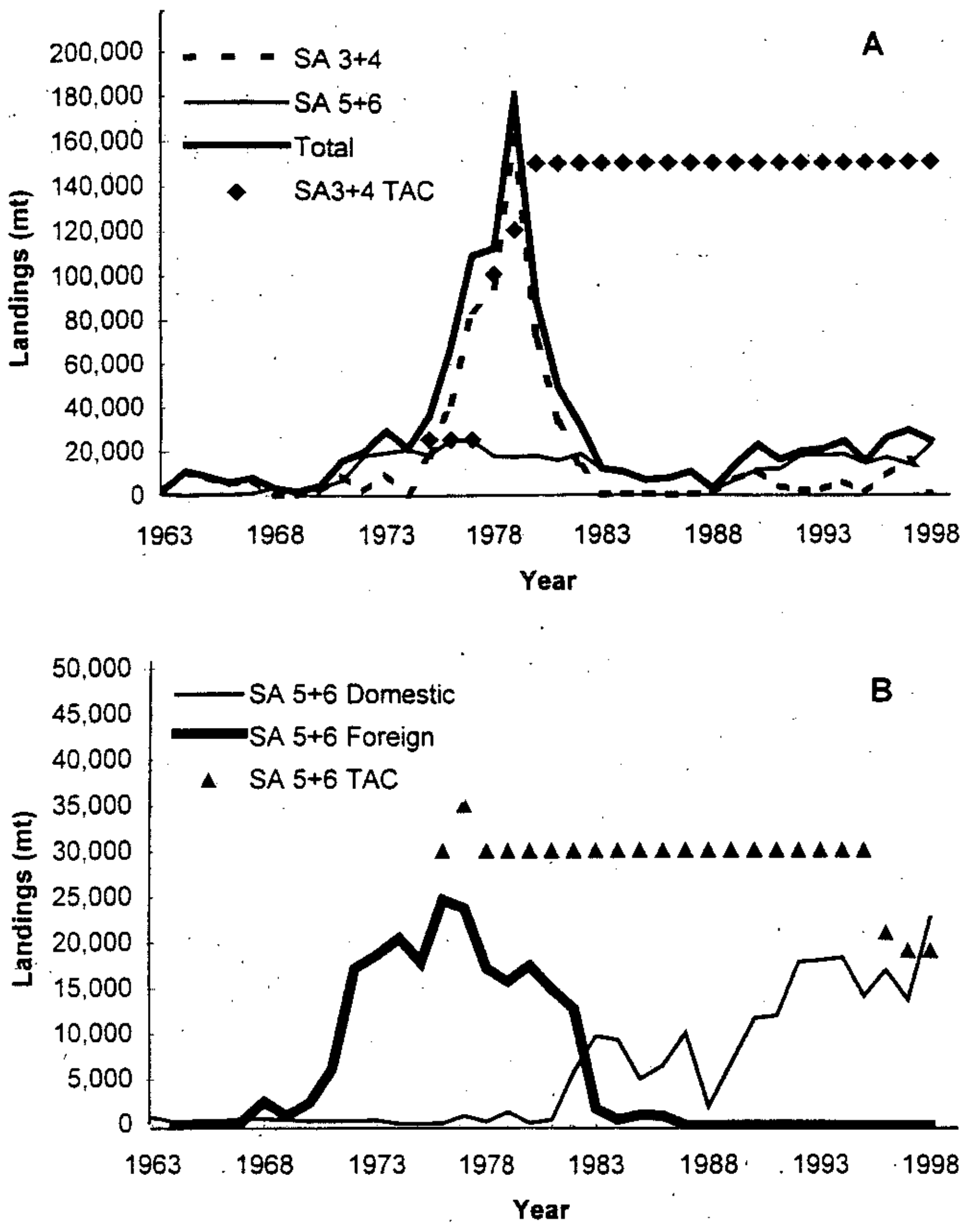



Figure D2. Landings of *Illex illecebrosus* in (A) Subareas 3-6 and (B) NAFO Subareas 5+6, with respect to TAC limits, during 1963-1998.

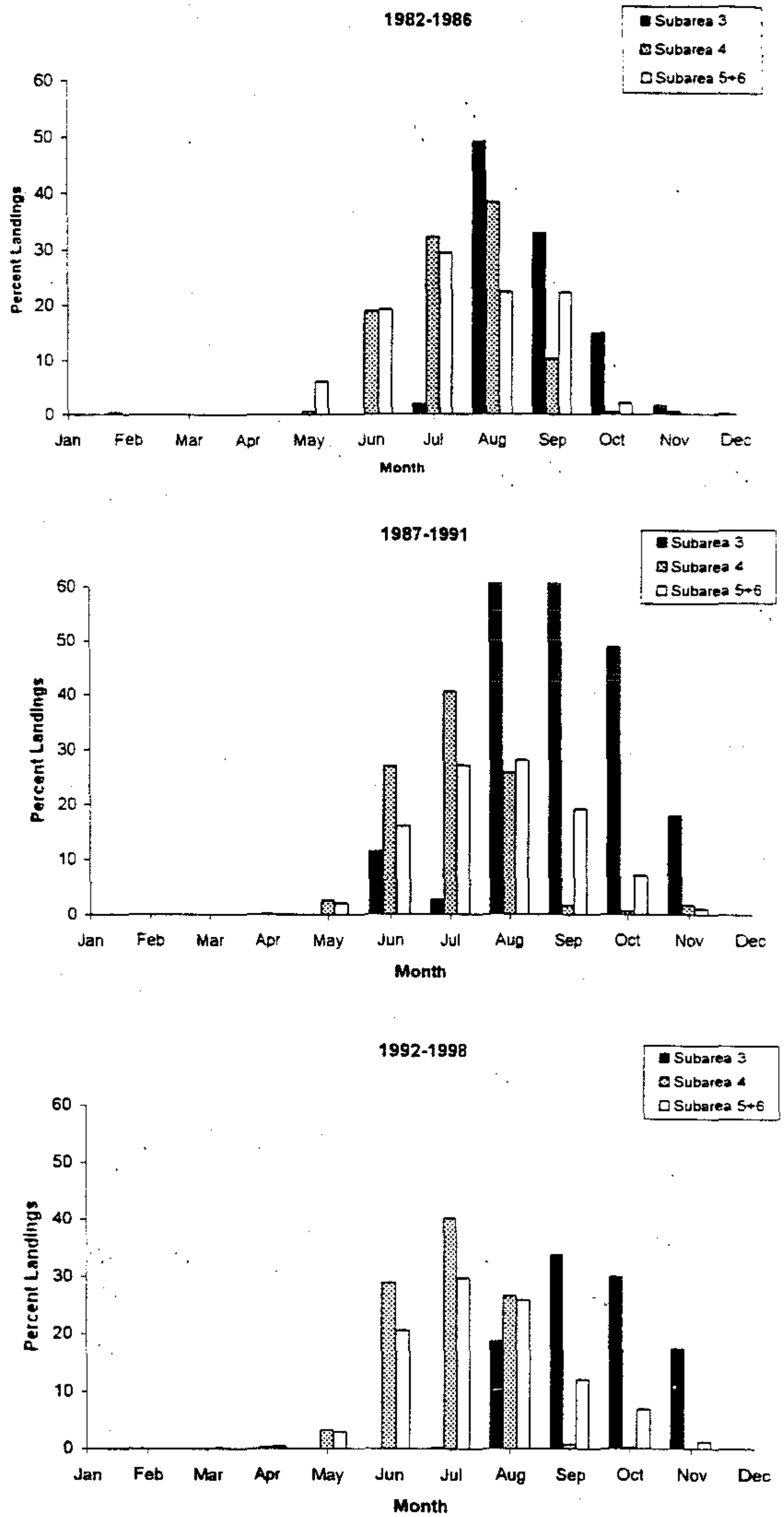



Figure D3. Percent landings of shortfin squid, *Illex illecebrosus*, by month and NAFO Subarea, during 1982-1986, 1987-1991, and 1992-1998. Monthly landings for 1997-1998 were unavailable for Subareas 3 and 4.

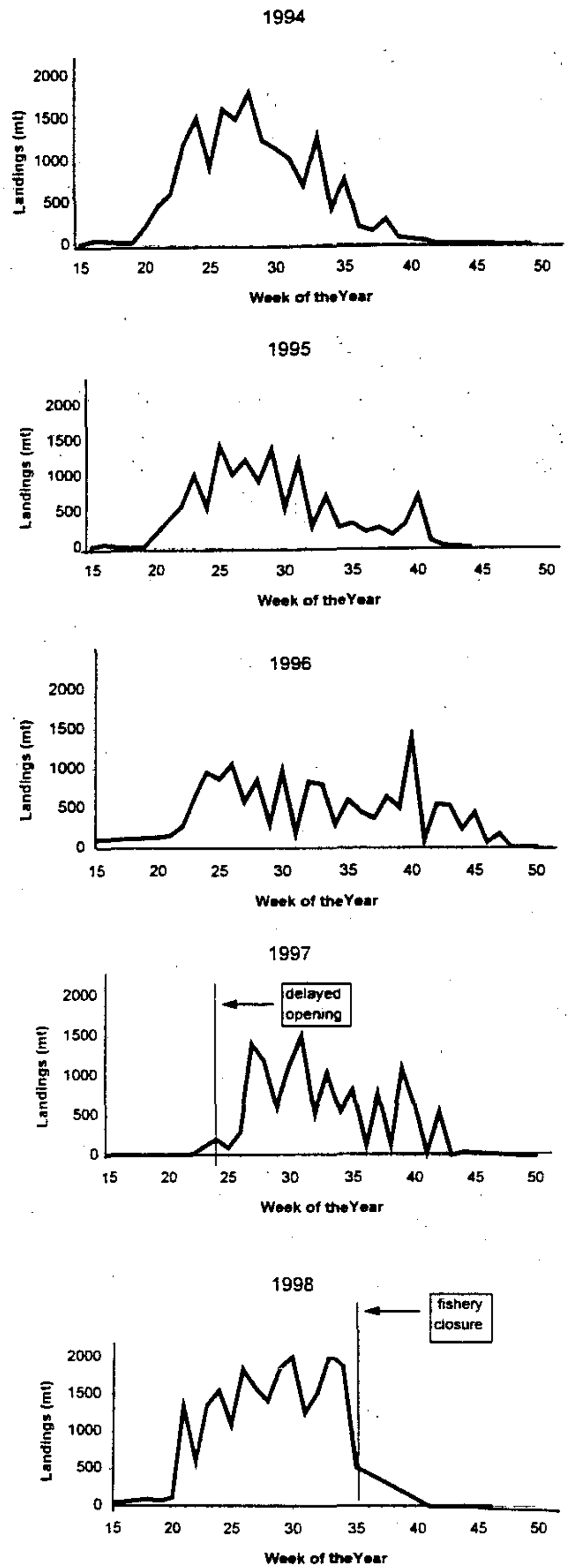



Figure D4. Trends in *Illex illecebrosus* landings by the U.S. bottom trawl fishery, by week of the year, during 1994-1998. Data source: NEFSC weighout database.

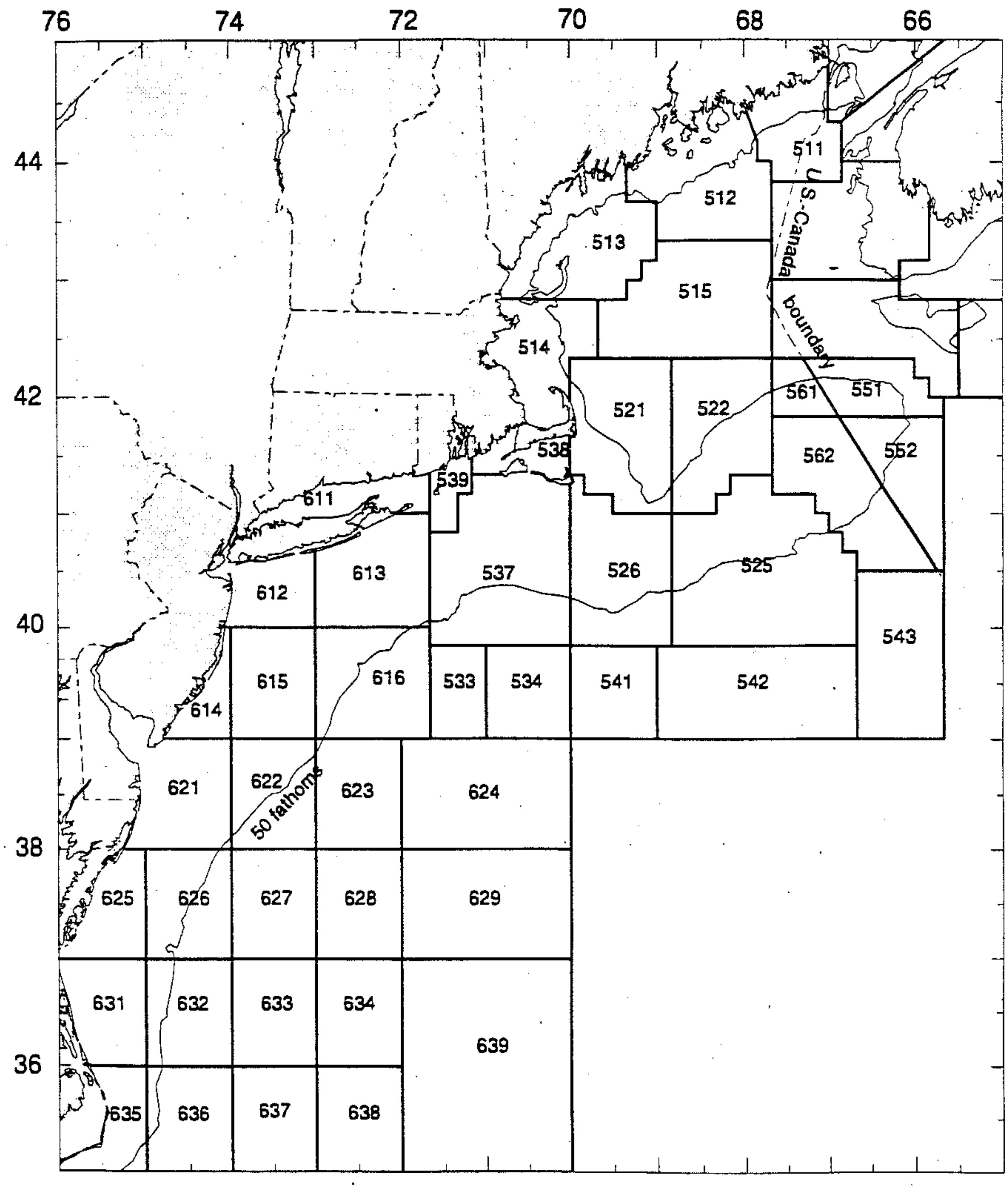



Figure D5. Statistical areas for reporting landings in the Northwest Atlantic Ocean.

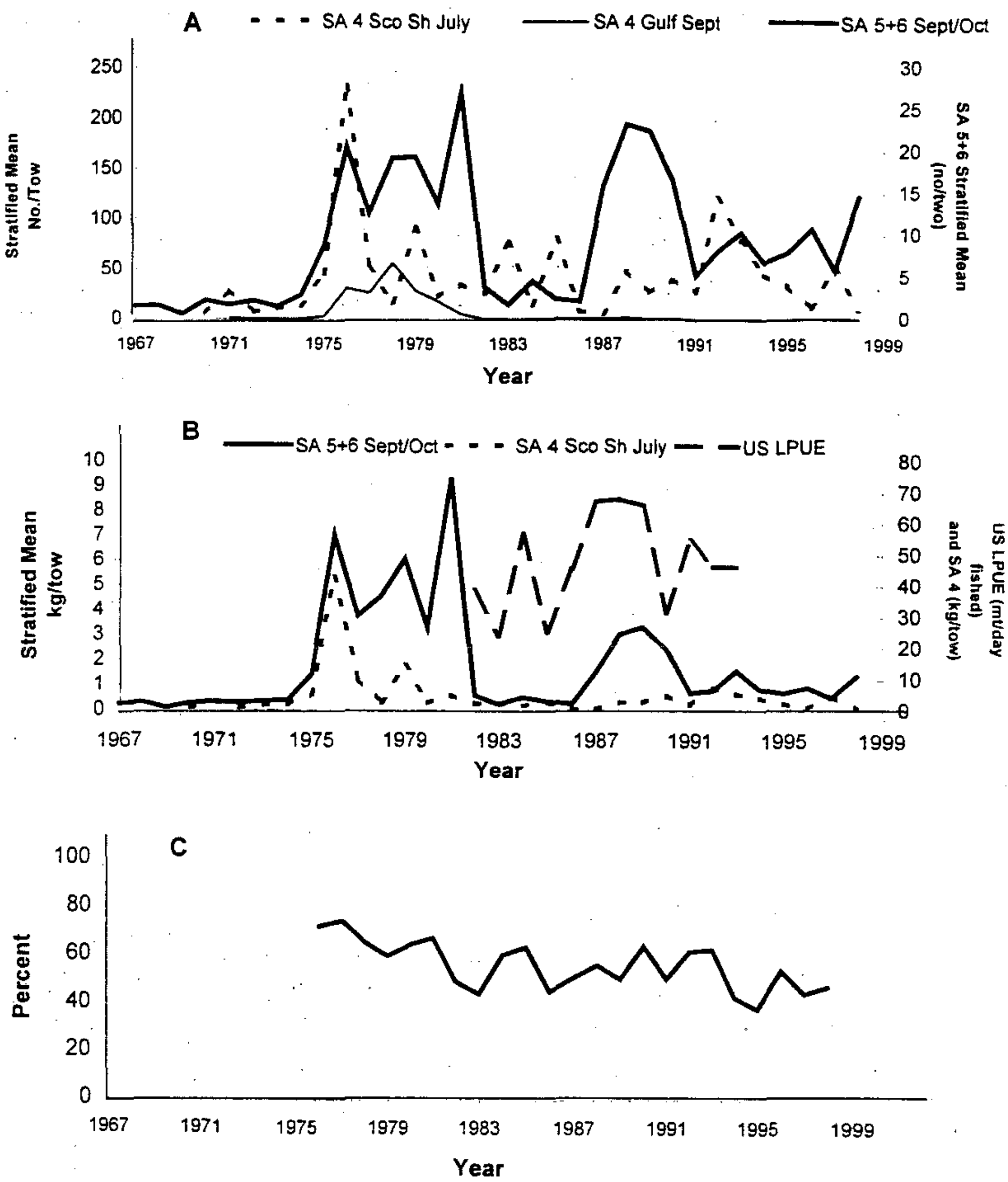



Figure D6. Indices of relative abundance (A) and biomass (B) of *Illex illecebrosus* from research bottom trawl surveys (SA 5+6 1967-1998; SA 4 Scotian Shelf 1970-1998; SA 4 Gulf of St. Lawrence 1971-1998) and standardized U.S. domestic LPUE (1982-1993), and percentage of U.S. autumn survey tows in which *Illex* squid were caught during September (1976-1998).

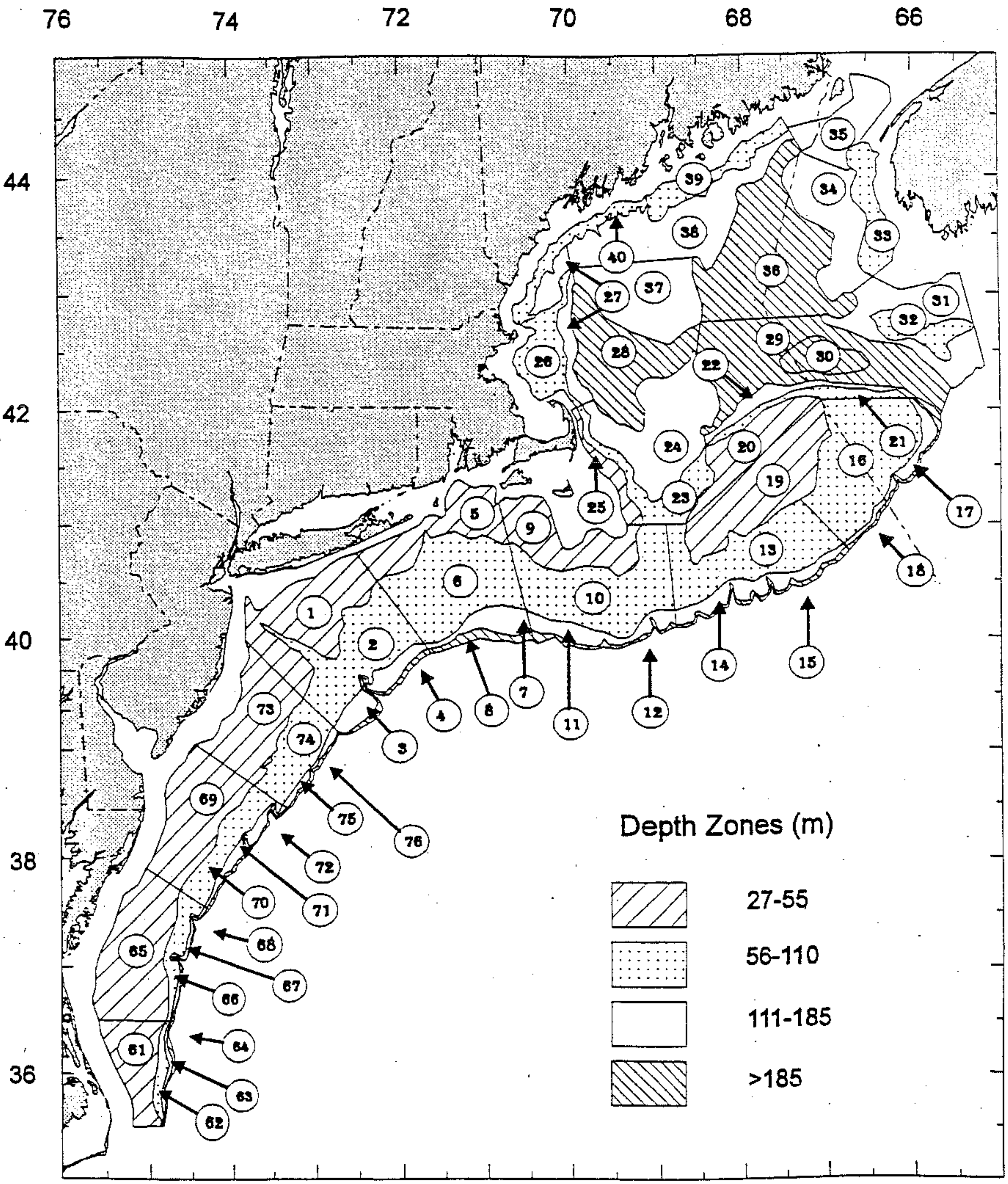



Figure D7. Area of the northwest Atlantic showing NMFS, NEFSC bottom trawl survey strata.

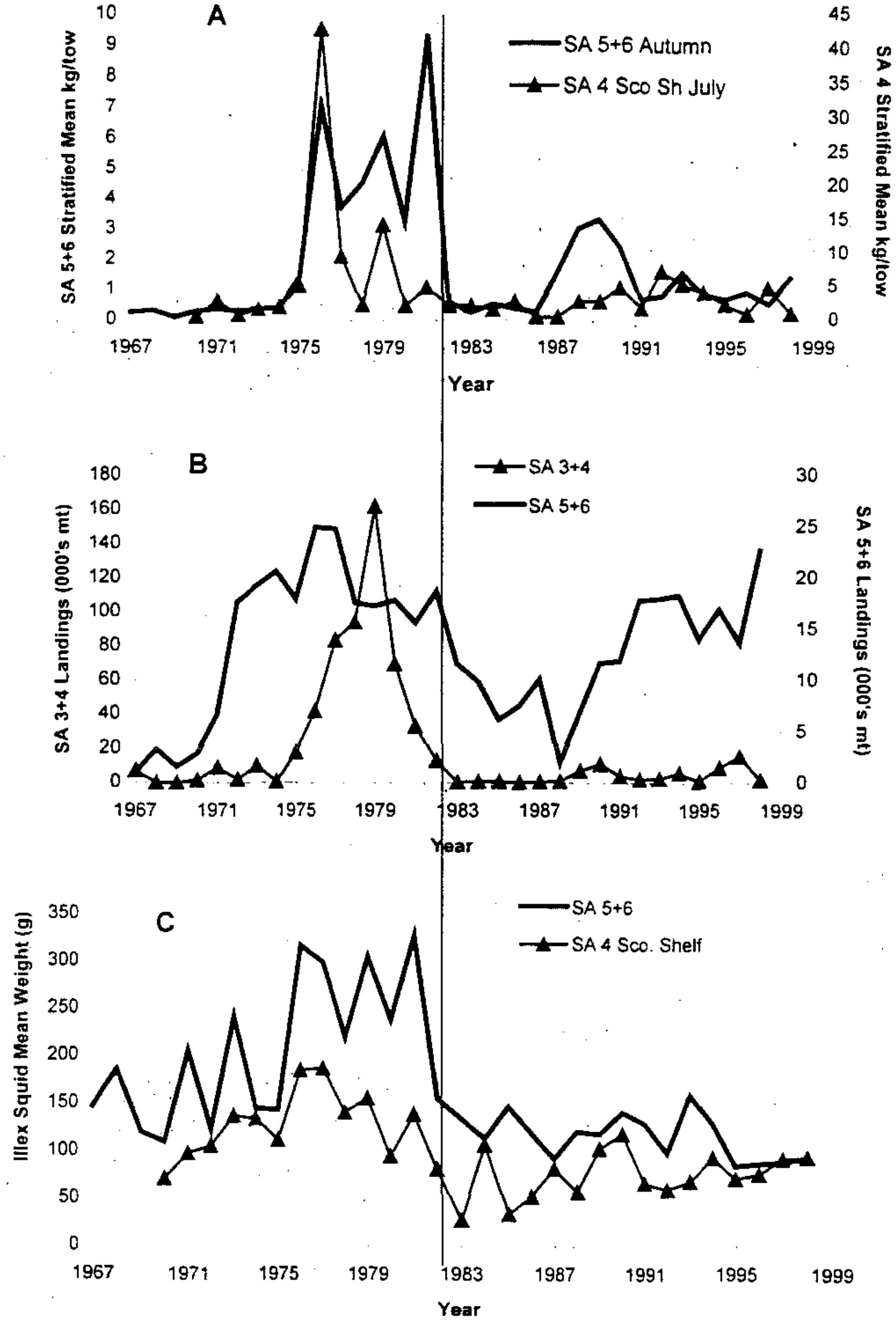



Figure D8. Trends in (A) stratified mean weight (kg) per tow indices of *Illex illecebrosus* captured in SA 5+6 autumn surveys 91967-1998) and SA 4 Scotian Shelf July survey indices (1970-1998; (B) trends in landings for Subareas 5+6 and Subareas 3+4 (1967-1998); and (C) trends in *Illex* squid mean weights of *Illex* squid captured in SA 5+6 and SA 4 Scotian Shelf surveys,.

Figure D9. Length-frequency distributions (stratified mean number per tow) of *Illex illecebrosus* from U.S. research bottom trawl surveys during autumn, 1967-1997.

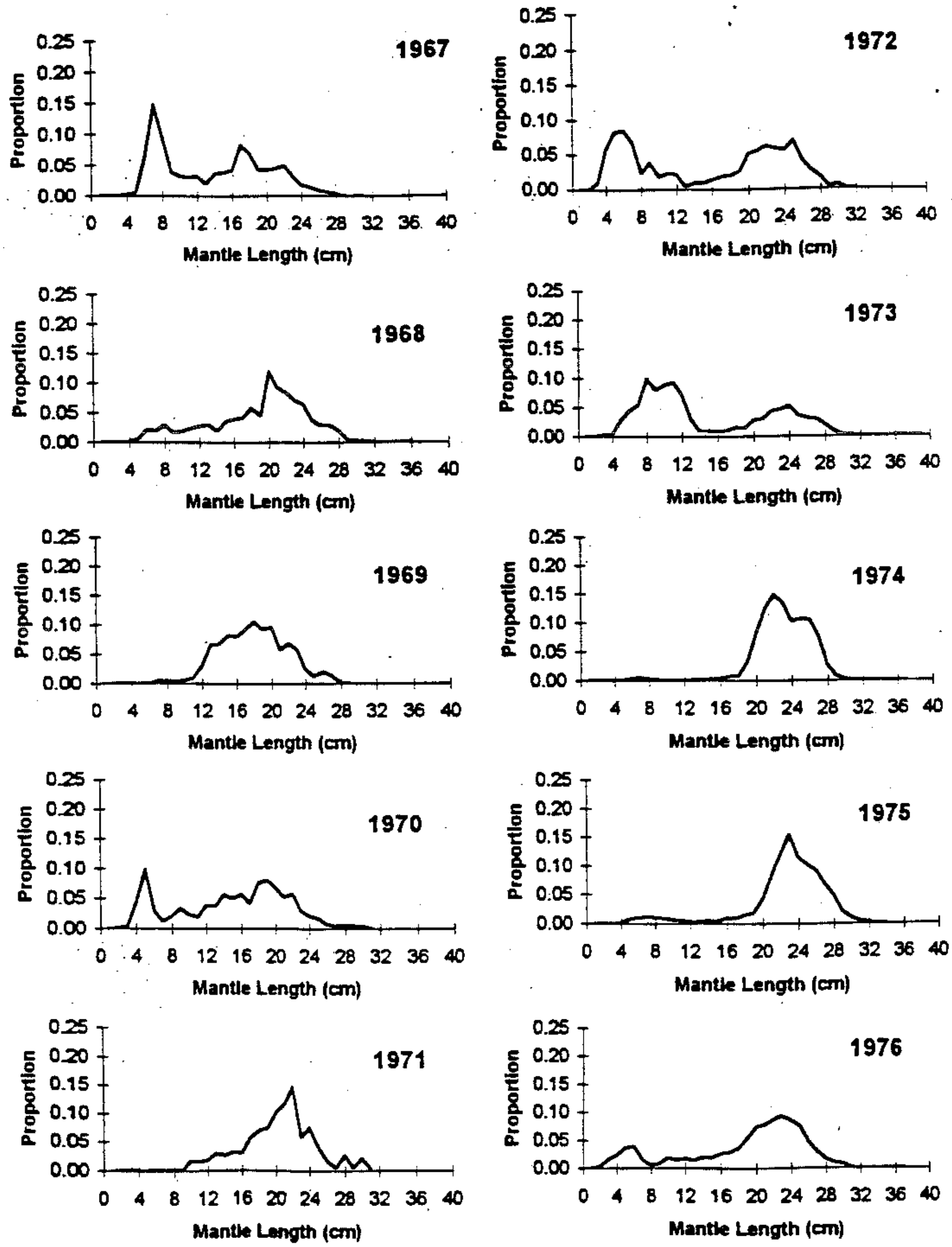


Figure D9. Continued

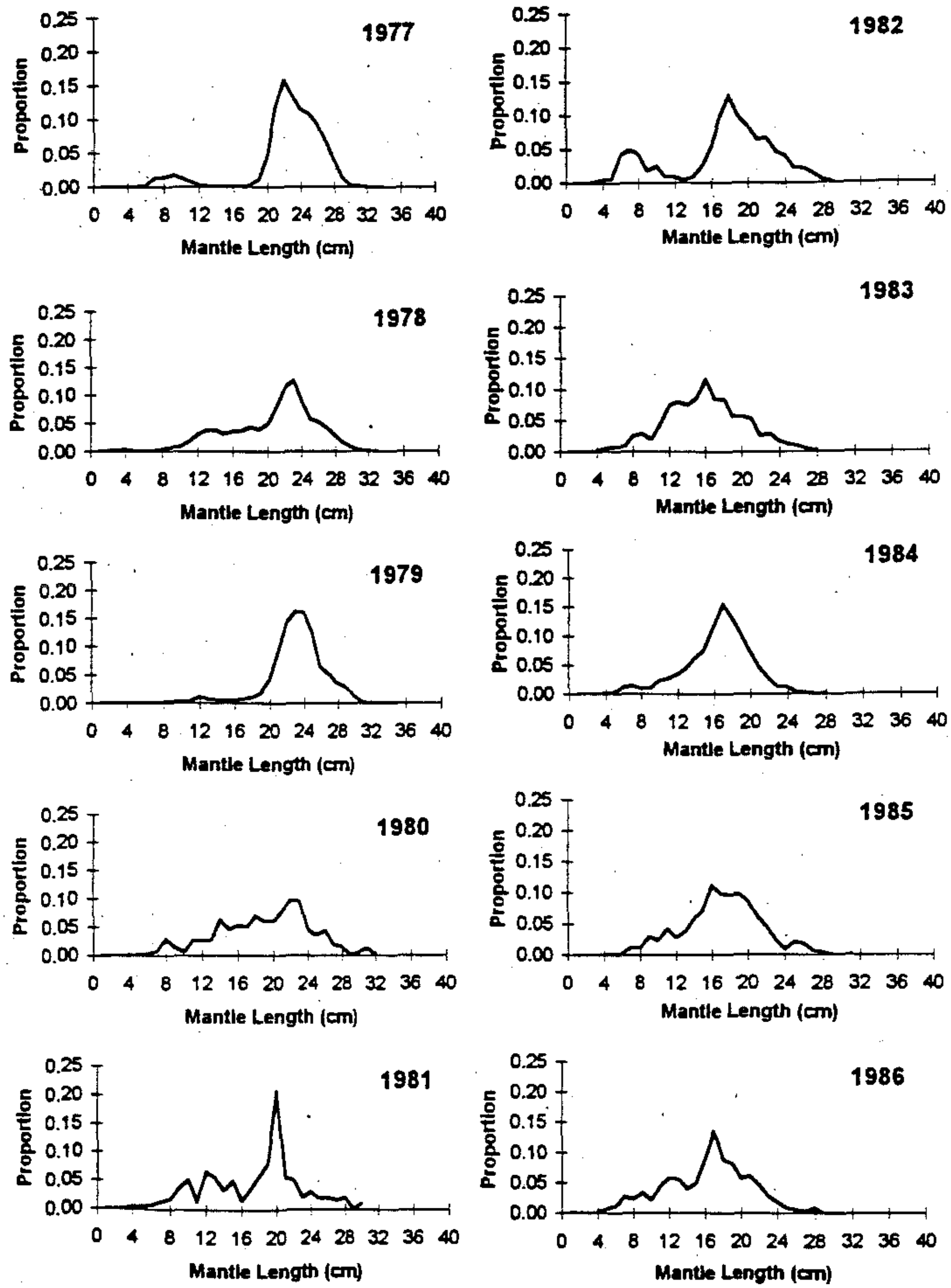


Figure D9. Continued

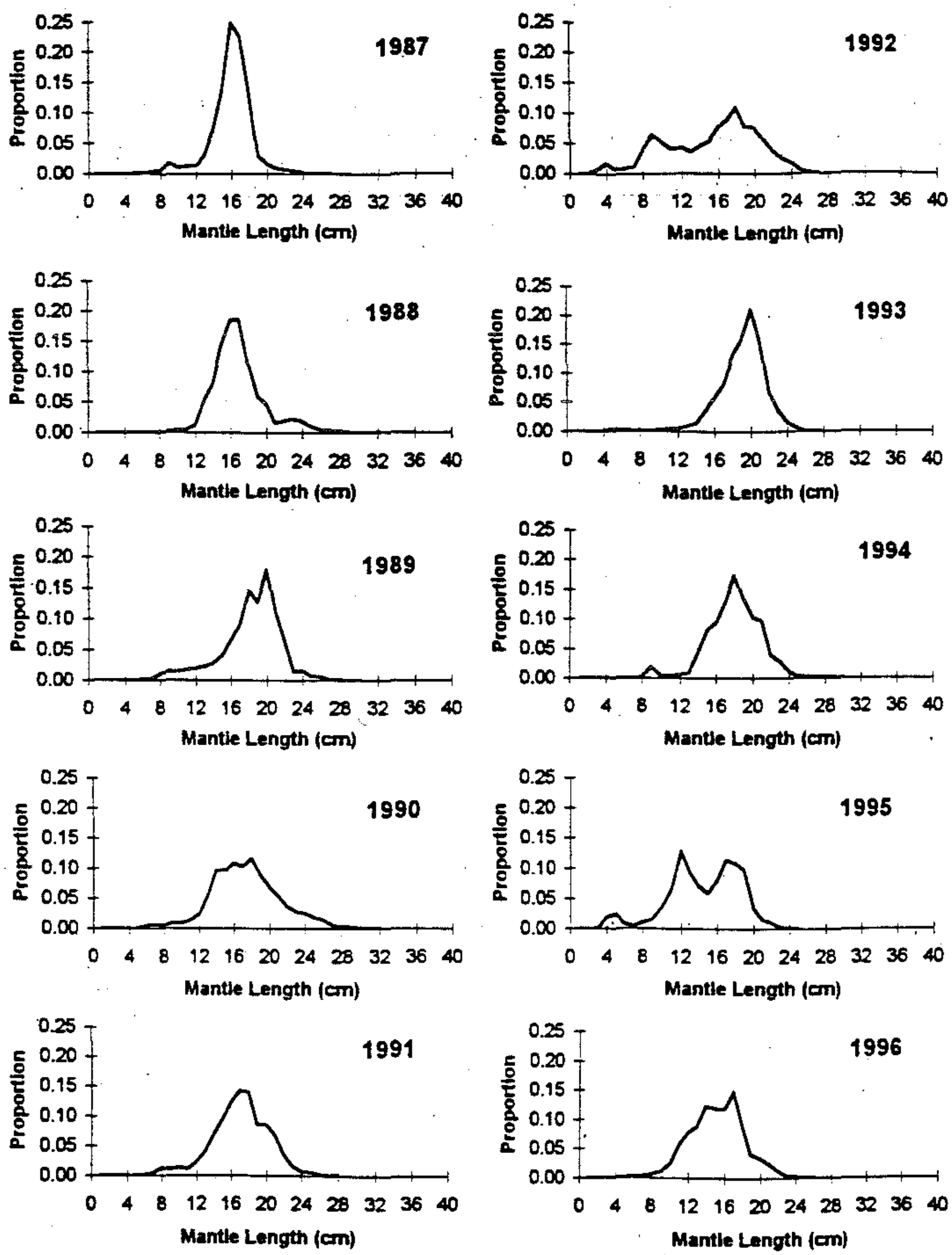


Figure D9. Continued

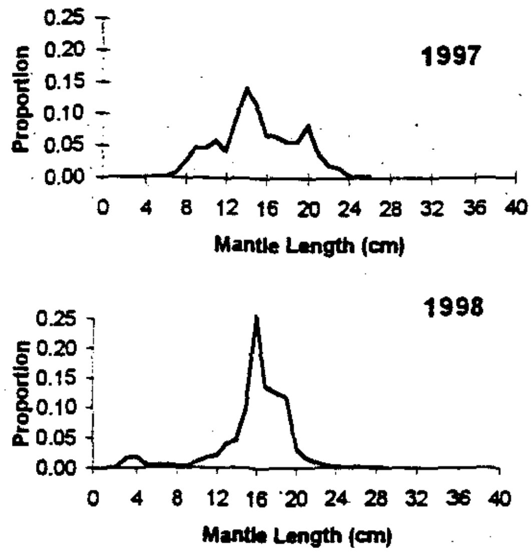
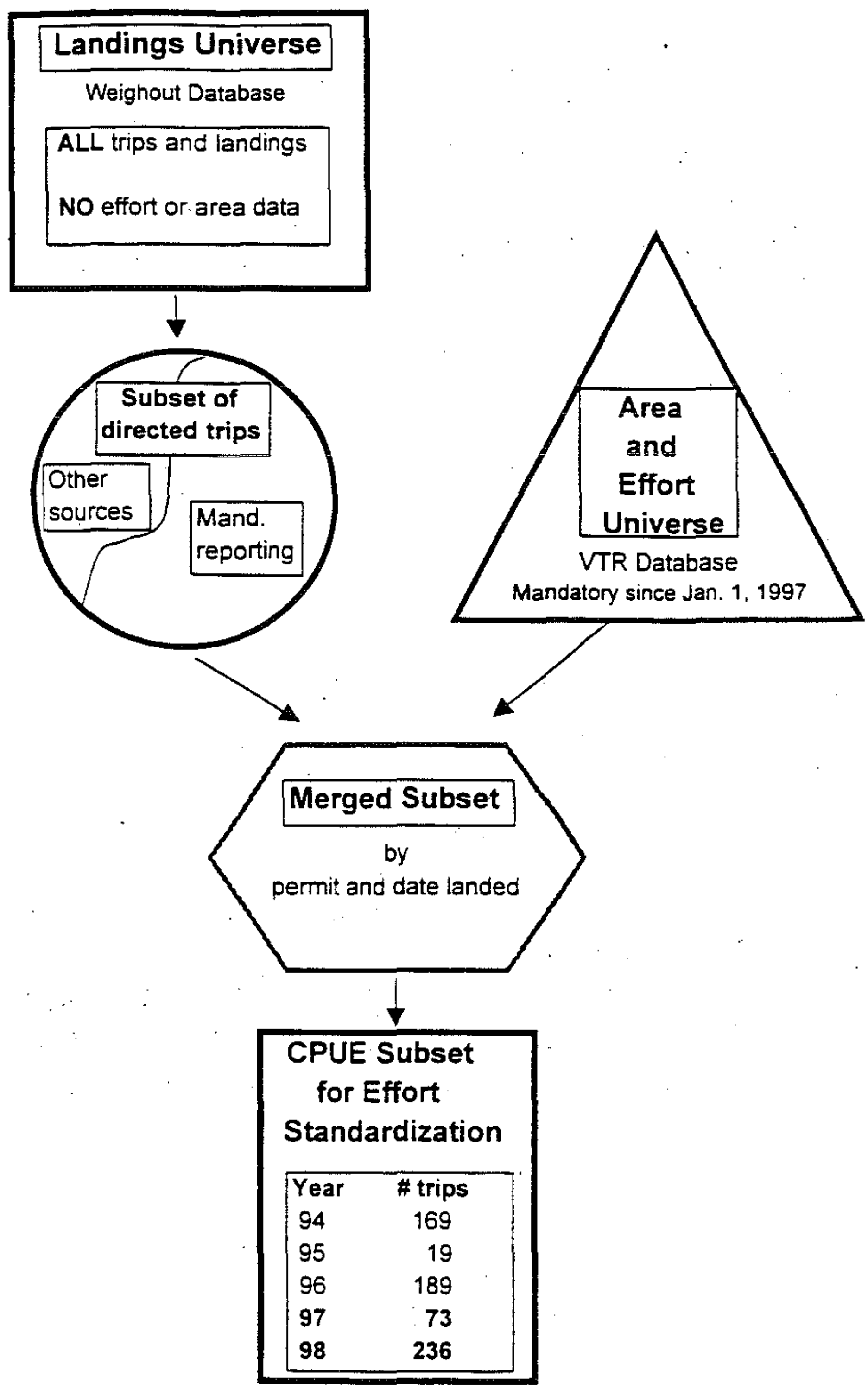


Figure 10. Creation of *Illex* squid CPUE time series.



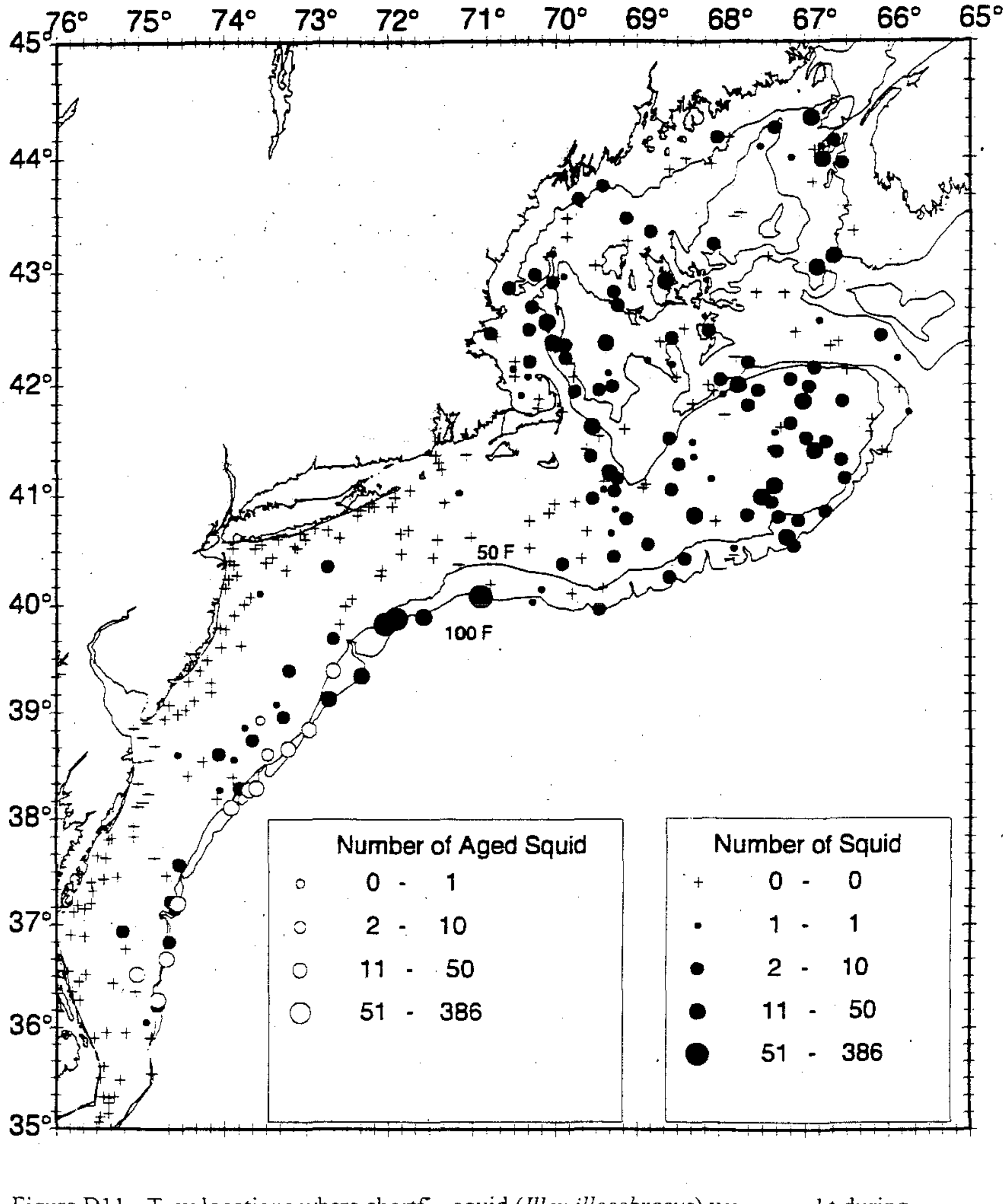



Figure D11. Tow locations where shortfin squid (*Illex illecebrosus*) were caught during the Fall 1997 Bottom Trawl Survey. Open circles represent age sample locations.

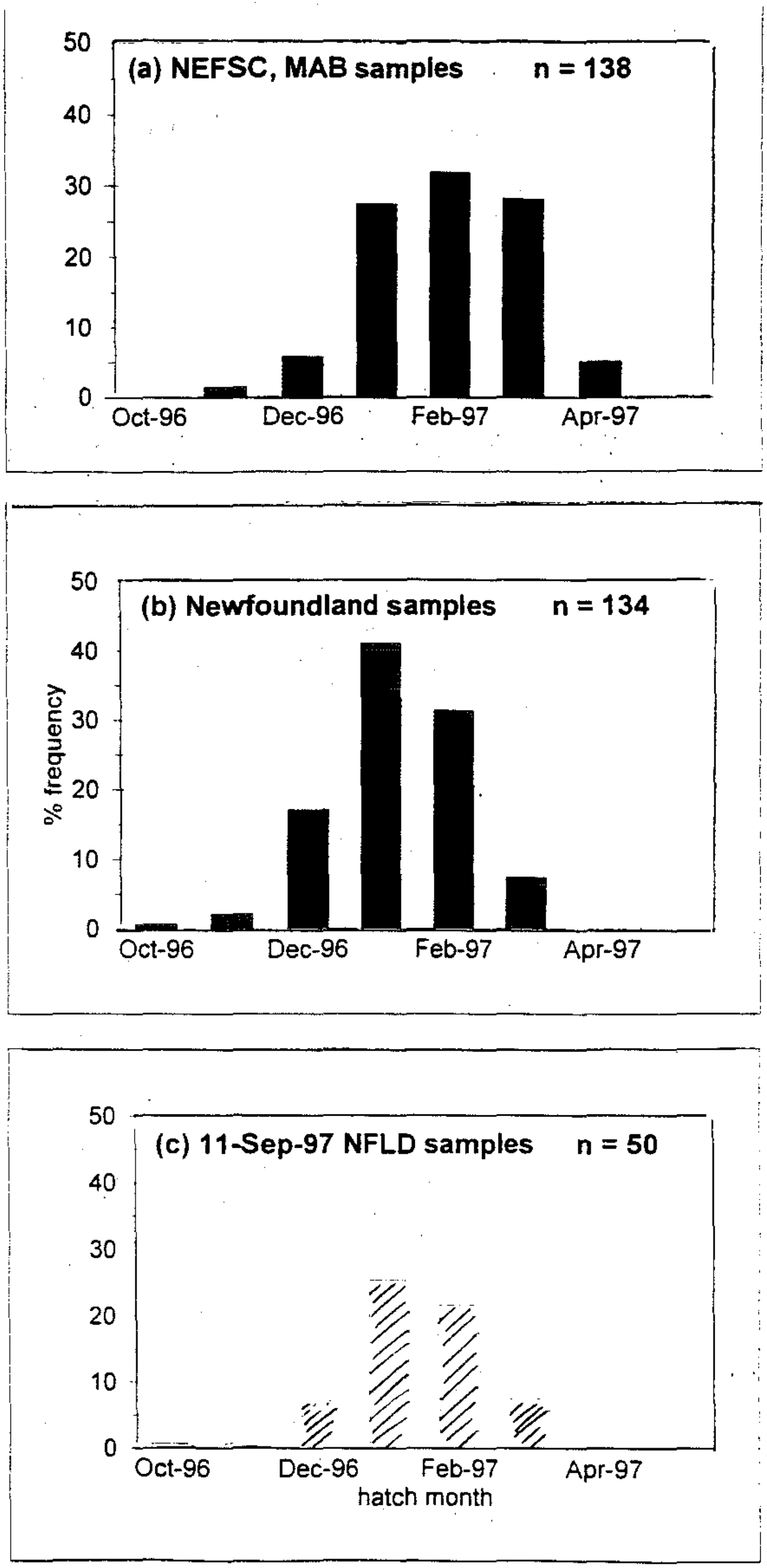



Figure D12. Hatch month distribution *Illex illecebrosus* caught in (A) the Mid-Atlantic Bight during the 1997 NEFSC autumn bottom trawl survey and (B and C) in the 1997 Newfoundland jig fishery. Hatch dates determined from back-calculation of age, via statolith increment counts, from date of capture.

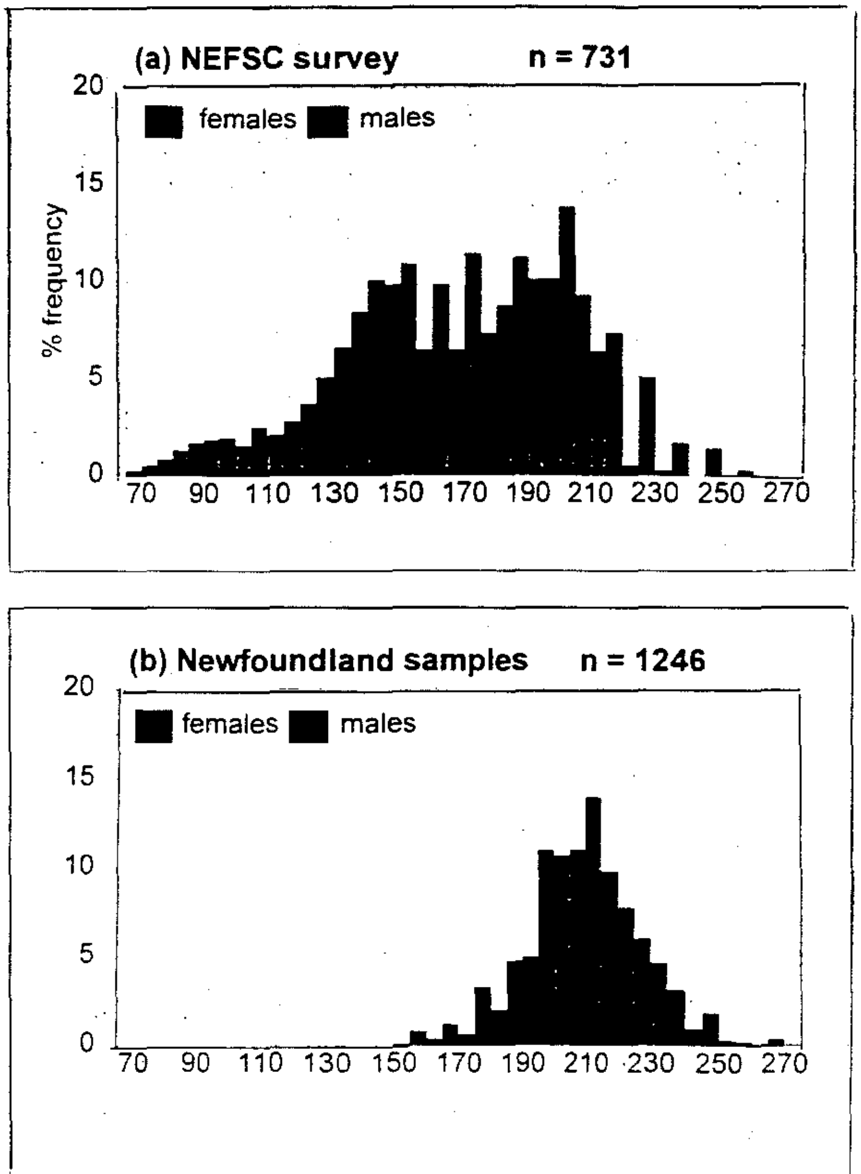
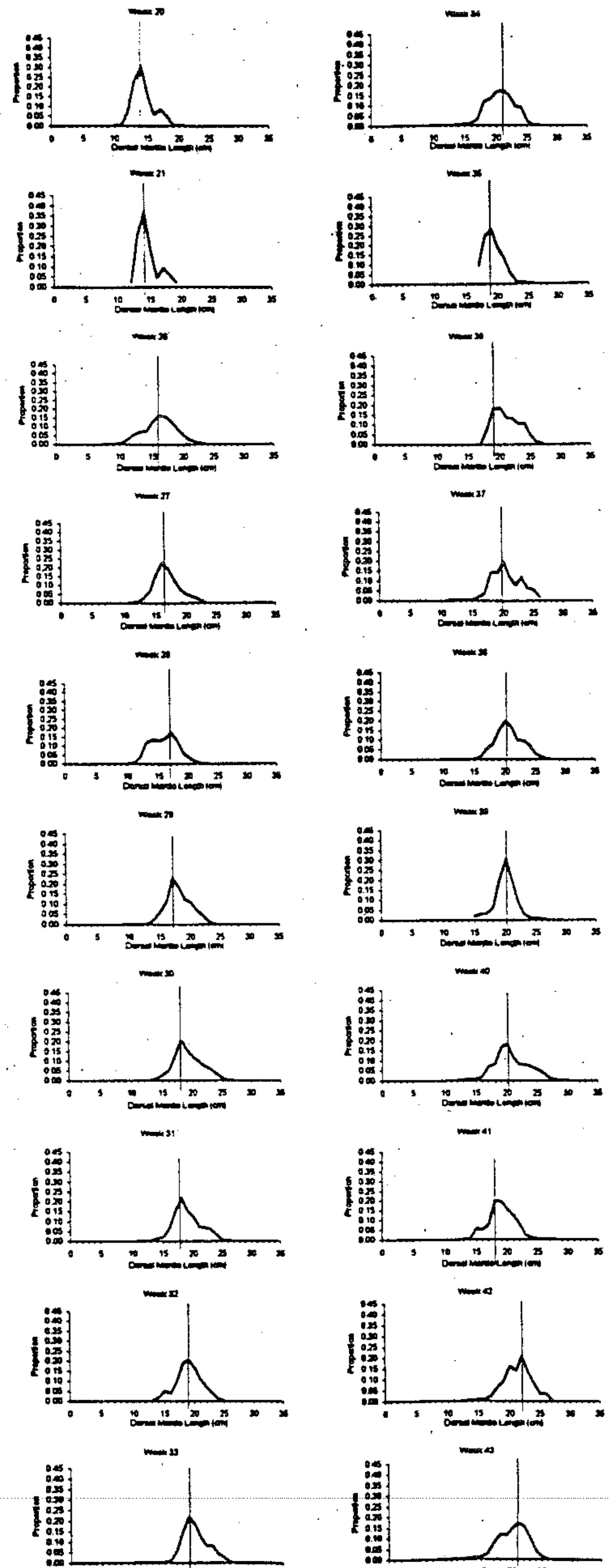



Figure D13. Length-frequency distribution of male and female *Illex illecebrosus* caught in (A) the 1997 NEFSC autumn bottom trawl survey and (B) in the 1997 Newfoundland jig fishery, which were examined for sexual maturity staging.

Date provided by *Illex* squid fishing industry from the bottom trawl landings.



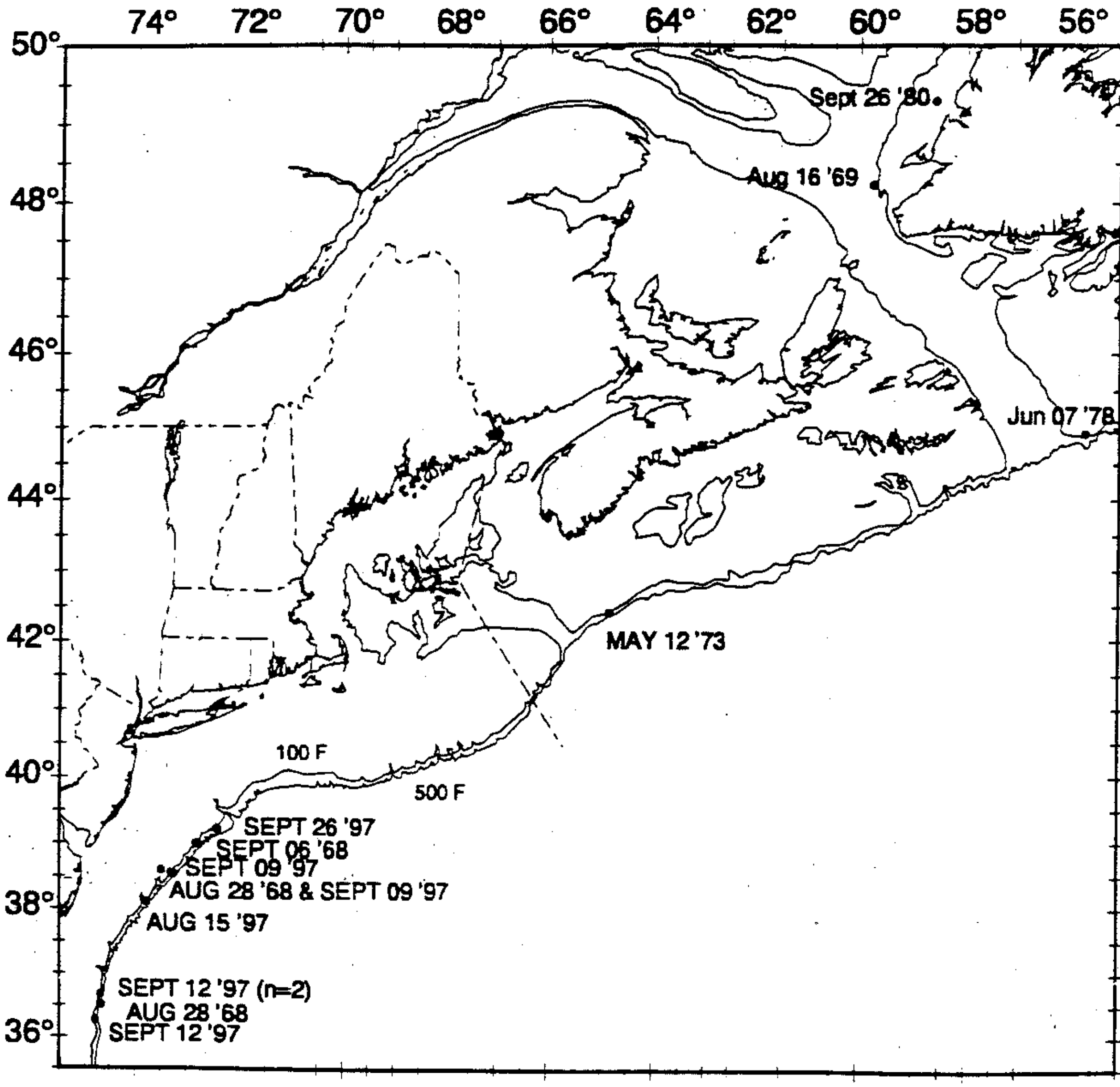



Figure D15. Map showing location and time of capture of mature female shortfin squid, *Illex illecebrosus*, in the Northwest Atlantic.

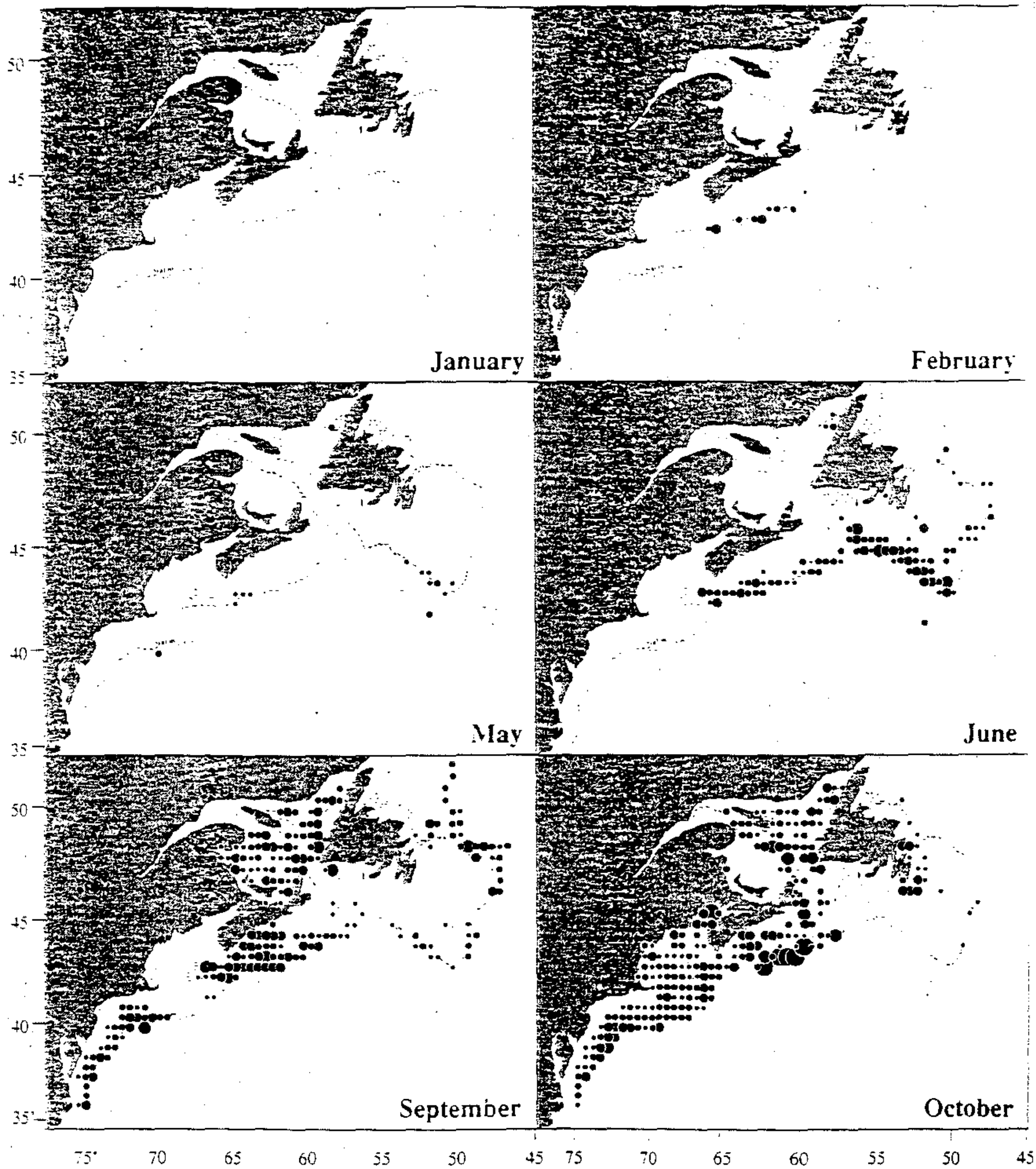
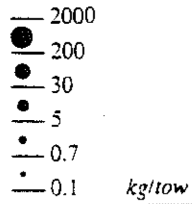



Figure D16. Monthly distribution patterns of *Illex illecebrosus* in the Northwest Atlantic Ocean, showing kg/tow, based on research bottom trawl surveys conducted during 1970-1980 (from Black, et. al., 1987). Area sampled is indicated by shading, and mean catch in kg/tow for each 0.5" square is represented by a solid circle scaled to catch level.



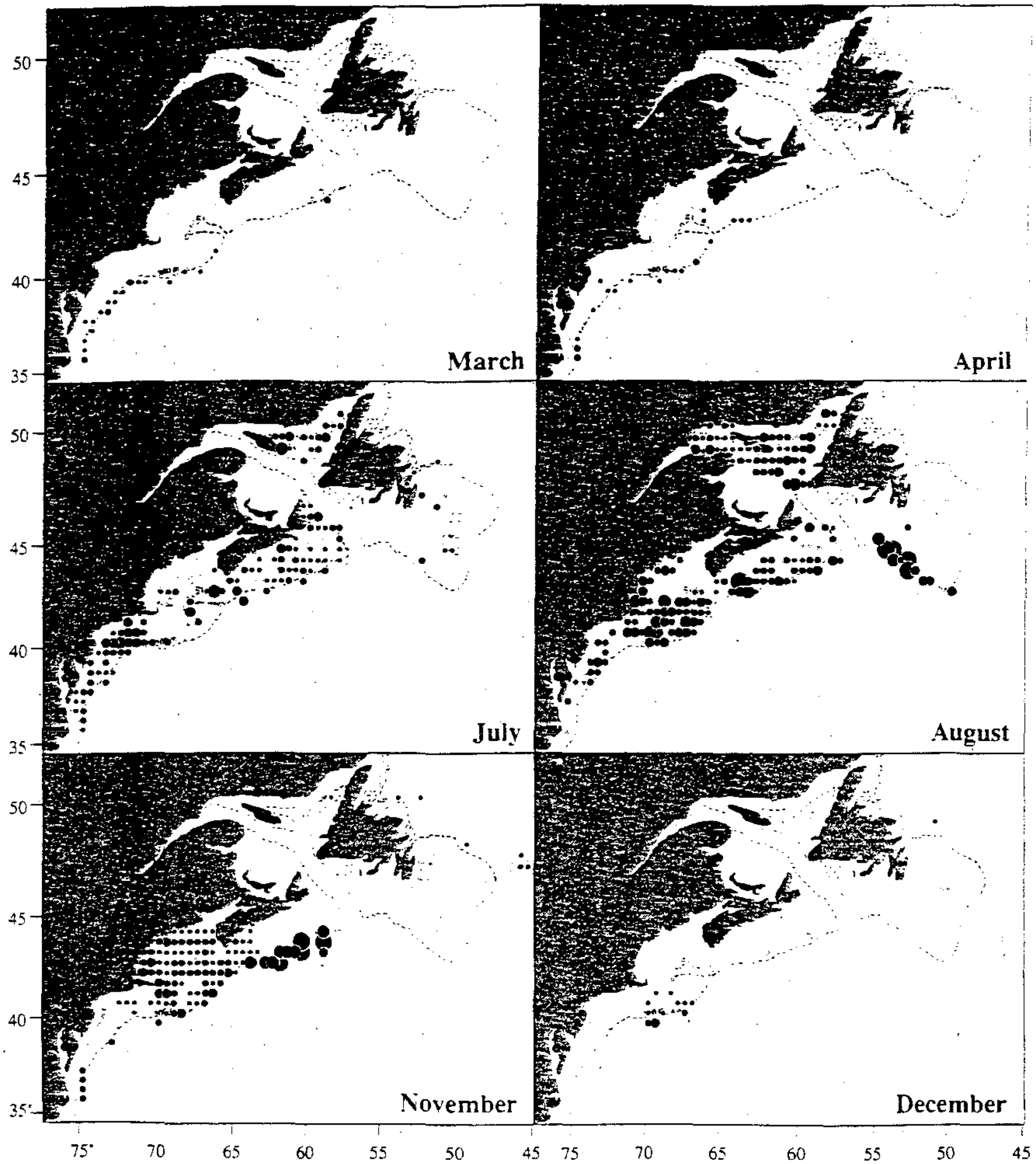
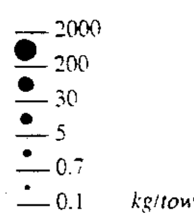



Figure D16. Monthly distribution patterns of *Illex illecebrosus* in the Northwest Atlantic Ocean, showing kg/tow, based on research bottom trawl surveys conducted during 1970-1980 (from Black, et. al., 1987). Area sampled is indicated by shading, and mean catch in kg/tow for each 0.5° square is represented by a solid circle scaled to catch level.



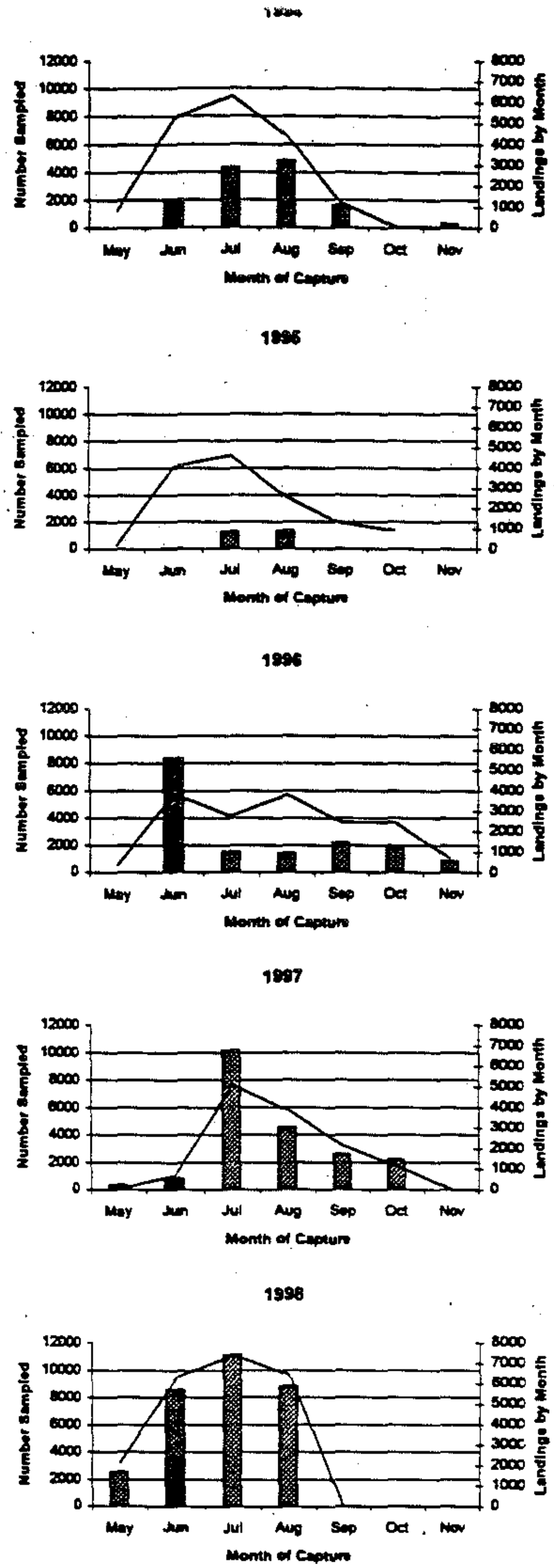



Figure D17. Trends in monthly *Illex* squid landings and number of length-weight samples from the U.S. bottom trawl fishery, during 1994-1998, which were used to derive stock size and fishing mortality rate estimates.

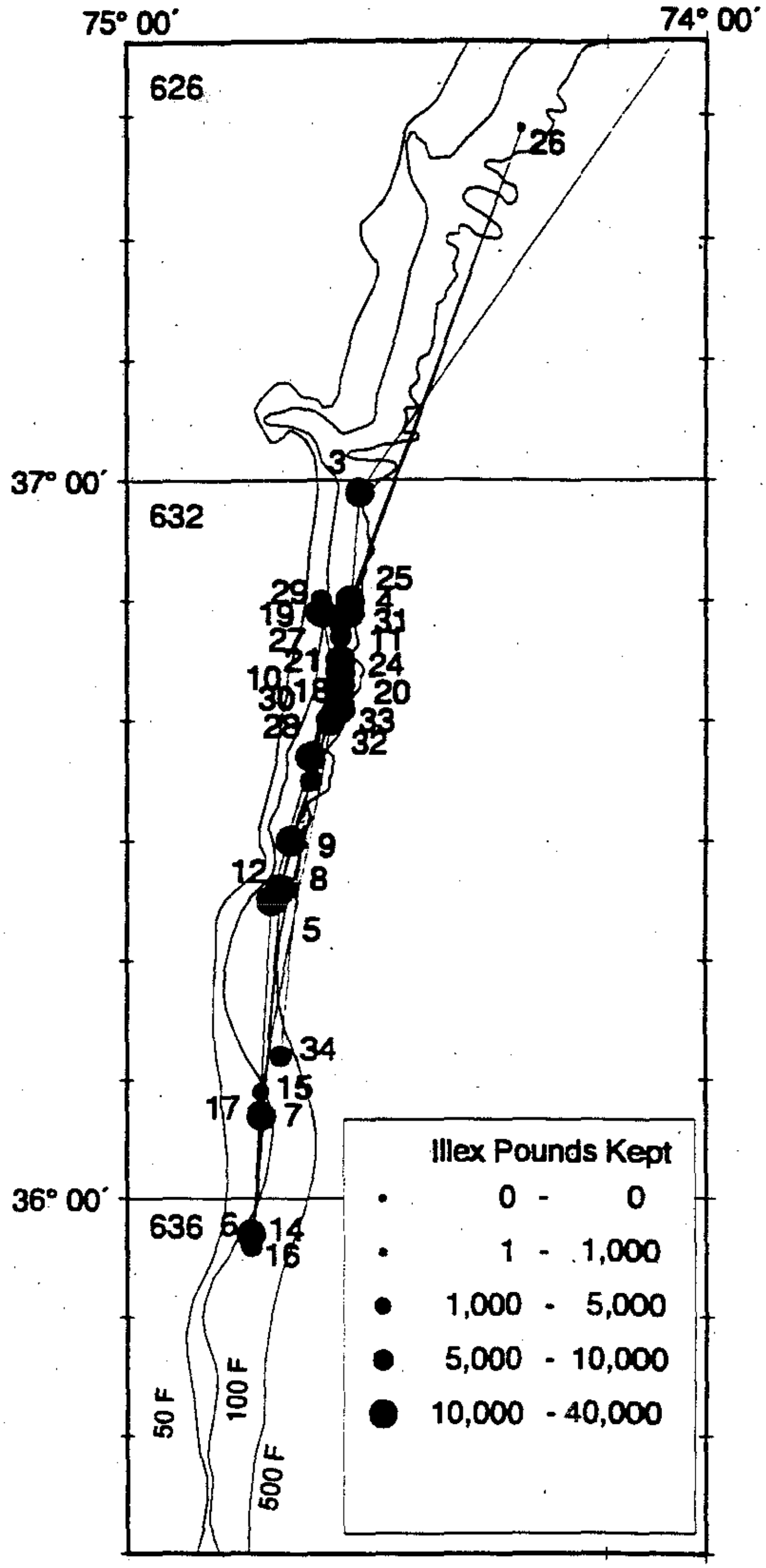



Figure D18. Tow locations along a track line of an *Illex* squid trip in NMFS Statistical Areas during June 24-29, 1996 (n=36).

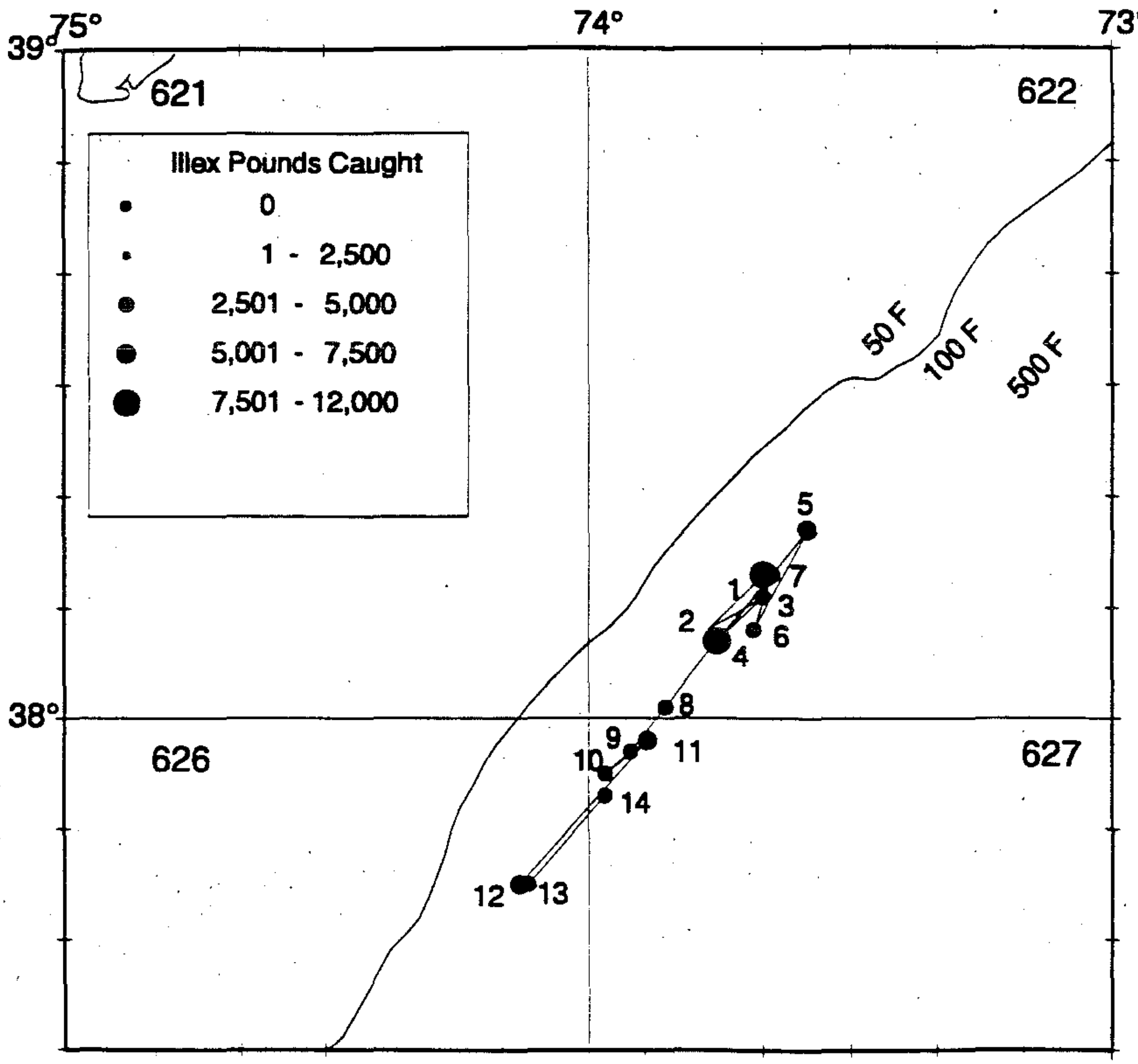



Figure D19. Tow locations along a track line of an *Illex* squid trip in NMFS Statistical Areas during June 24-29, 1996 (n=14).

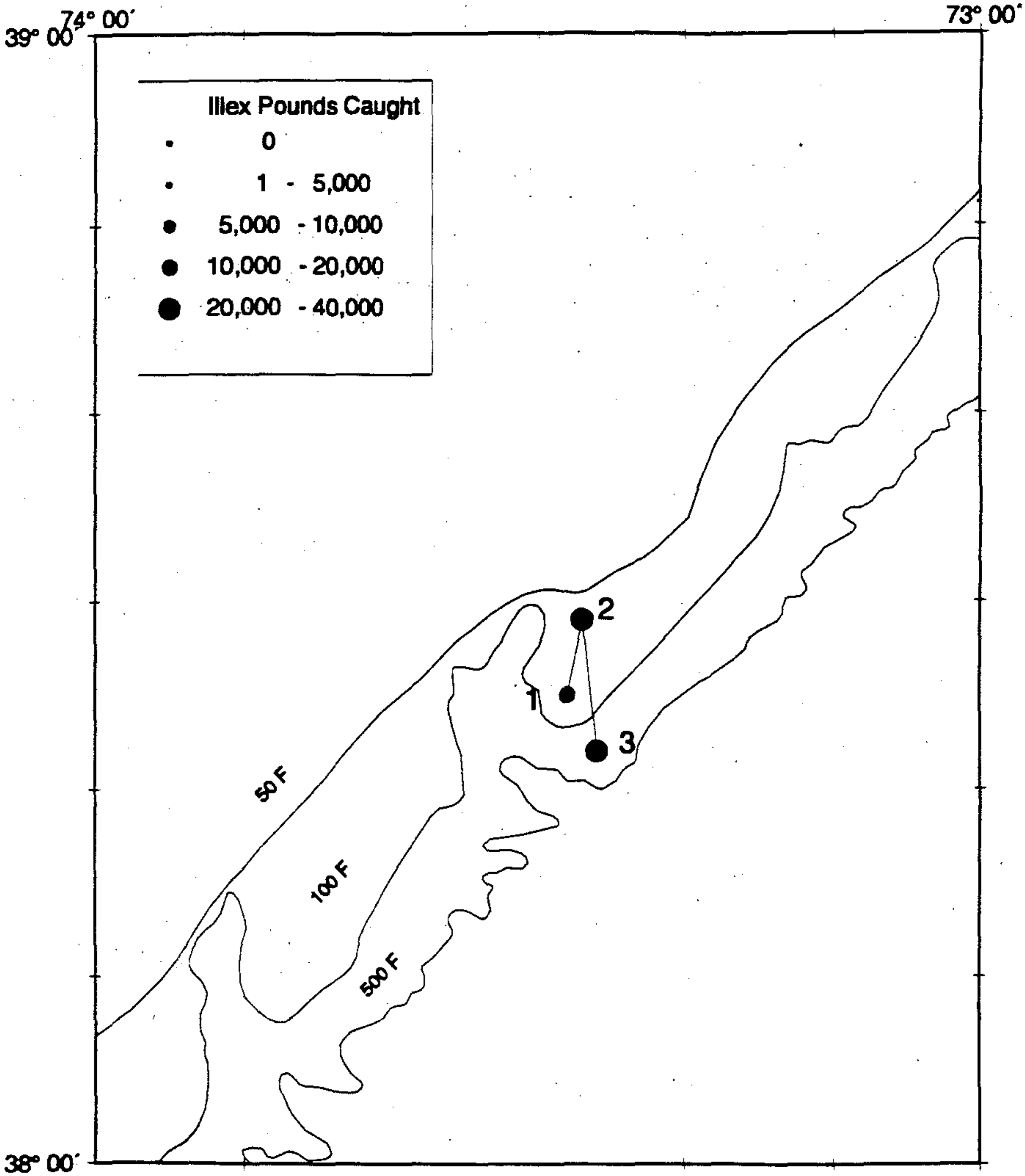



Figure D20. Tow locations along a track line of an *Illex* squid trip in NMFS Statistical Area 622 during June 18-20, 1996 (n=3).

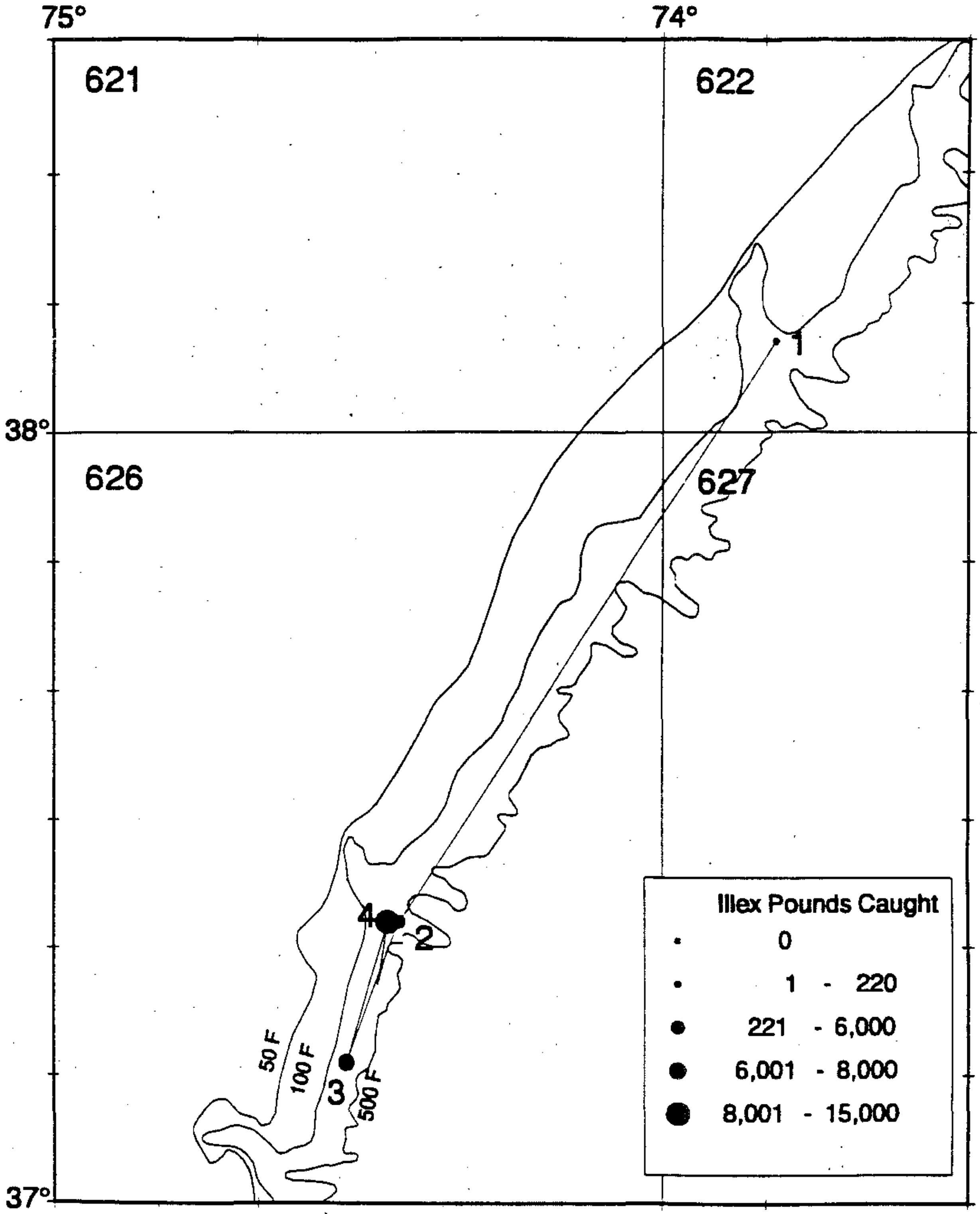



Figure D21. Tow locations along a track line of an *Illex* squid trip in NMFS Statistical Areas during July 1-4, 1996 (n=4).

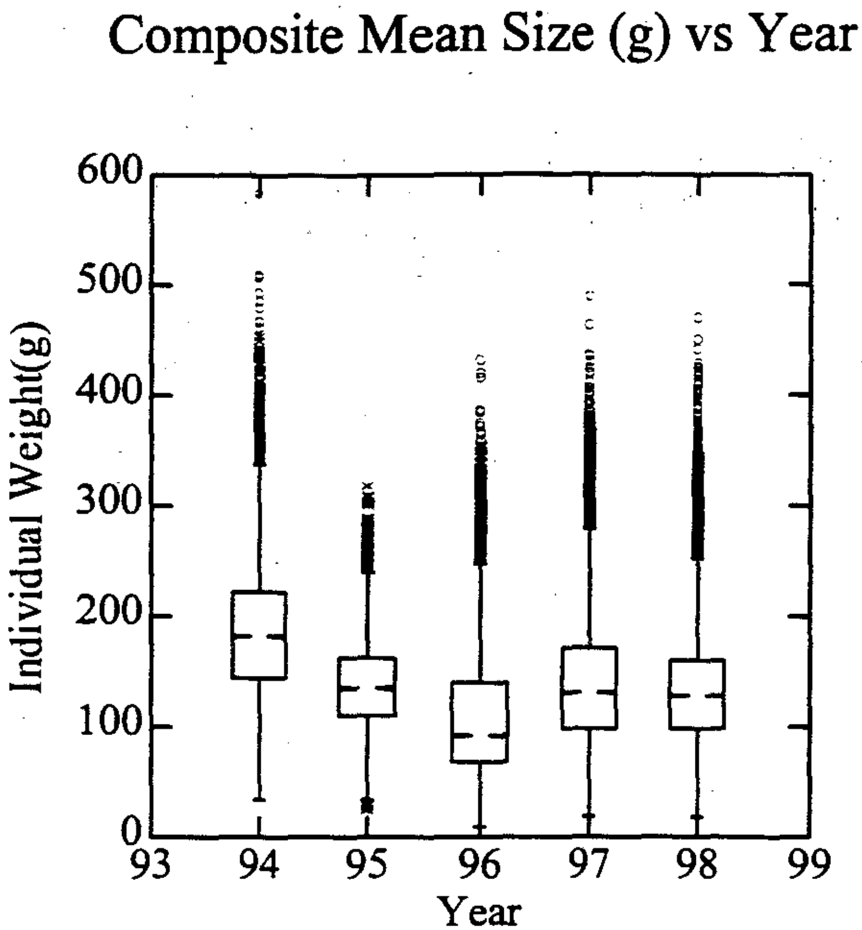



Figure D22. Box plots of the distribution of individual *Illex* weights obtained from industry-supplied measurements from landed squid, 1994-1998. The boxes illustrate the boundaries of the interquartile range and the notch in the middle represents the median value.

Composite Mean Length (cm) vs Year

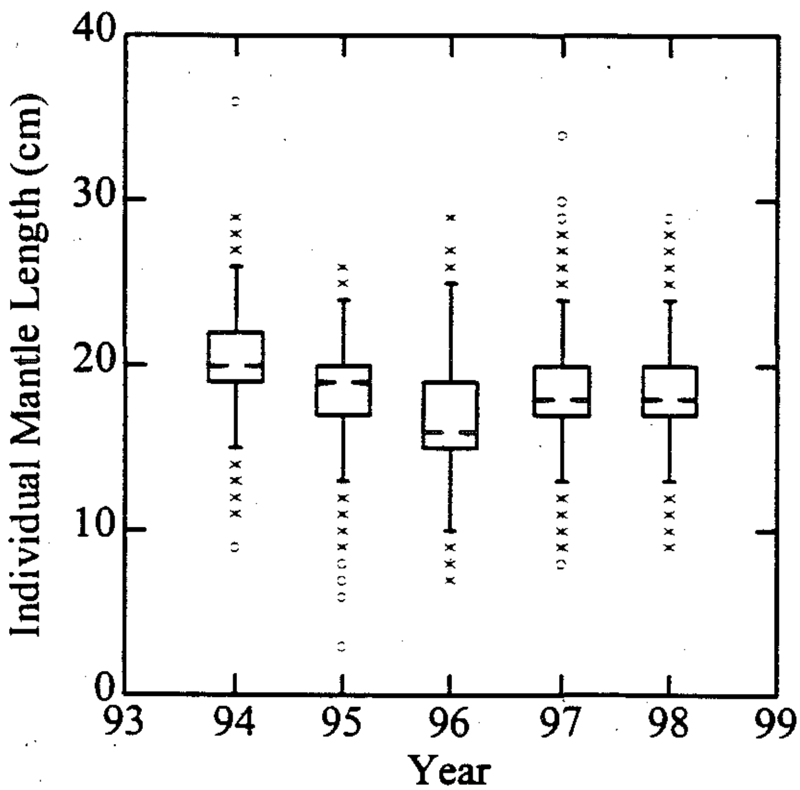



Figure D23. Box plots of the distribution of individual *Illex* mantle lengths obtained from industry-supplied measurements from landed squid, 1994-1998. The boxes illustrate the boundaries of the interquartile range and the notch in the middle represents the median value.

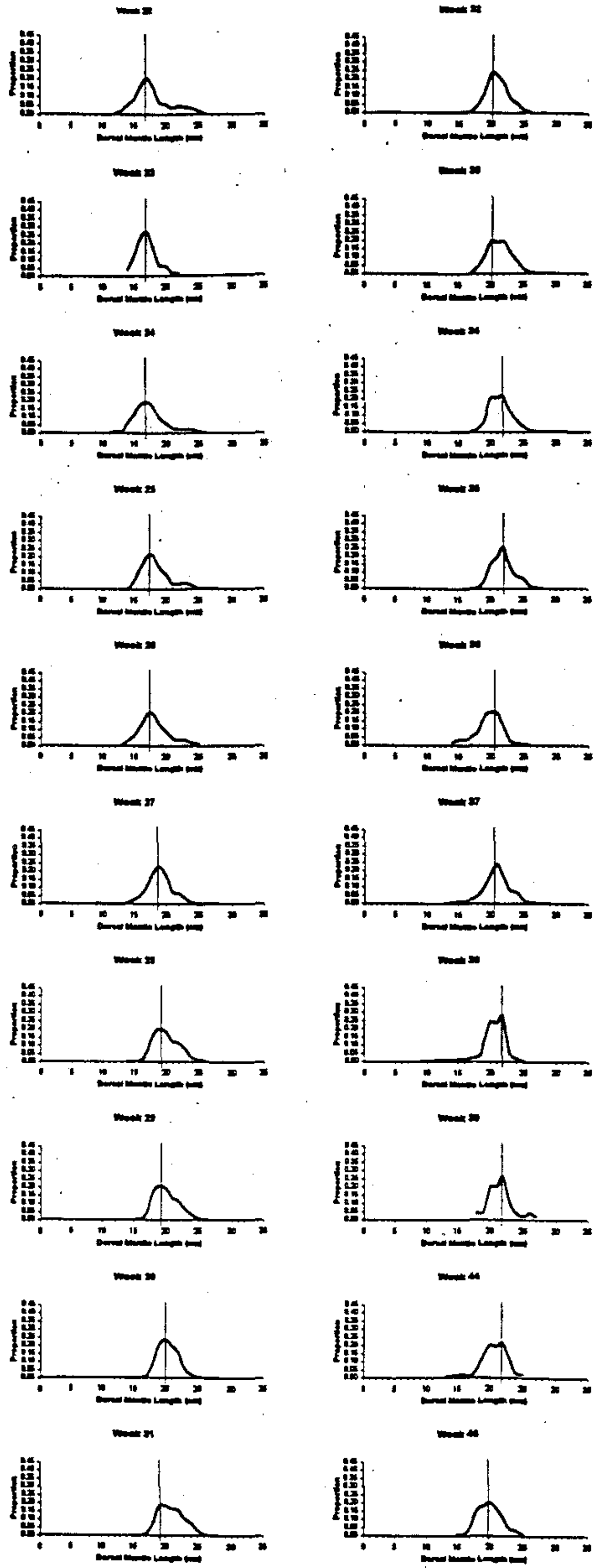


Figure D24. Proportion at length (cm) of *Illex illecebrosus*, by week of the year, during 1994. Data provided by *Illex* squid fishing industry from the bottom trawl landings.

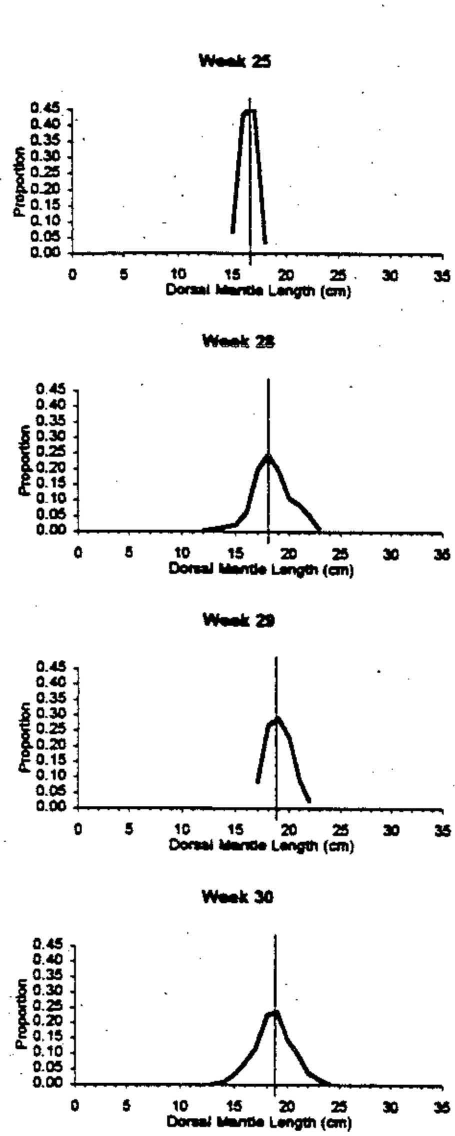



Figure D25. Proportion at length (cm) of *Illex illecebrosus*, by week of the year, during 1995. Data provided by *Illex* squid fishing industry from the bottom trawl landings.

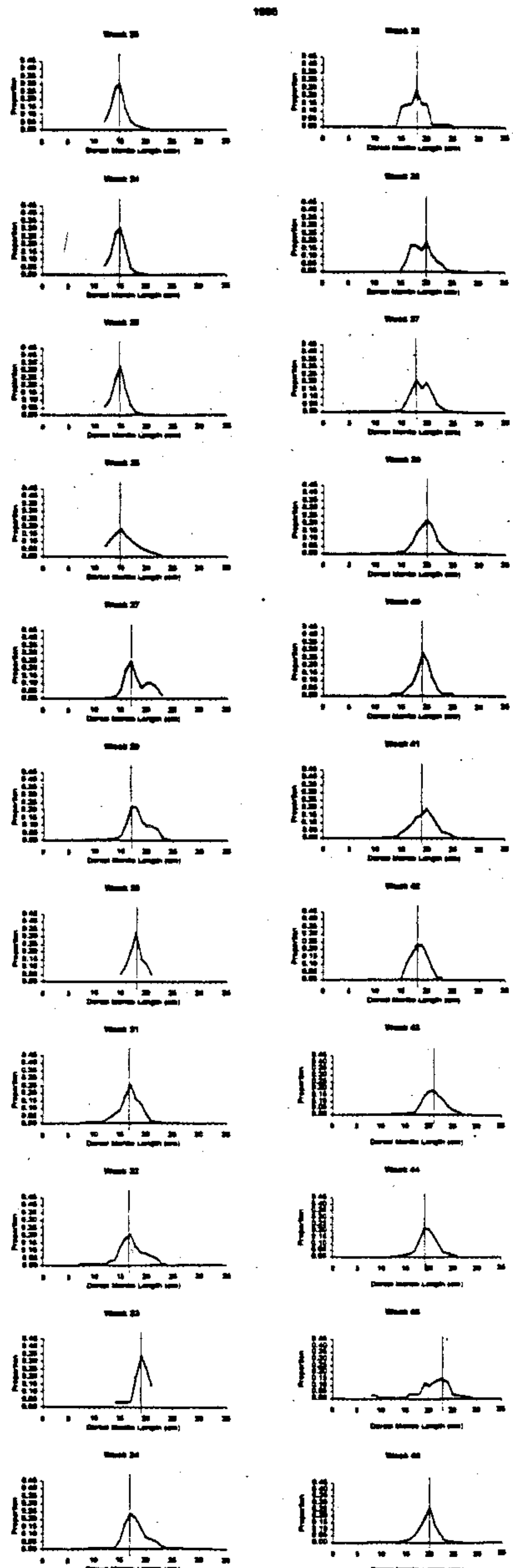


Figure D26. Proportion at length (cm) of *Illex illecebrosus*, by week of the year, during 1996. Data provided by *Illex* squid fishing industry from the bottom trawl landings.

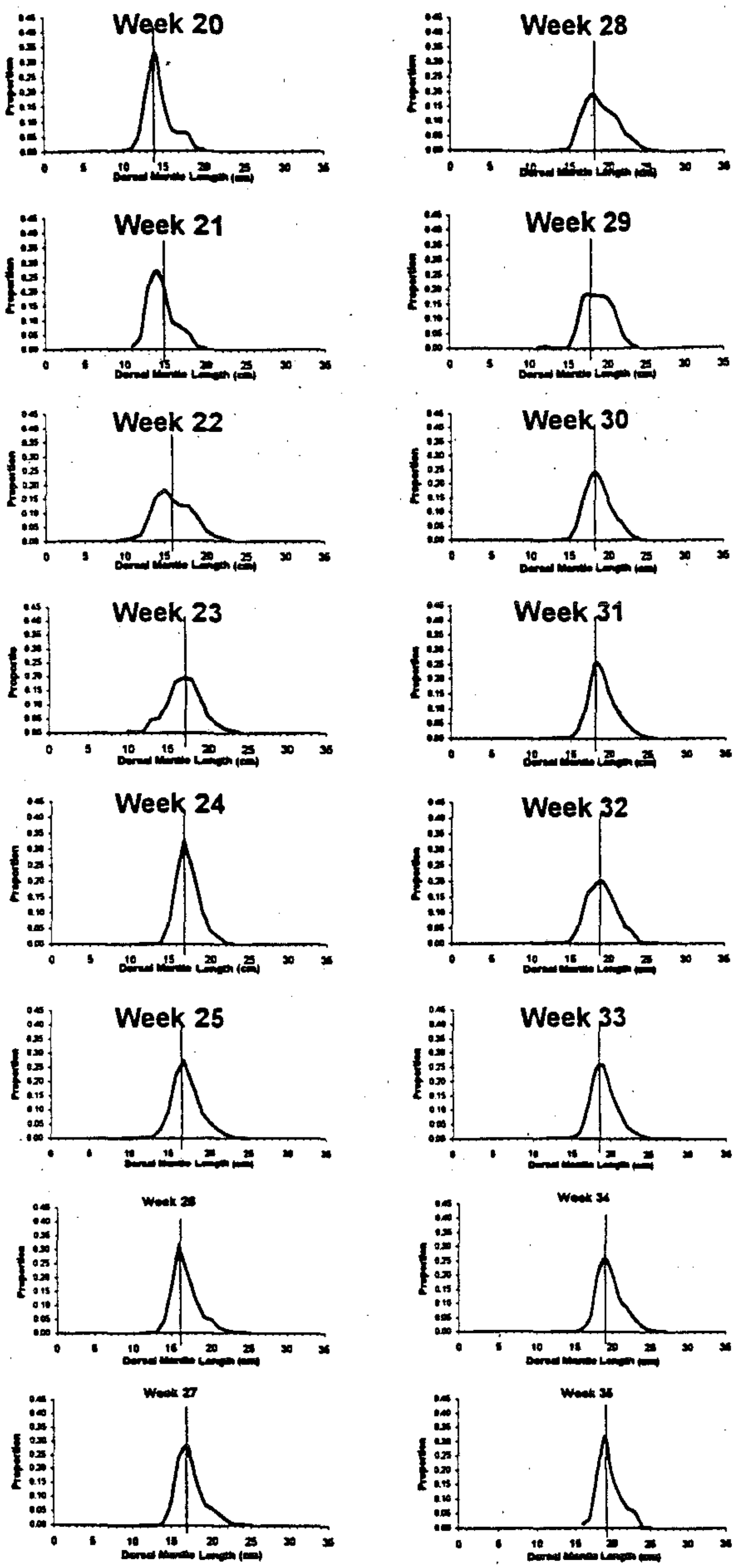



Figure D27. Proportion at length (cm) of *Illex illecebrosus*, by week of the year, during 1998. Data provided by *Illex* squid fishing industry from the bottom trawl landings.

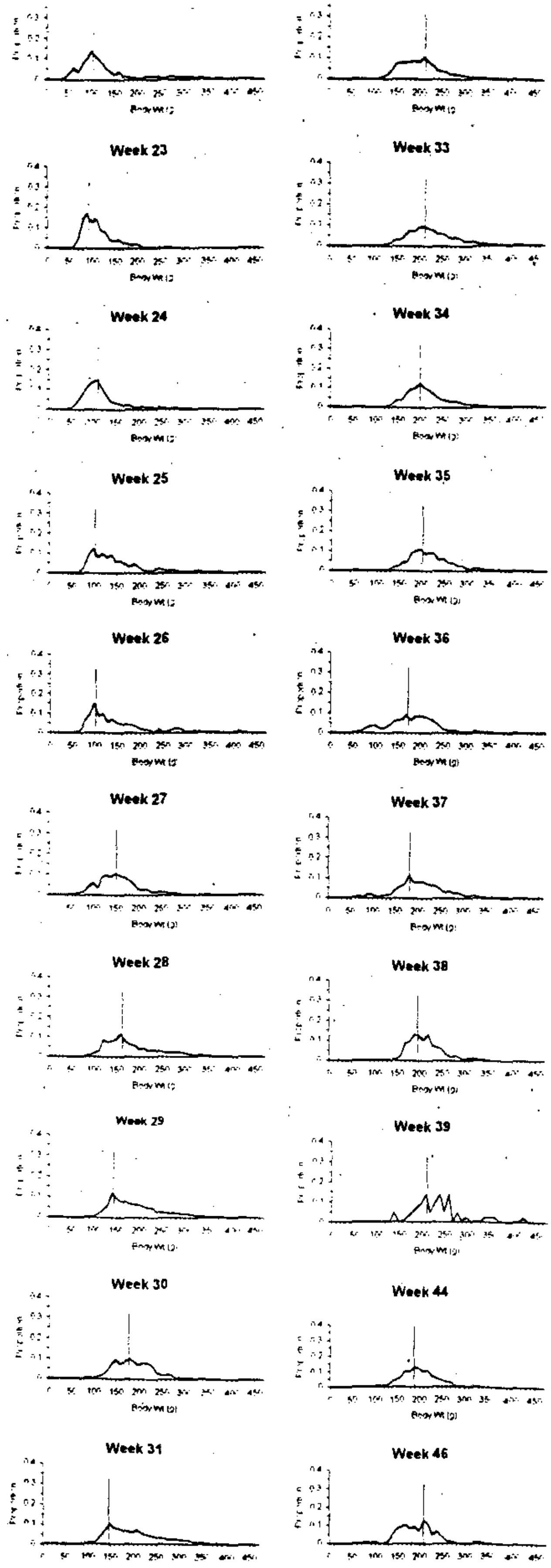



Figure D28. Proportion of *Illex* squid, by body weight (g) and week of the year, during 1994. Data provided by *Illex* squid fishing industry from bottom trawl landings.

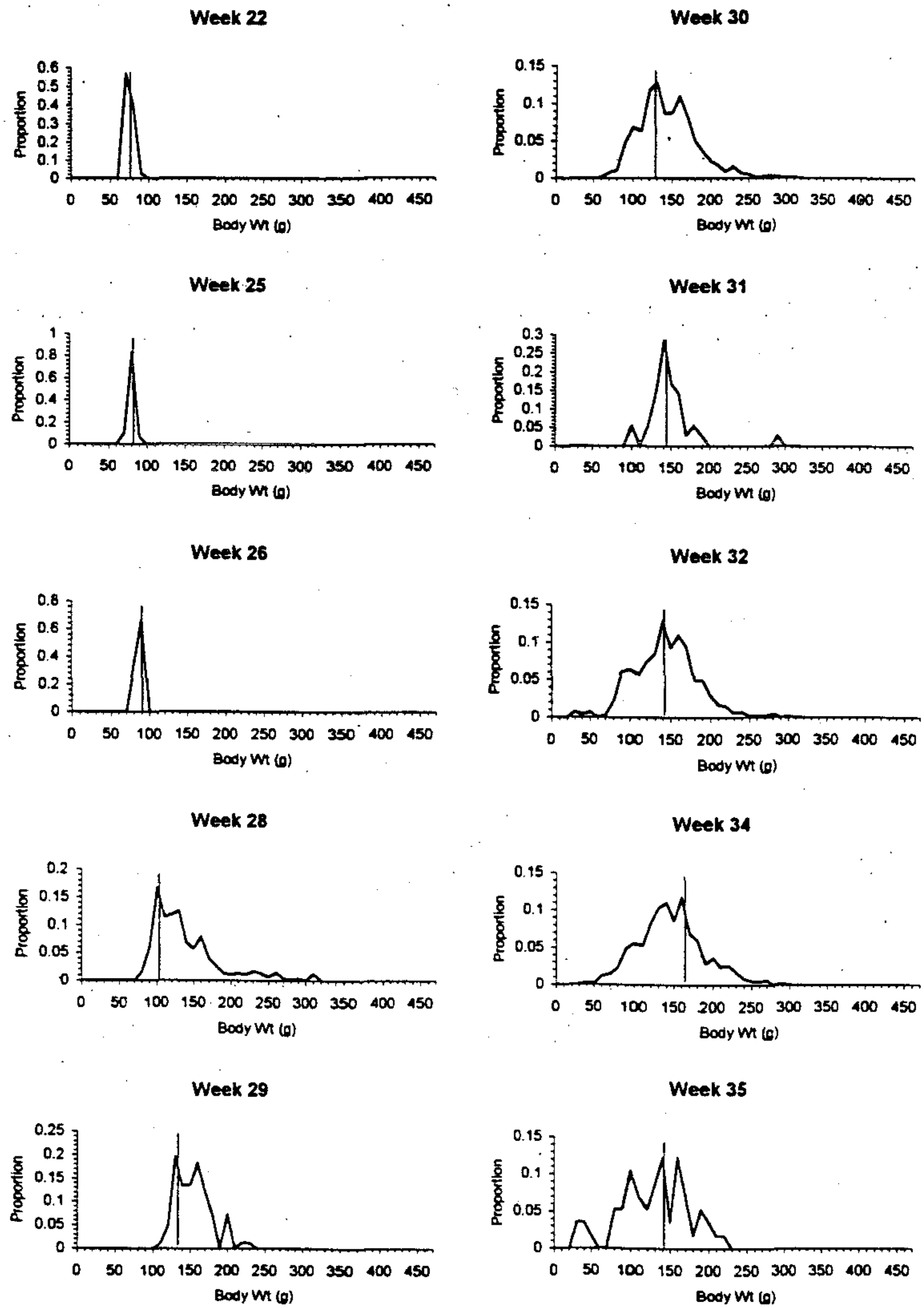



Figure D29. Proportion of *Illex* squid, by body weight (g) and week of the year, during 1995. Data source: *Illex* squid bottom trawl landings. Y-axis has variable scales.

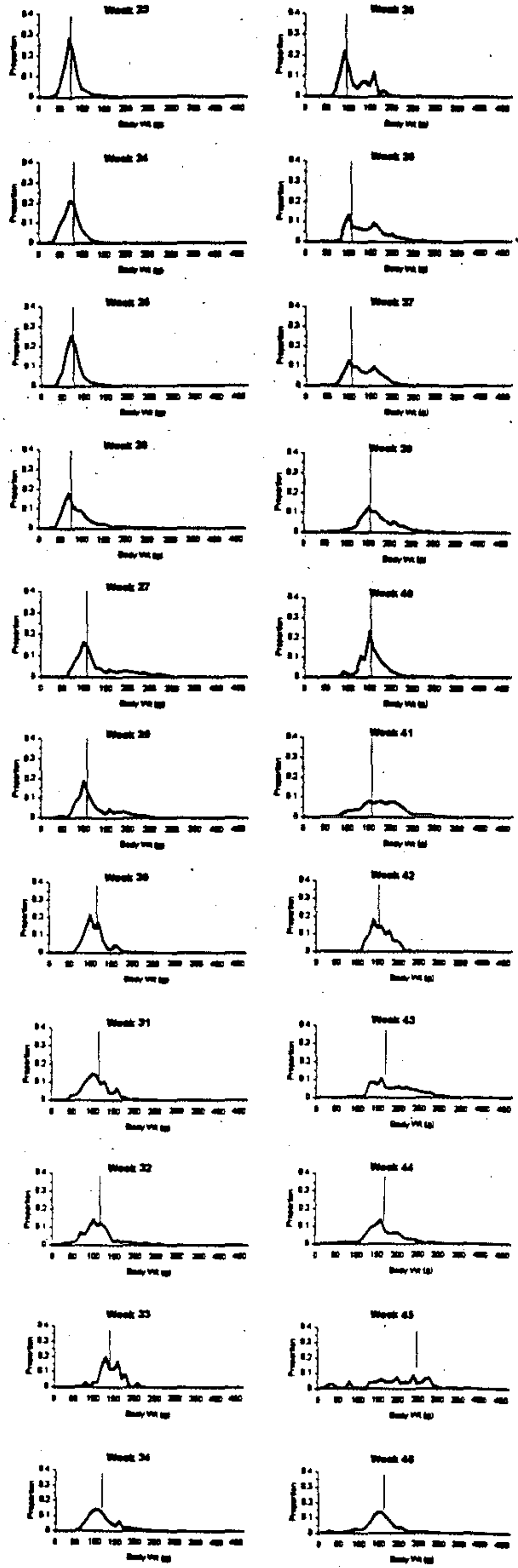


Figure D30. Proportion of *Illex* squid, by body weight (g) and week of the year, during 1996. Data source: *Illex* squid bottom trawl landings.

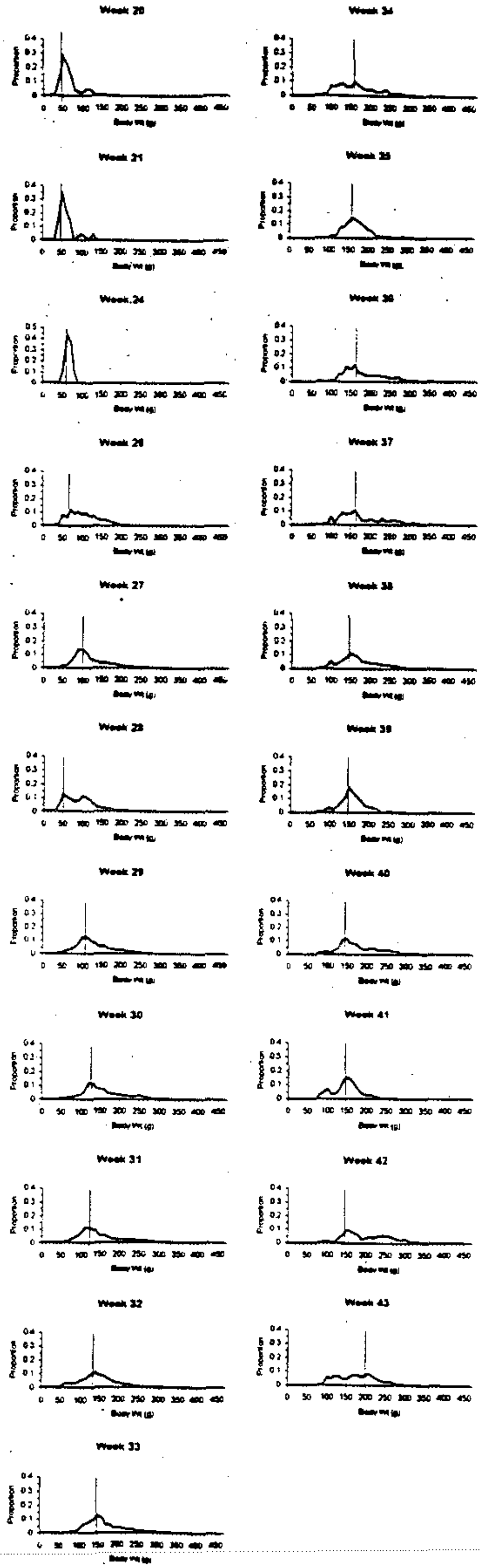



Figure D31. Proportion of *Illex* squid, by body weight (g) and week of the year, During 1997. Data source: *Illex* squid bottom trawl landings.

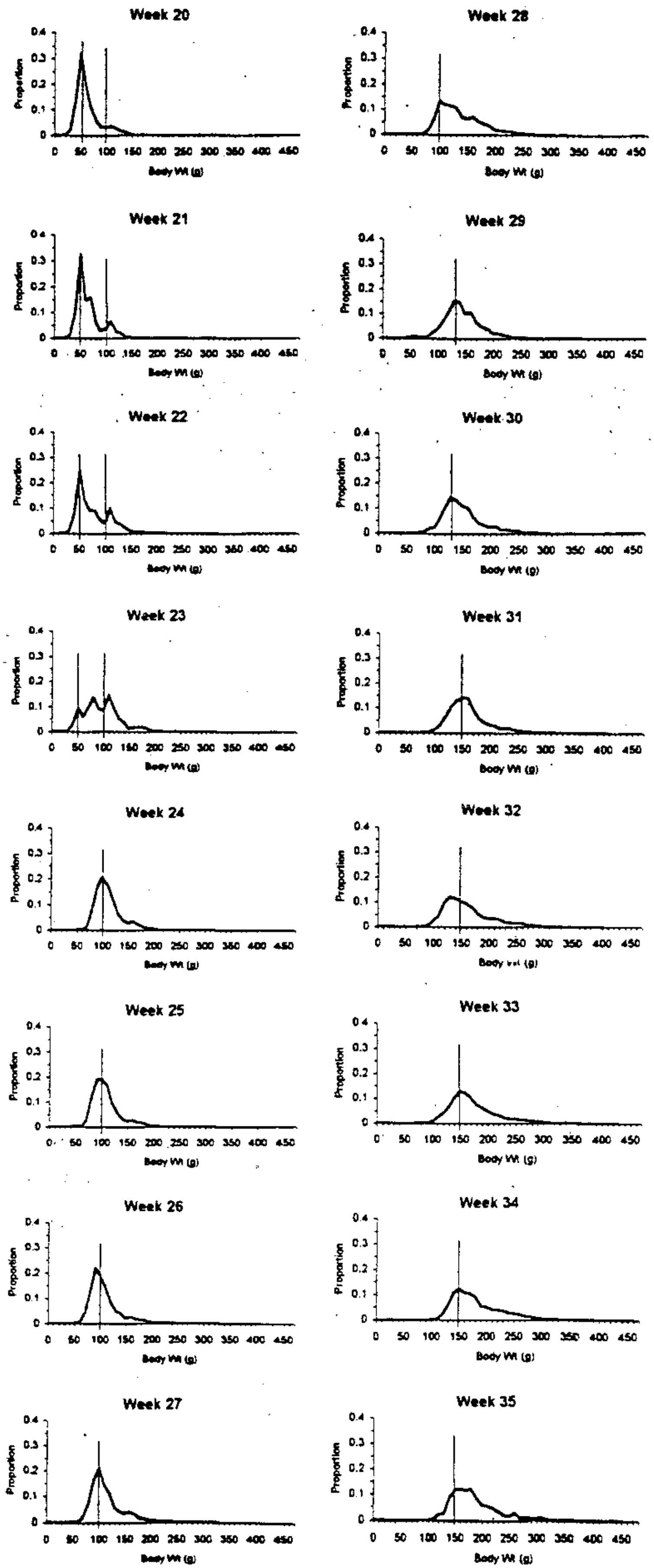



Figure D32. Proportion of *Illex* squid, by body weight (g) and week of the year, during 1998. Data source: *Illex* squid bottom trawl landings.

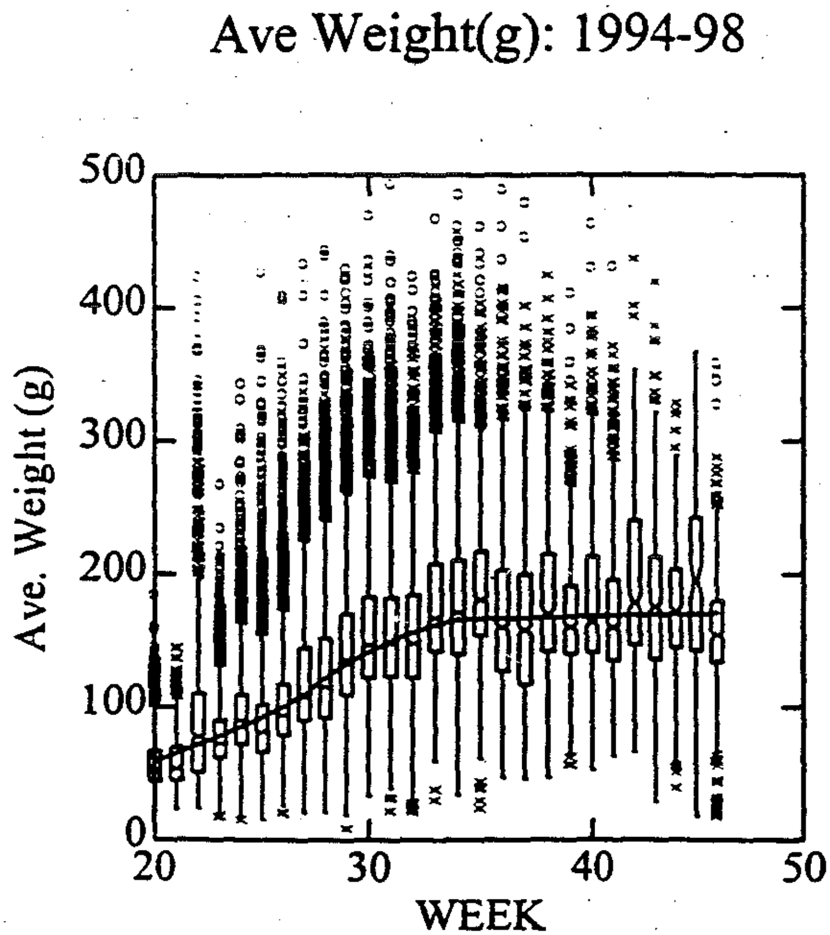



Figure D33. Box plots of the distribution of individual *Illex* weights obtained from industry-supplied measurements from landed squid, across weeks, with 1994-1998 observations pooled. The boxed illustrate the boundaries of the interquartile range and the notch in the middle represents the median value. The solid line

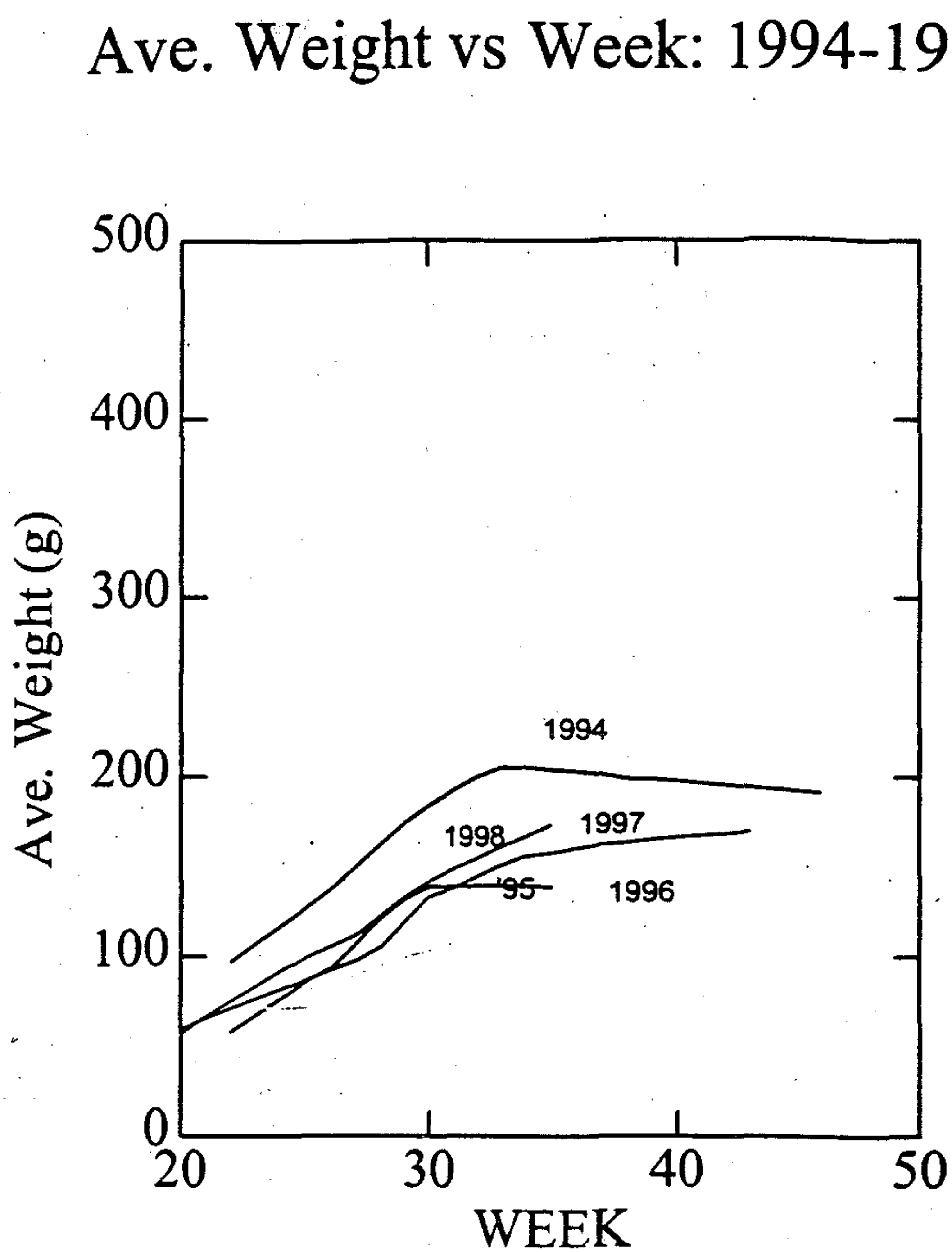



Figure D34. Lowess smoothed estimates of average weight of *Illex* weights across weeks for each year 1994 to 1998; tension factor = 0.5. Individual observations were not plotted to permit visualization of the overall pattern.

Landings per Unit Effort: 1994-98

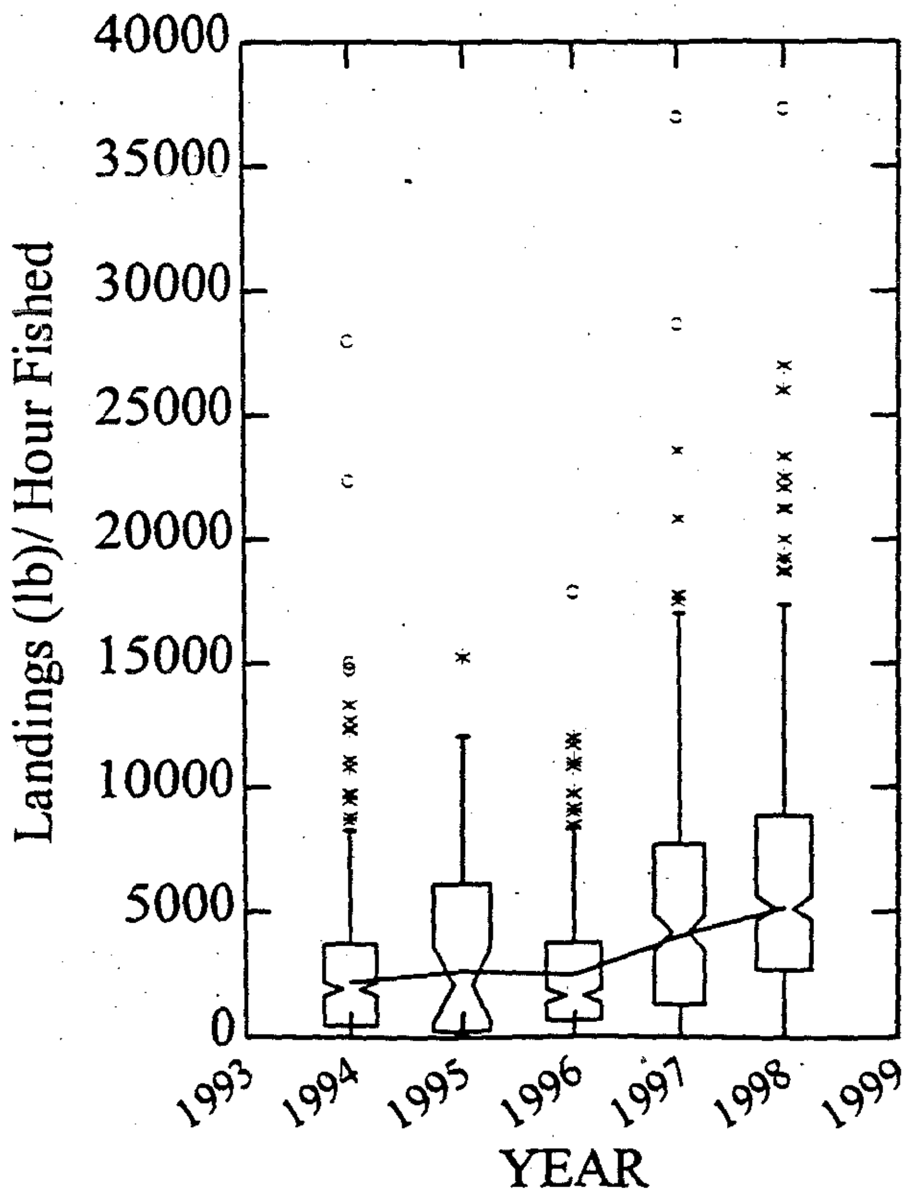



Figure D35. Box plots of the distribution landings (lb) per hour fished for commercial vessels, 1994-1998. Observations obtained from the "Vessel Trip Report" database. The boxes illustrate the boundaries of the interquartile range and the notch in the middle represents the median value. The solid line represents the lowess smooth of the observations; tension factor = 0.5.

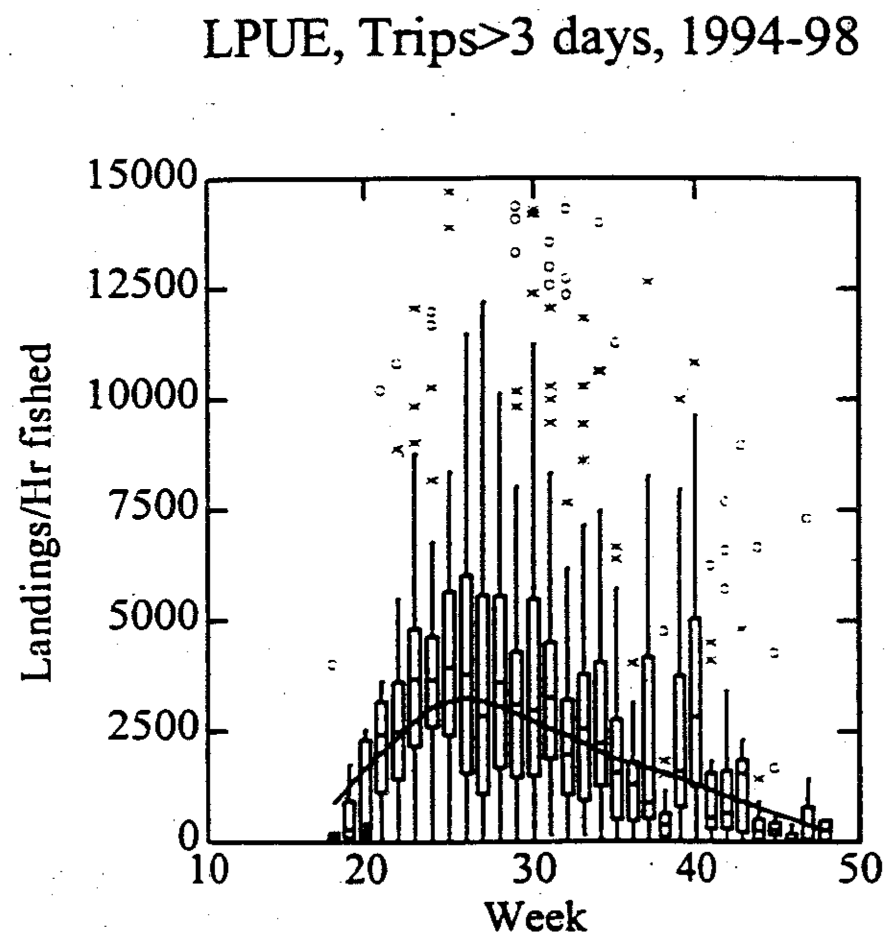



Figure D36. Box plots of the distribution landings (lb) per hour fished for commercial vessels, 1994-1998 pooled. Observations obtained from the "Vessel Trip Report" database and were restricted to trip durations greater than 3 days. The boxes illustrate the boundaries of the interquartile range and the notch in the middle represents the median value. The solid line represents the lowess smooth of the observations; tension factor = 0.5.

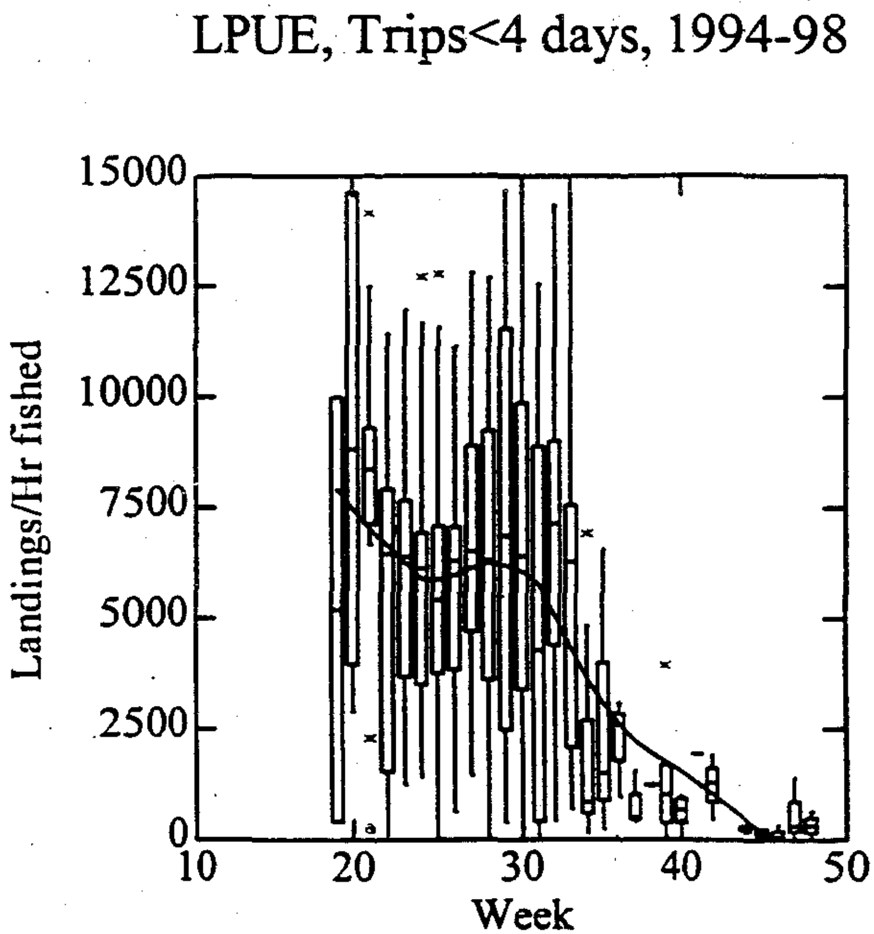



Figure D37. Box plots of the distribution landings (lb) per hour fished for commercial vessels, 1994-1998 pooled. Observations obtained from the "Vessel Trip Report" database and were restricted to trip durations greater than 4 days. The boxes illustrate the boundaries of the interquartile range and the notch in the middle represents the median value. The solid line represents the lowess smooth of the observations; tension factor = 0.5.

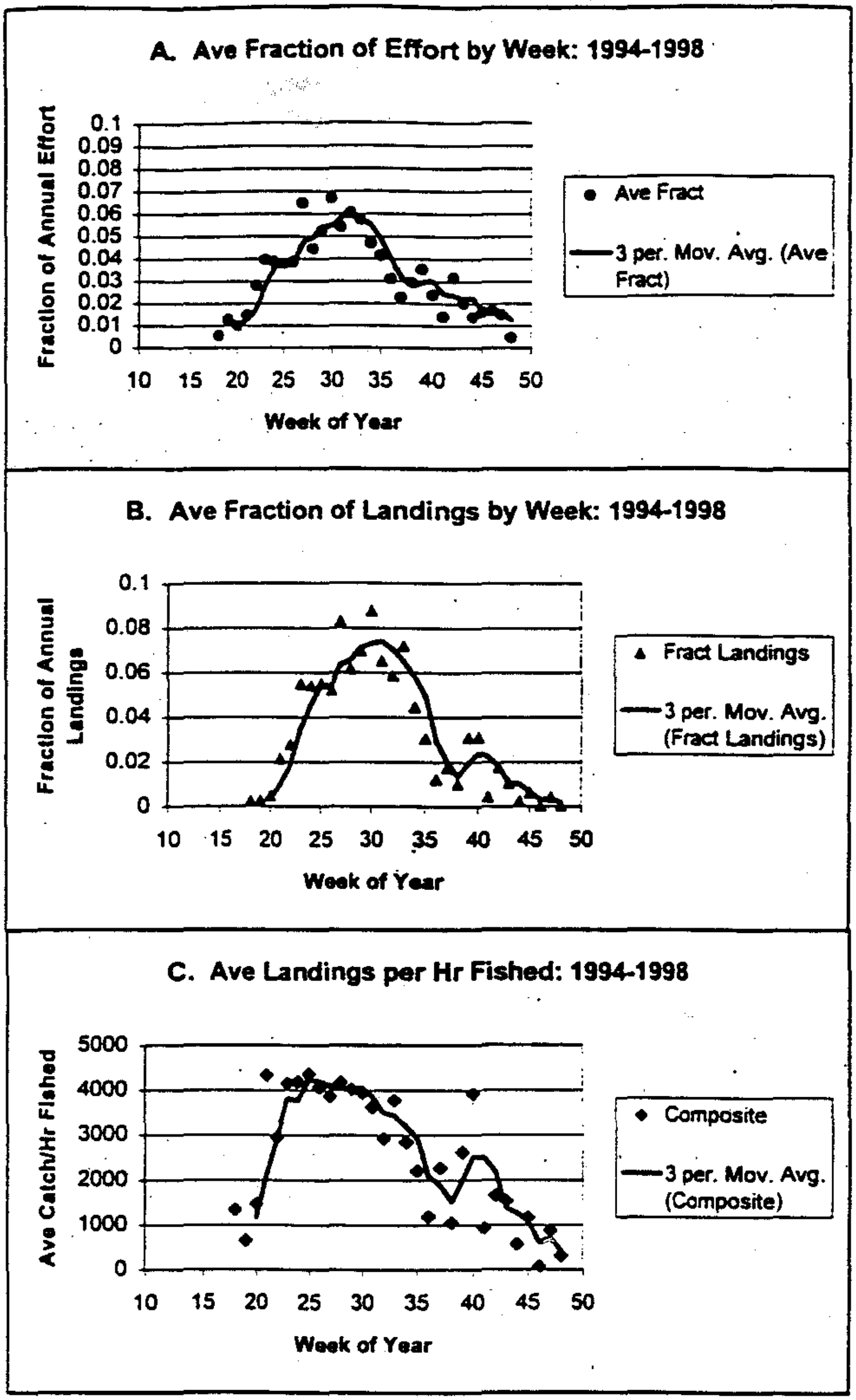
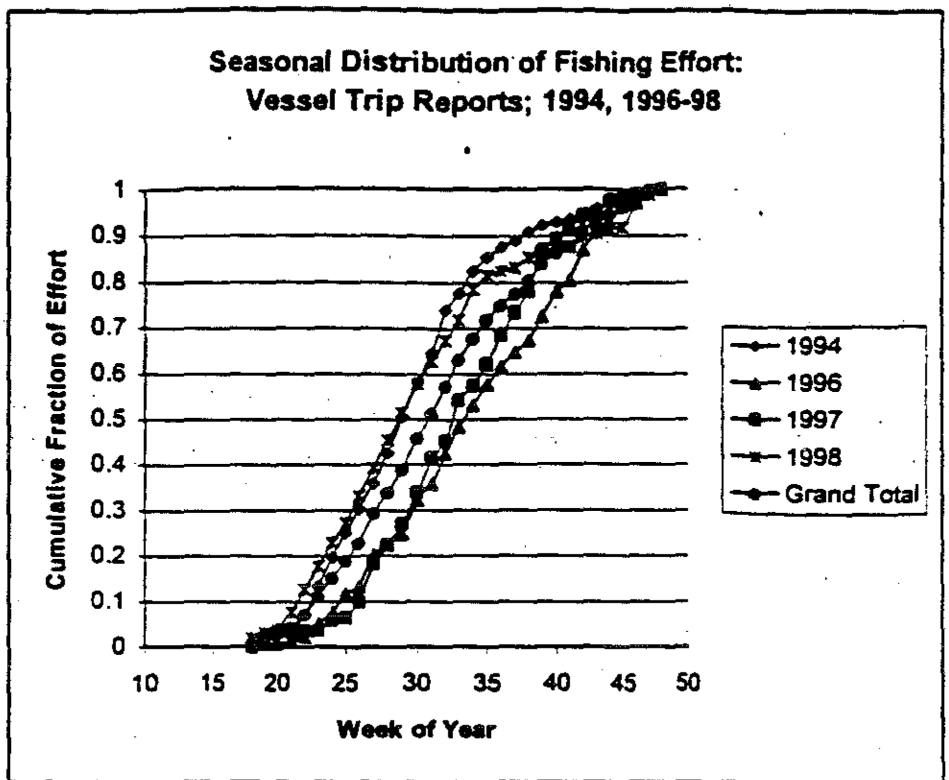



Figure D38. Summary of average seasonal fishing patterns (A) and landings (B) by week. Average landings per unit effort are based on ratio estimator of total landings to total effort.



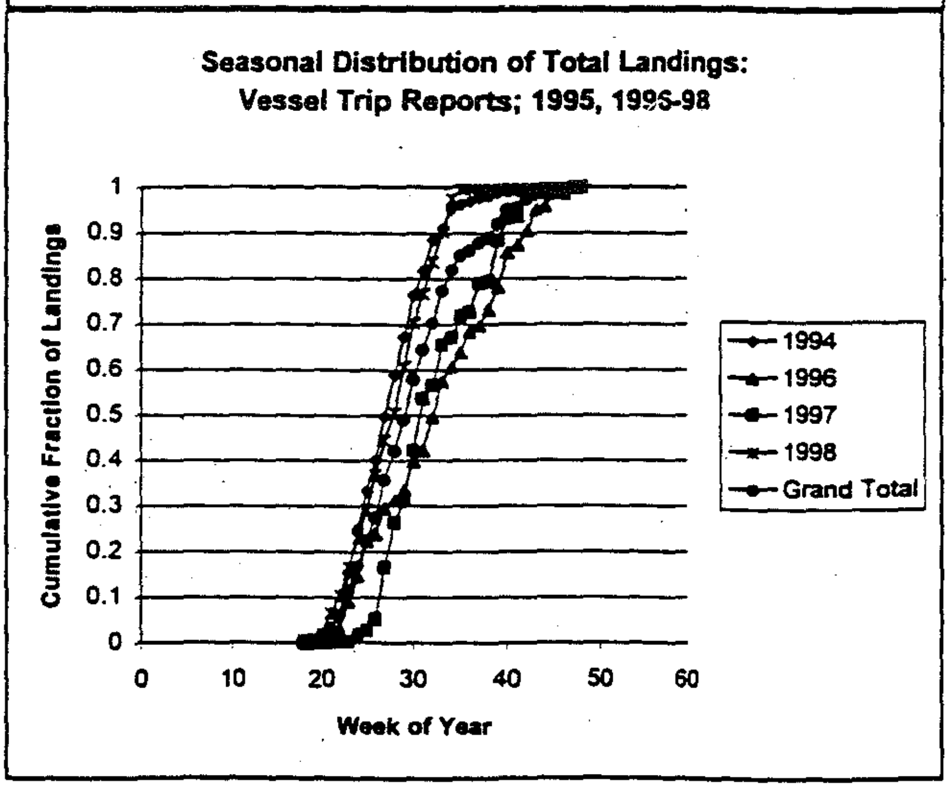
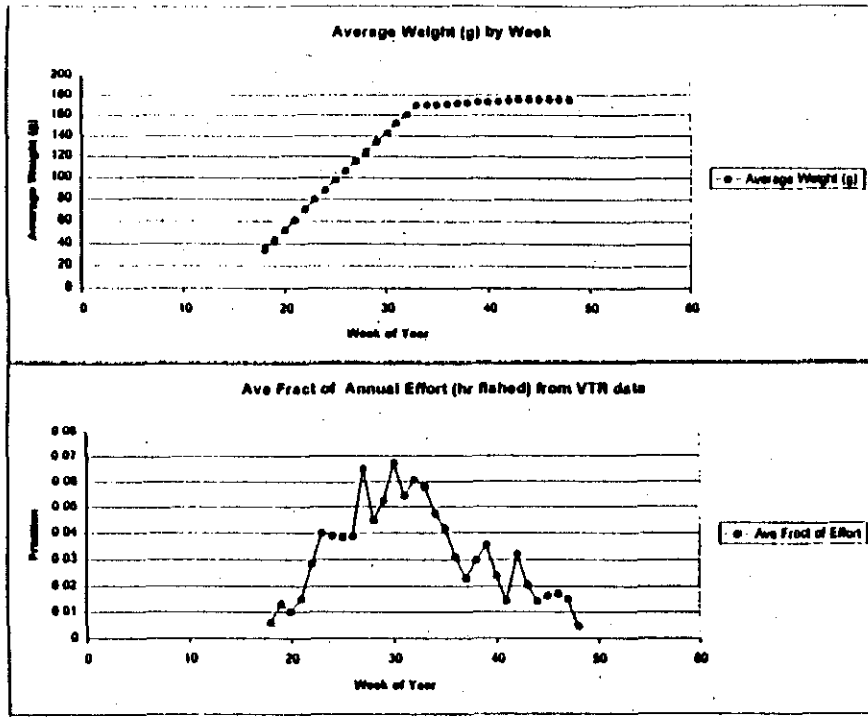



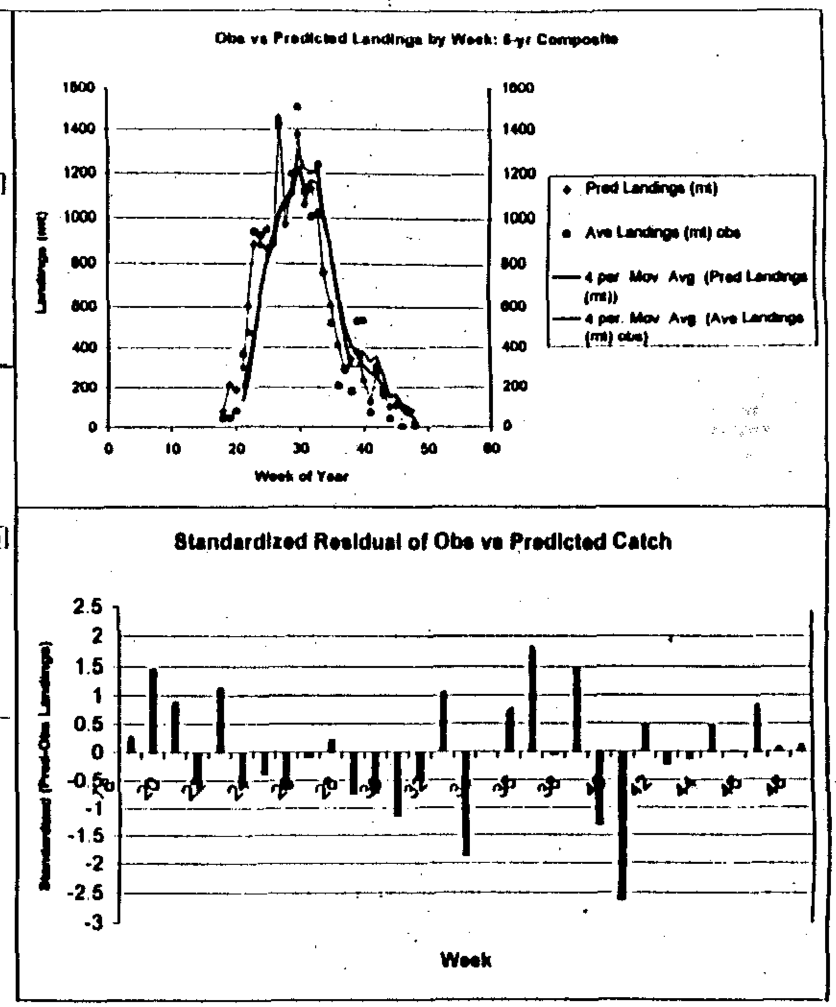

Figure D39. Comparison of seasonal distributions of fishing effort and landings for *Illex* squid fisheries in 1994, 1996-1998 based on Vessel trip reports. Data for 1995 were incomplete.

## Results for 1994-1998 Composite Fishery

### Model Inputs




### Observed vs Predicted Values




**Summary Statistics for Fishing Mortality Estimates for 5-yr Composite**

| Estimated Parameters | Value |
|---|---|
| Total F | 0.743064 |
| Initial Population | 5.57E+08 |

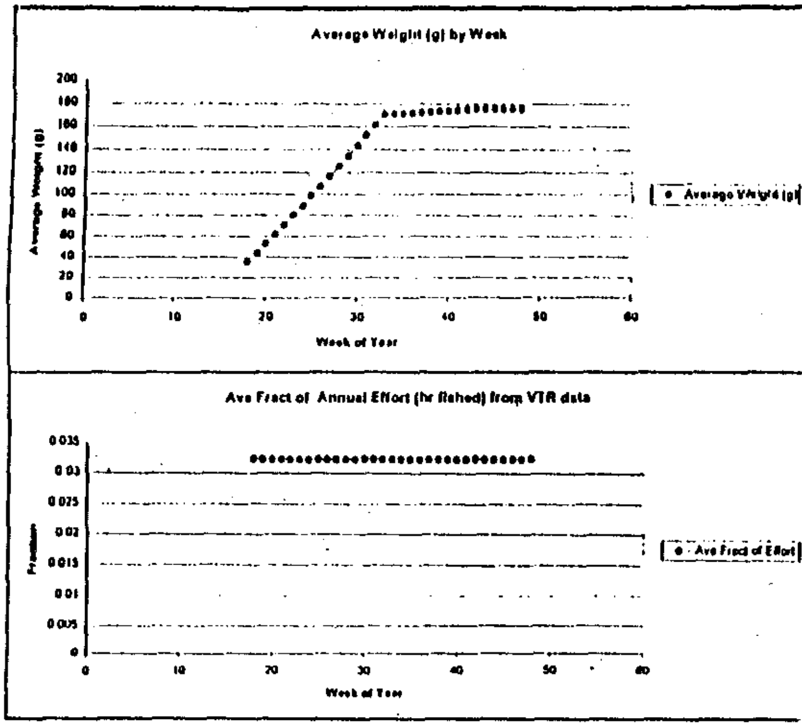
| | |
|---|---|
| Total Landings | 17142 |

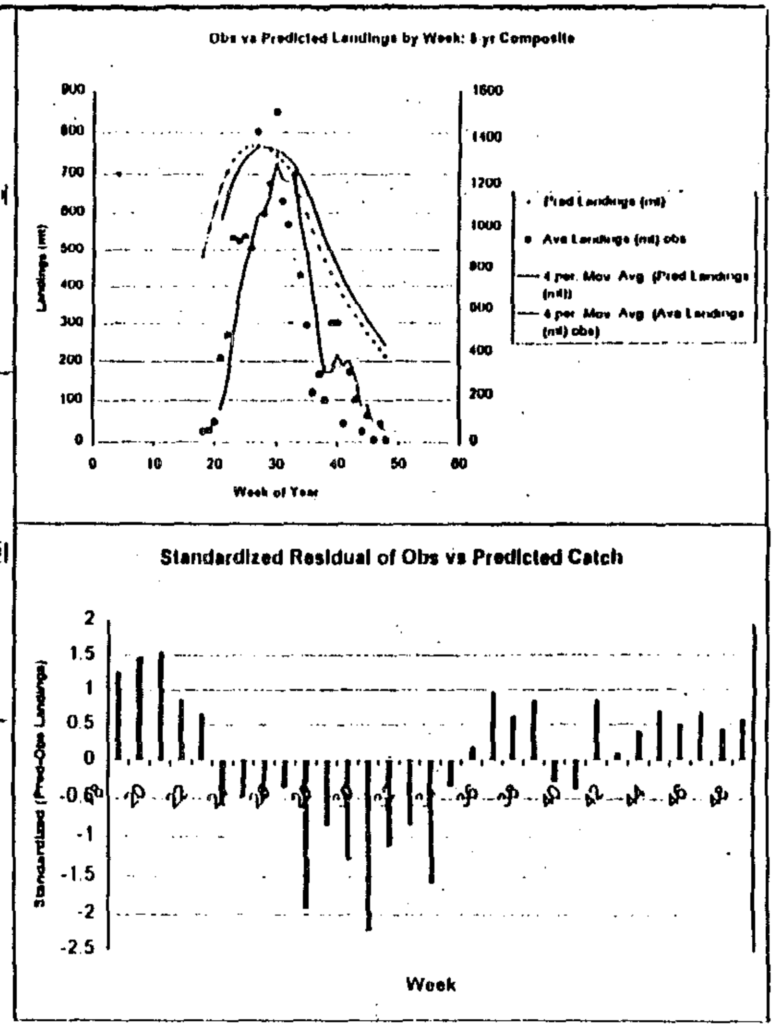
| | |
|---|---|
| Obj Fcn SSQ | 383032 |

Figure D40. Summary of model-based estimates of average population size and total fishing mortality rate for *Illex*. Model inputs are based on average patterns of mean weight (upper left) and annual effort (lower left0 by week for the period 1994-98. Model results are compared to observed values (upper right0 both as point estimates and as 4-point moving averages. Standardized residuals are summarized in the lower right graph.

## Null Model: Constant Monthly F; 1994-1998 Composite Fishery

**Model Inputs** | **Observed vs Predicted Values**




**Summary Statistics for Fishing Mortality Estimates for 5-yr Composite**

| Estimated Parameters | Value |
|---|---|
| Catchability q | 0.644251 |
| Initial Population | 6.88E+08 |

| | |
|---|---|
| Total Landings | 17142 |

| | |
|---|---|
| Obj Fcn SSQ | 3430660 |

Figure D41. Summary of model-based estimates of average population size and total fishing mortality rate for *Illex*. Model inputs are based on average patterns of mean weight (upper left) and annual effort (lower left) by week for the period 1994-98 and a hypothetical uniform distribution of effort (lower left) by week. Model results are compared to observed values (upper right) both as point estimates and as 4-point moving averages. Standardized residuals are summarized in the lower right graph.

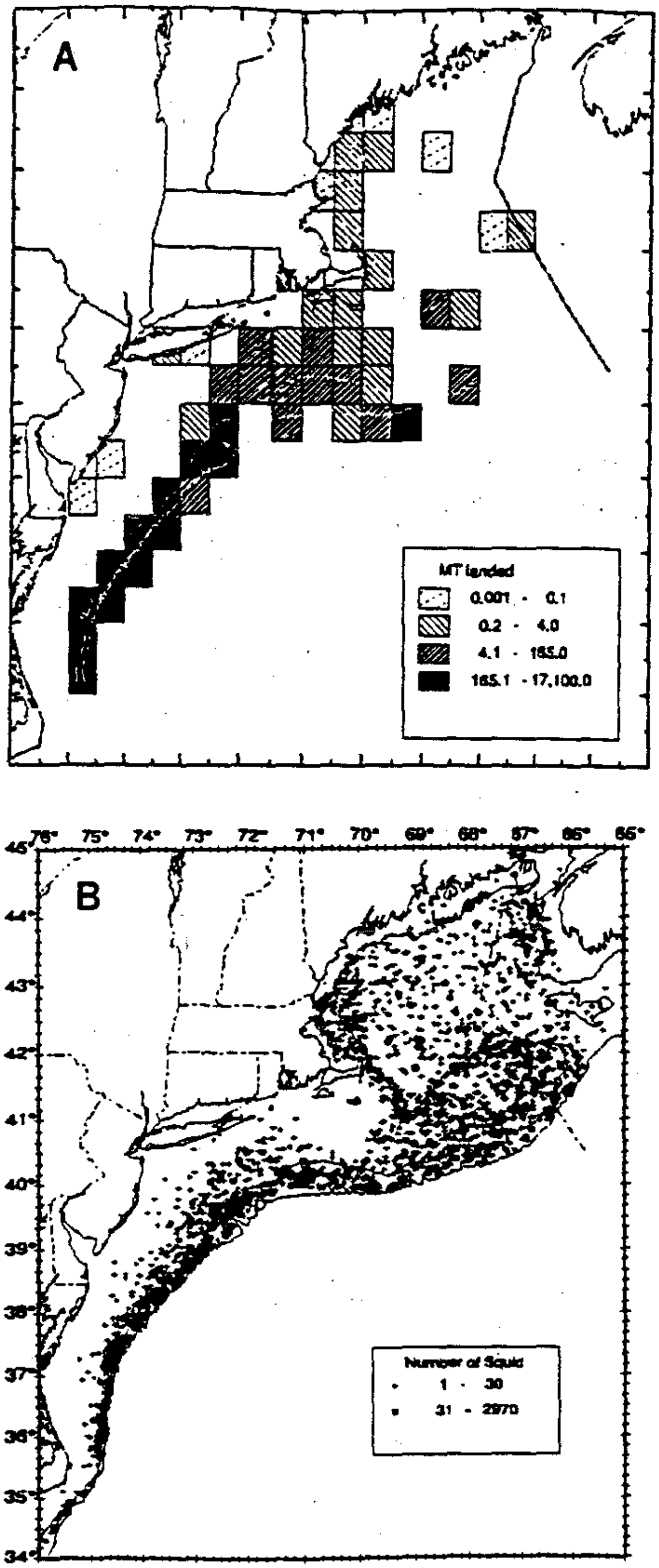



Figure D42. U.S. EEZ *Illex illecebrosus* fishery areas, (A) 1991-1993 landings (mt) by quarter-degree square, and (B) *Illex* habitat during NEFSC autumn bottom trawl surveys (1982-1998).

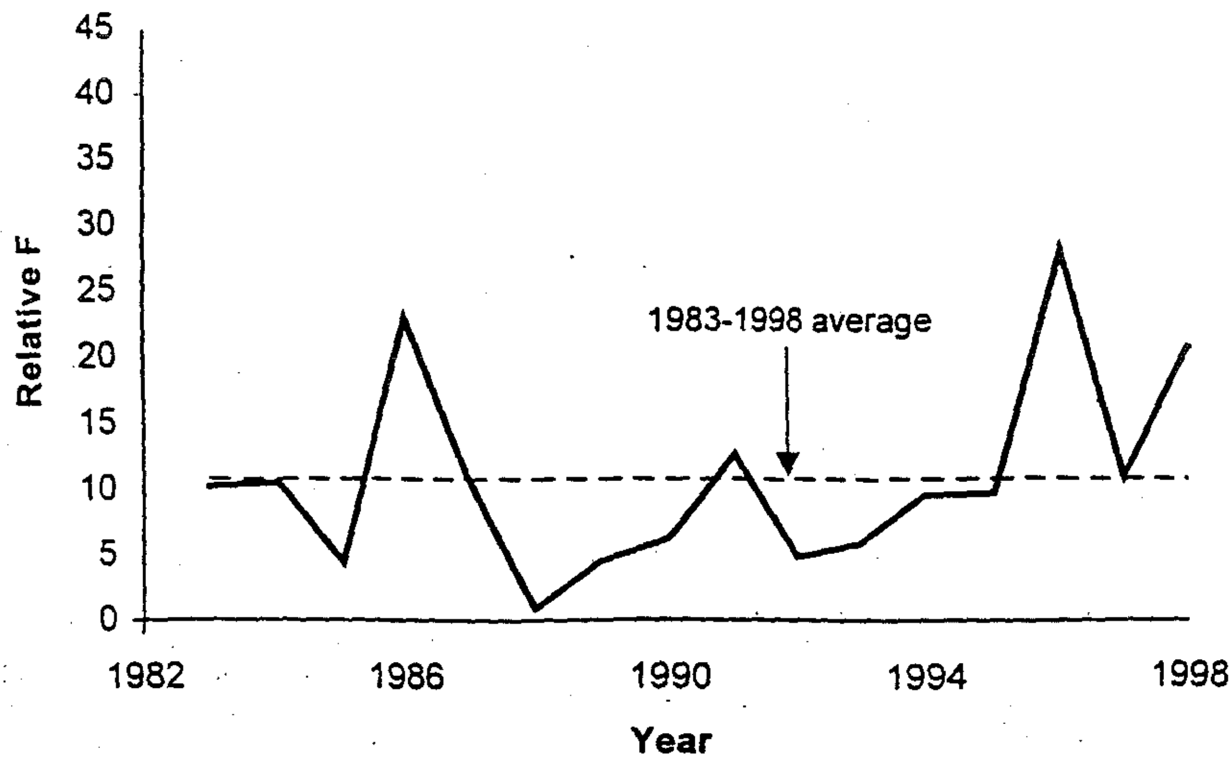



Figure D43. Trends in relative fishing mortality rates for the *Illex illecebrosus* stock (SA 3-6 landings/average of SA 4 July and SA 5+6 survey biomass indices), during 1983-1998.

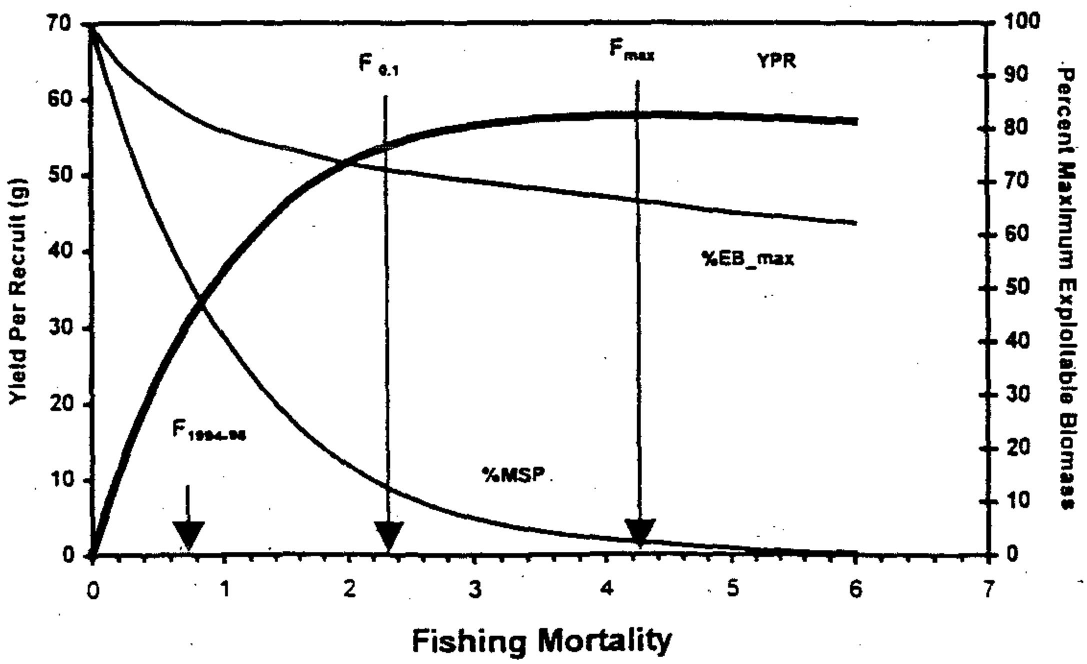



Figure D44. Yield-per-recruit (YPR) and exploitable biomass-per-recruit based on 1994-1998 weekly exploitation pattern in the U.S. EEZ *Illex illecebrosus* bottom trawl fishery.

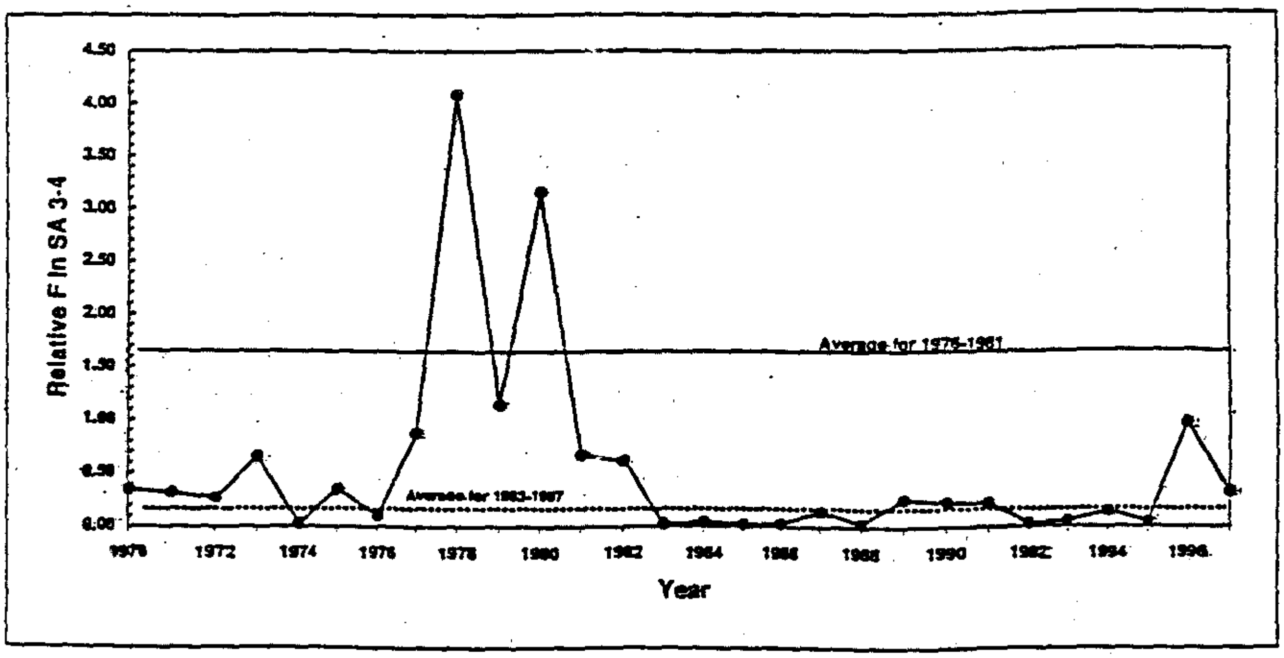



Figure D45. Relative Fishing Mortality Rate of *Illex* squid in SA3-4, 1970-1997.
Source: Rivard et.al. (1998).

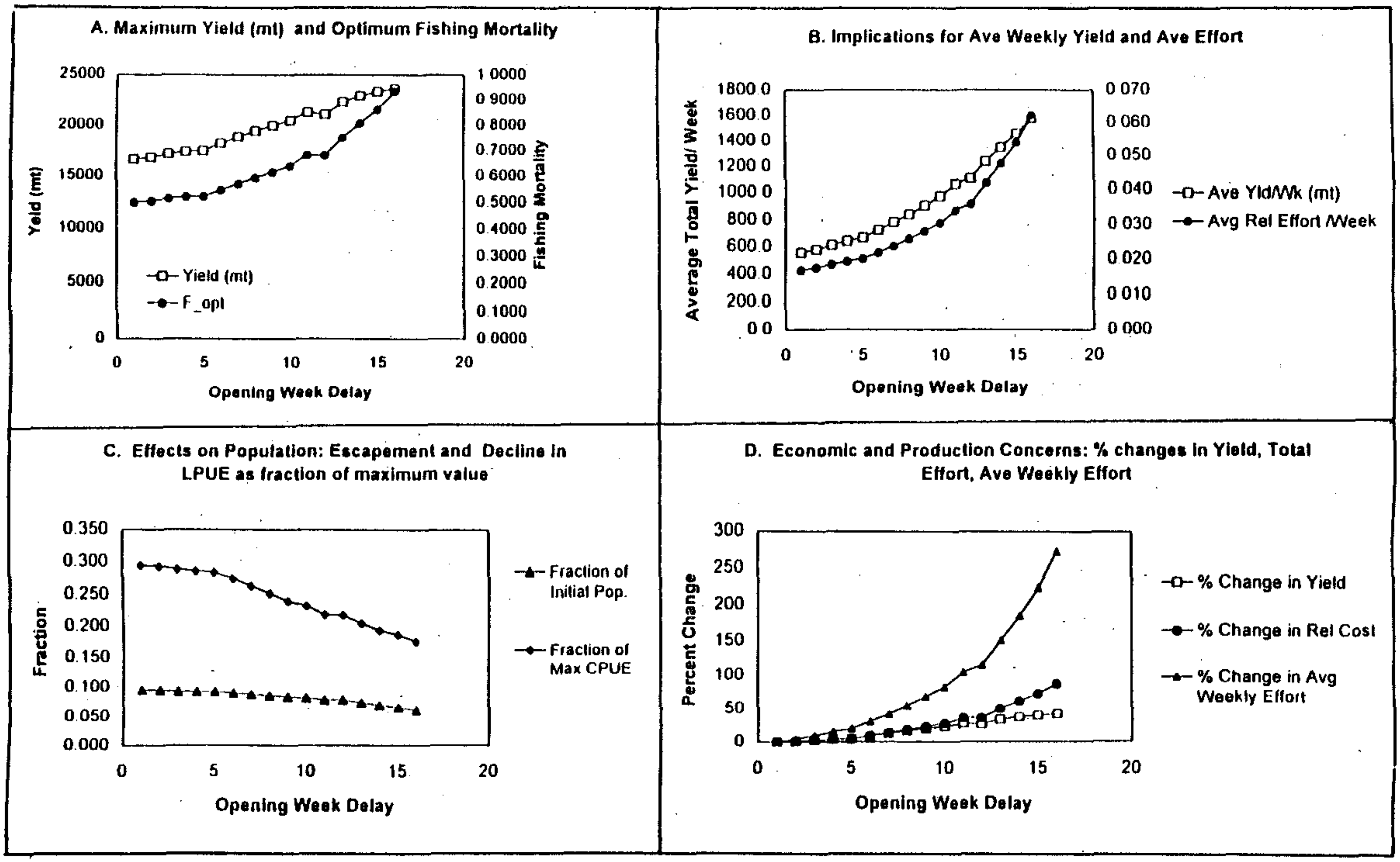



Figure D46. Scenario 1: Maximum yields and optimum fishing mortality rates for *Illex* fishery under a constant number policy in which the residual population at the end of the fishing season is set equal to the predicted population for the baseline model. This policy is equivalent to a minimum LPUE threshold in which fishing ceases when harvest rates fall below a fixed value.

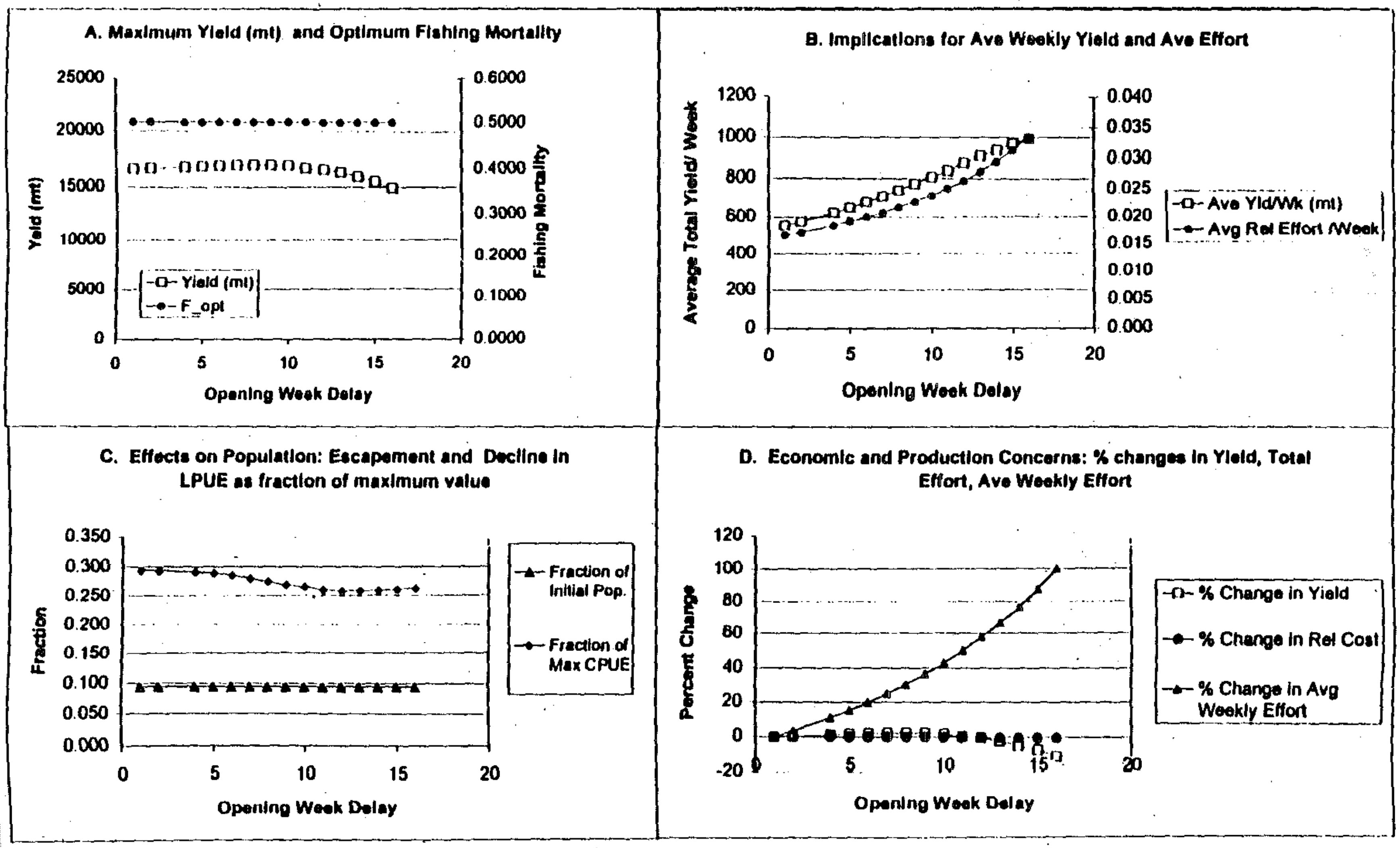



Figure D47. Scenario 2: Maximum yields and optimum fishing mortality rates for *Illex* fishery under a constant ESCAPEMENT policy in which the residual population at the end of the fishing season is set equal to the predicted population for the baseline model. This policy is equivalent to a minimum LPUE threshold in which fishing ceases when harvest rates fall below a fixed value.

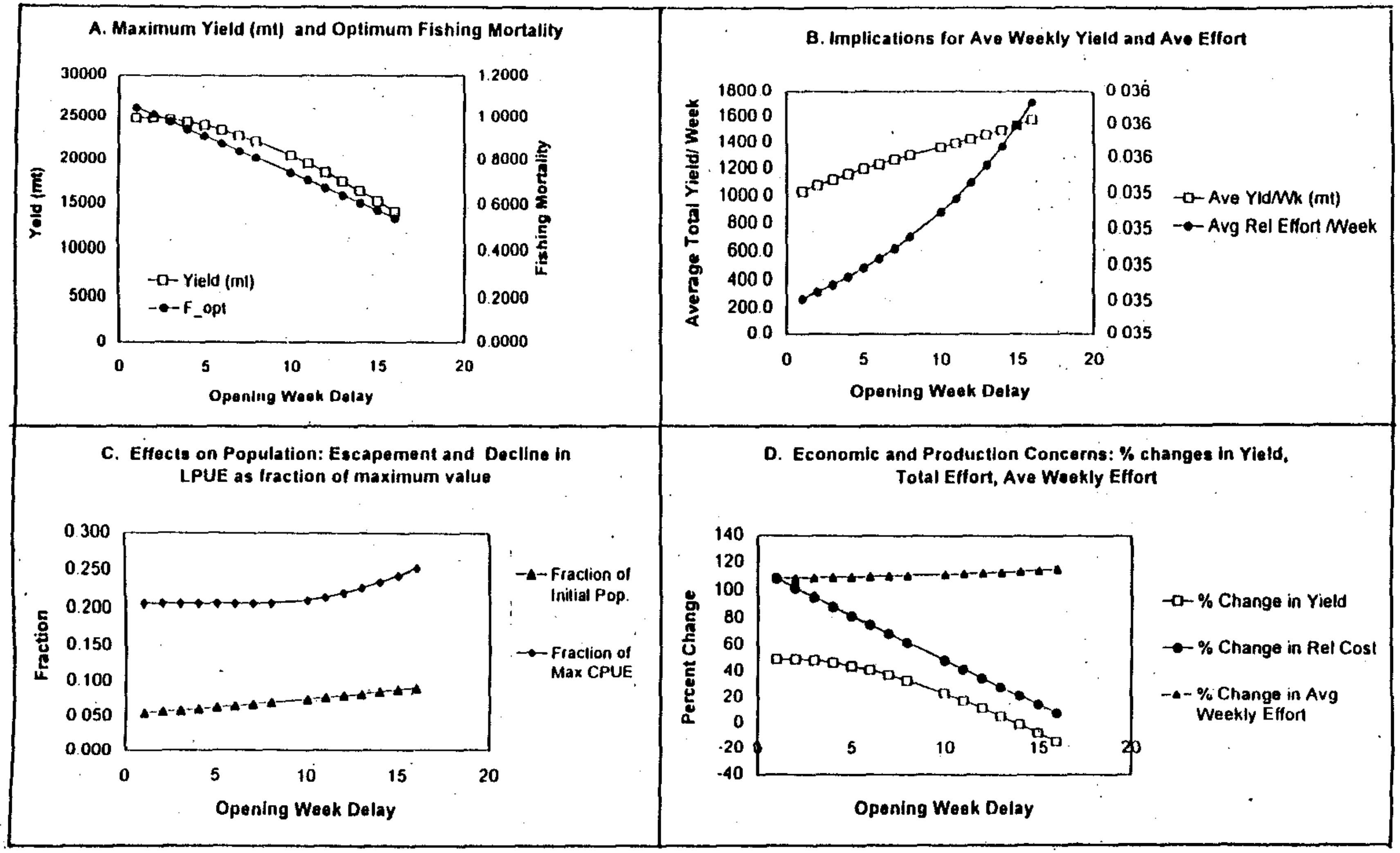



Figure D48. Scenario 3: Maximum yields and optimum fishing mortality rates for *Illex* fishery in which the weekly fishing mortality rate is limited by harvesting capacity. In this case, it is assumed that fishing time cannot exceed twice the long-term maximum fraction of effort for the period 1995-1998 from Vessel Trip Reports.

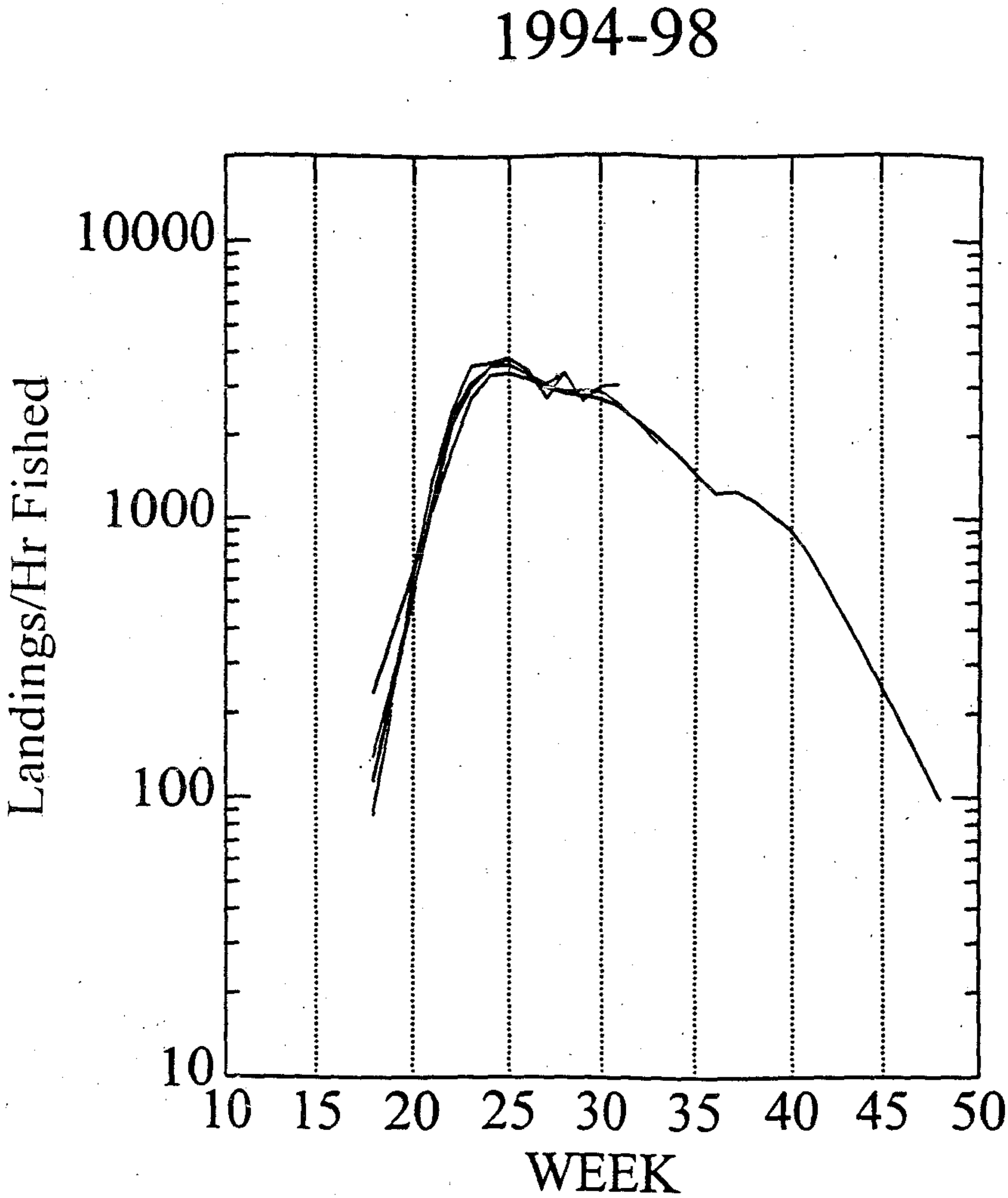



Figure D49. Lowess smooth of landings per unit effort (log scale) for the composite 1994-98 period; tension factor = 0.5. Individual observations not plotted to facilitate visualization. Lowess smooth lines are also plotted for the truncated series in which the time series is successively truncated with the terminal data point in week 33 or earlier. Agreement between the lowess smooth for the overall plot and the truncated series indicates an ability to detect in-season changes in landings per unit effort.

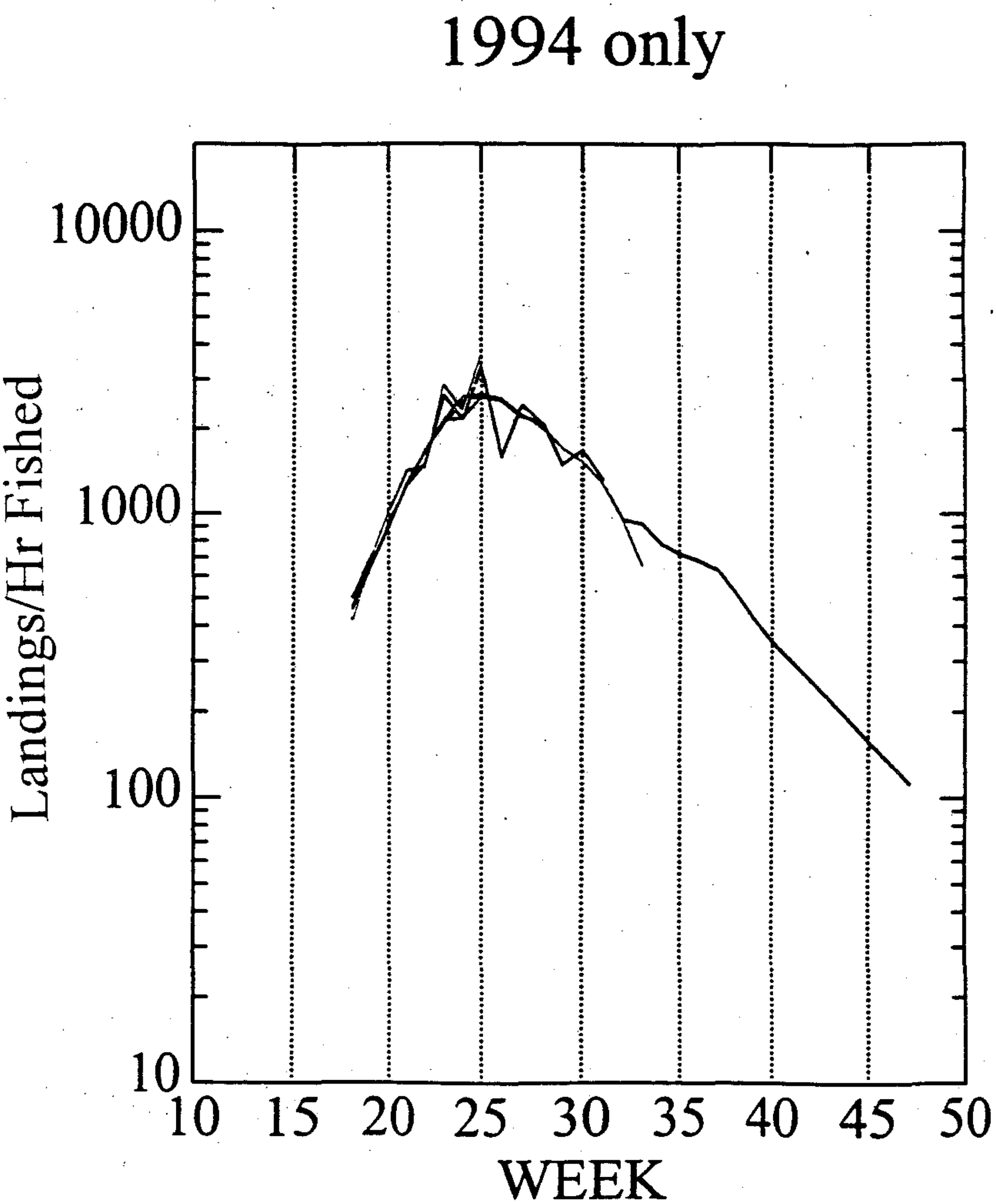



Figure D50. Lowess smooth of landings per unit effort (log scale) for the composite 1994 only; tension factor = 0.5. Individual observations not plotted to facilitate visualization. Lowess smooth lines are also plotted for the truncated series in which the time series is successively truncated with the terminal data point in week 33 or earlier. Agreement between the lowess smooth for the overall plot and the truncated series indicates an ability to detect in-season changes in landings per unit effort.

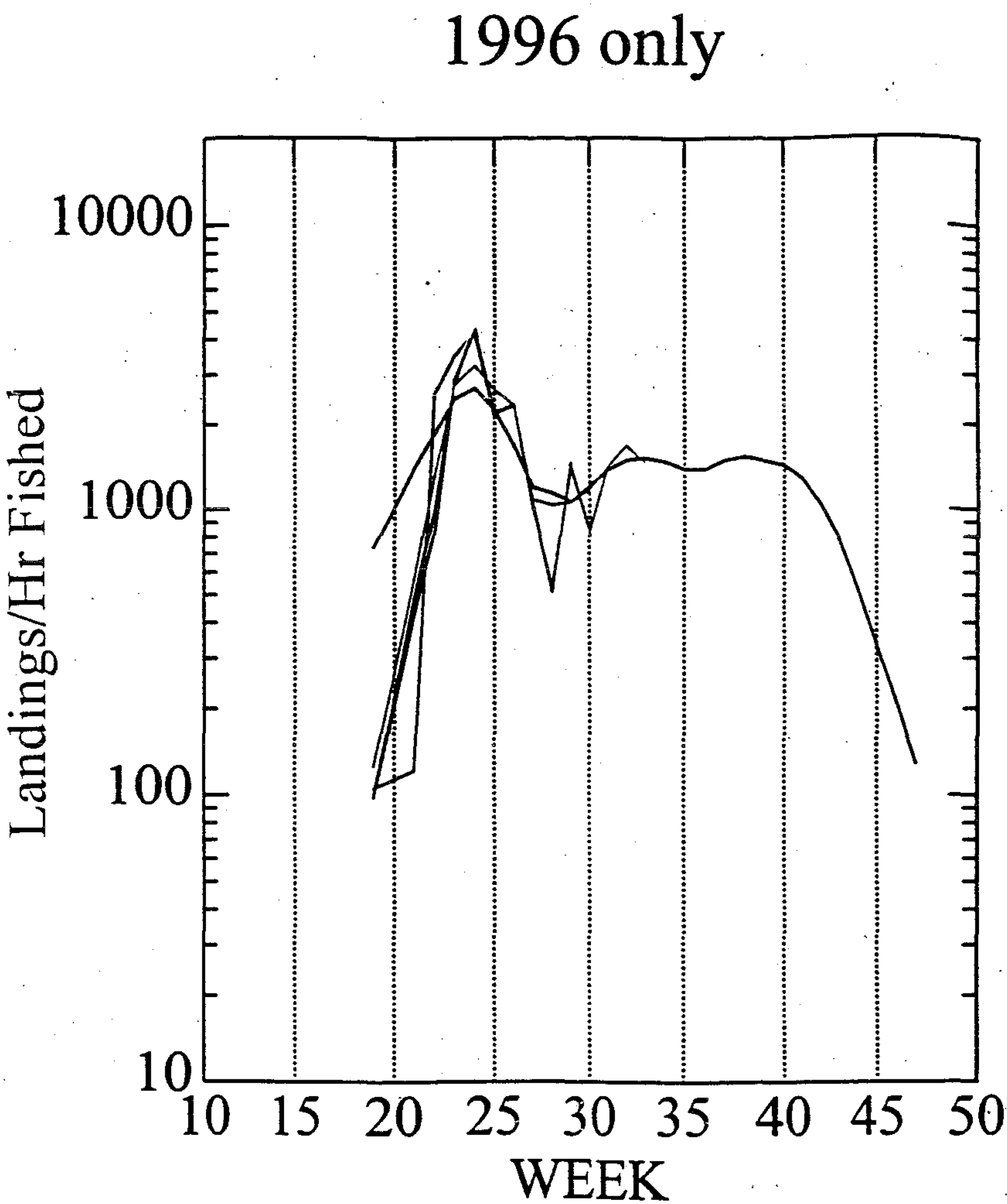



Figure D51. Lowess smooth of landings per unit effort (log scale) for the composite 1996 only; tension factor = 0.5. Individual observations not plotted to facilitate visualization. Lowess smooth lines are also plotted for the truncated series in which the time series is successively truncated with the terminal data point in week 33 or earlier. Agreement between the lowess smooth for the overall plot and the truncated series indicates an ability to detect in-season changes in landings per unit effort.

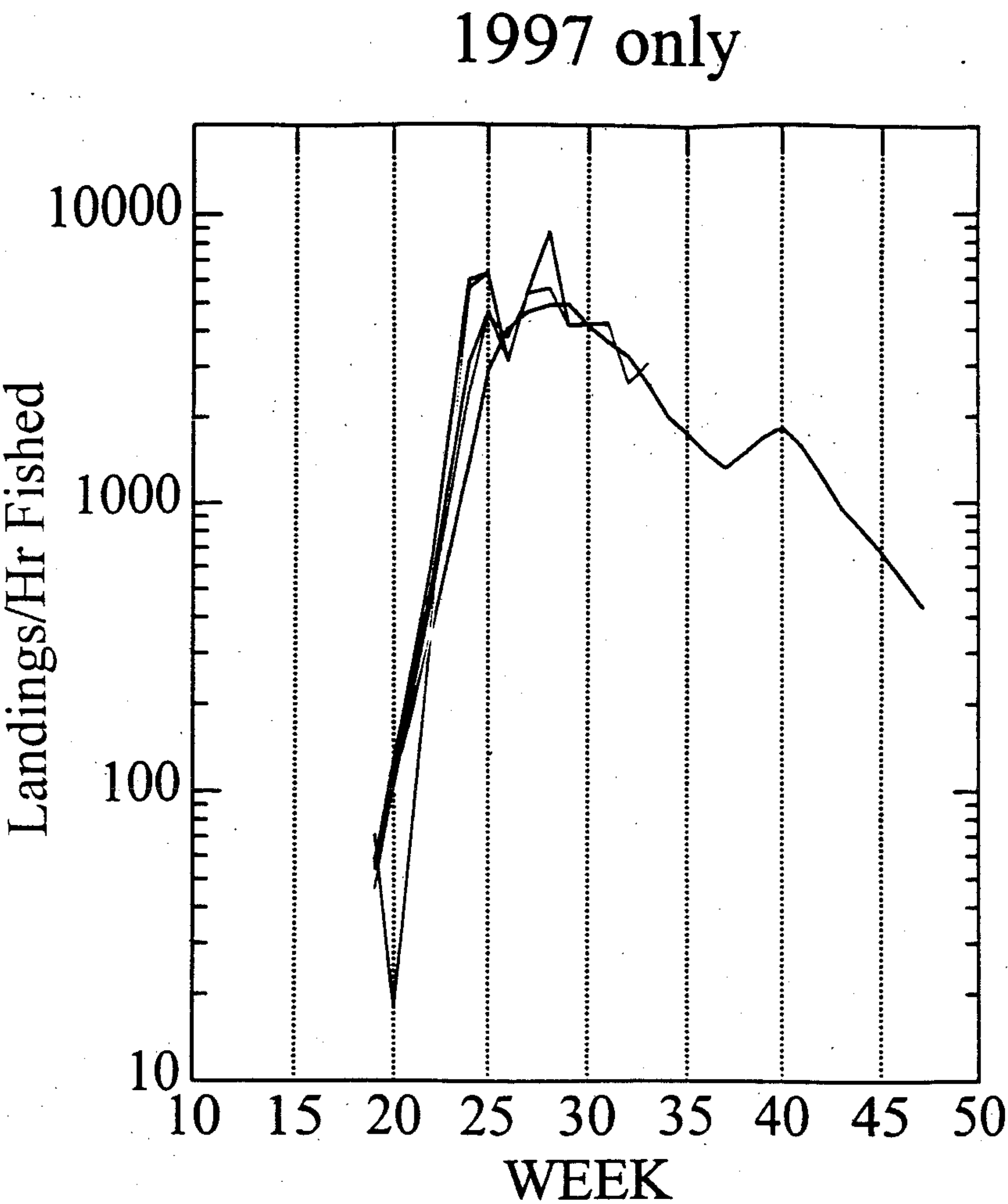



Figure D52. Lowess smooth of landings per unit effort (log scale) for the composite 1997 only; tension factor = 0.5. Individual observations not plotted to facilitate visualization. Lowess smooth lines are also plotted for the truncated series in which the time series is successively truncated with the terminal data point in week 33 or earlier. Agreement between the lowess smooth for the overall plot and the truncated series indicates an ability to detect in-season changes in landings per unit effort.

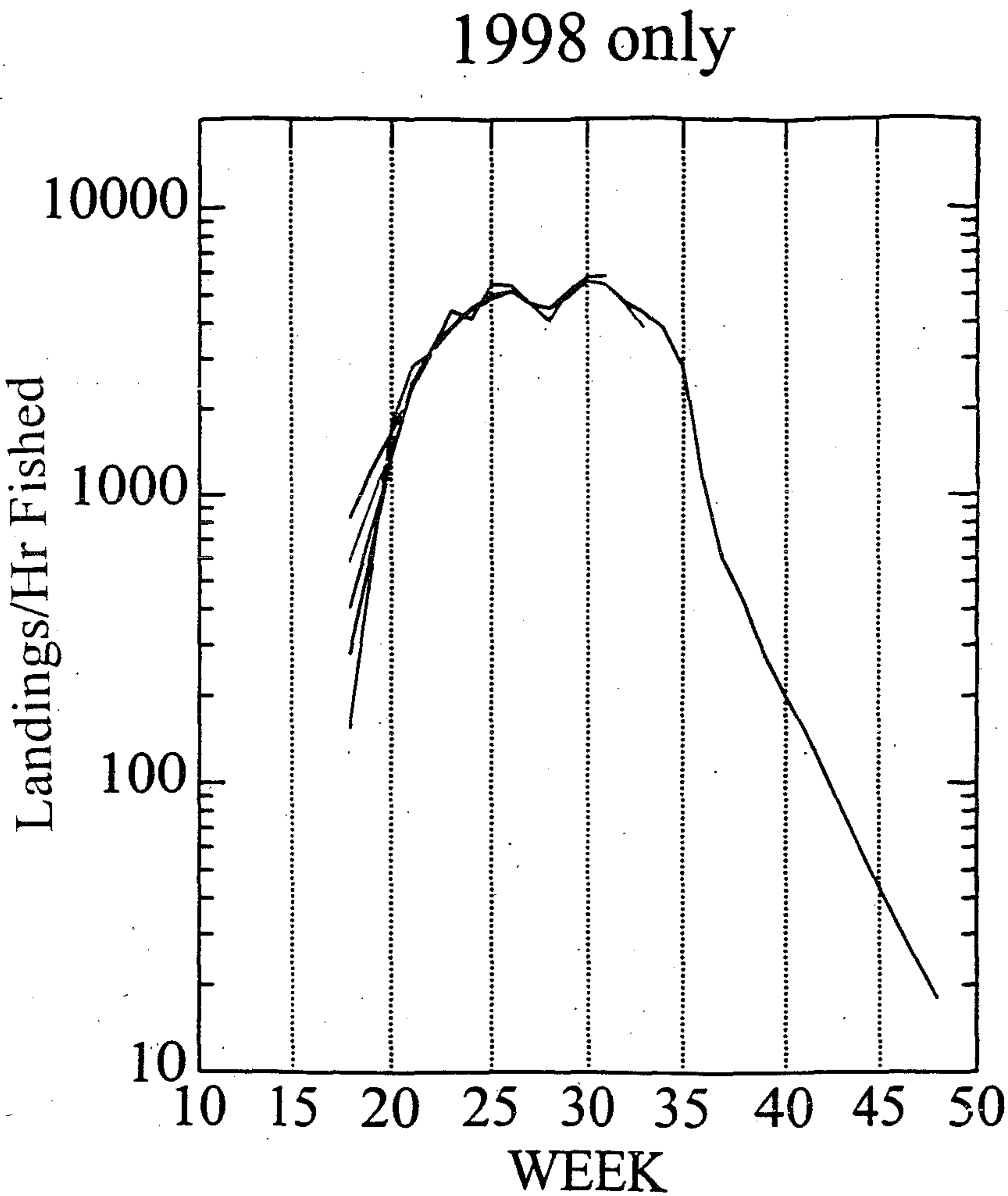



Figure D53. Lowess smooth of landings per unit effort (log scale) for the composite 1998 only; tension factor = 0.5. Individual observations not plotted to facilitate visualization. Lowess smooth lines are also plotted for the truncated series in which the time series is successively truncated with the terminal data point in week 33 or earlier. Agreement between the lowess smooth for the overall plot and the truncated series indicates an ability to detect in-season changes in landings per unit effort.

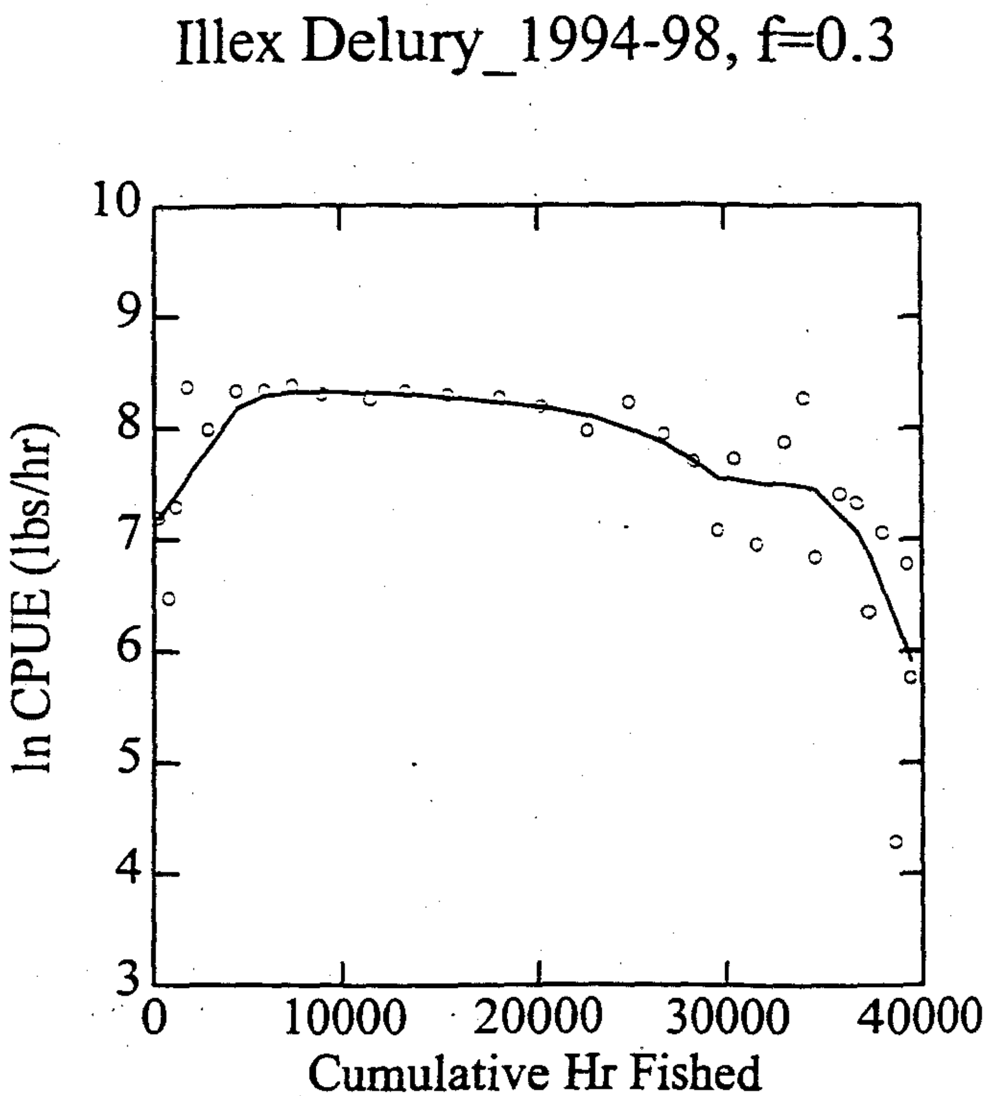



Figure D54. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the composite 1994-98 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

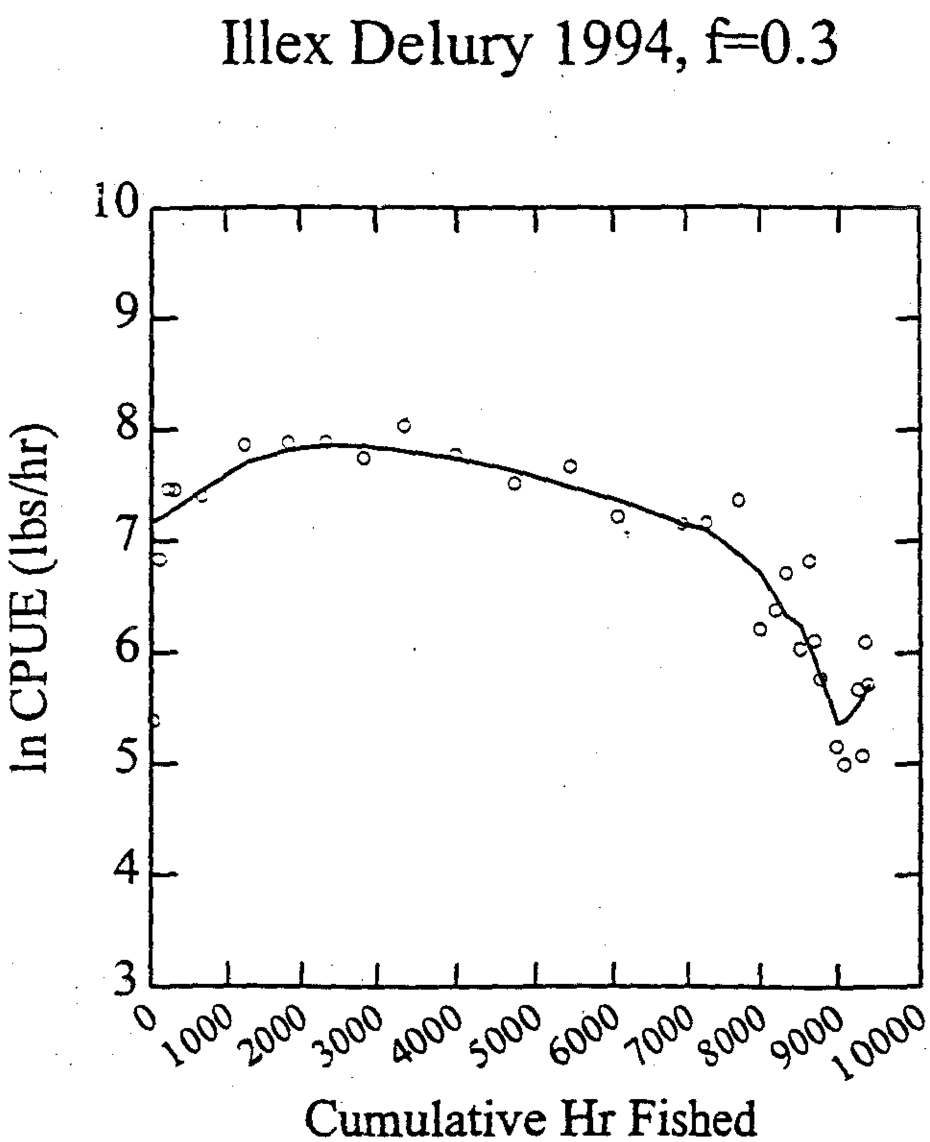



Figure D55. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the 1994 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

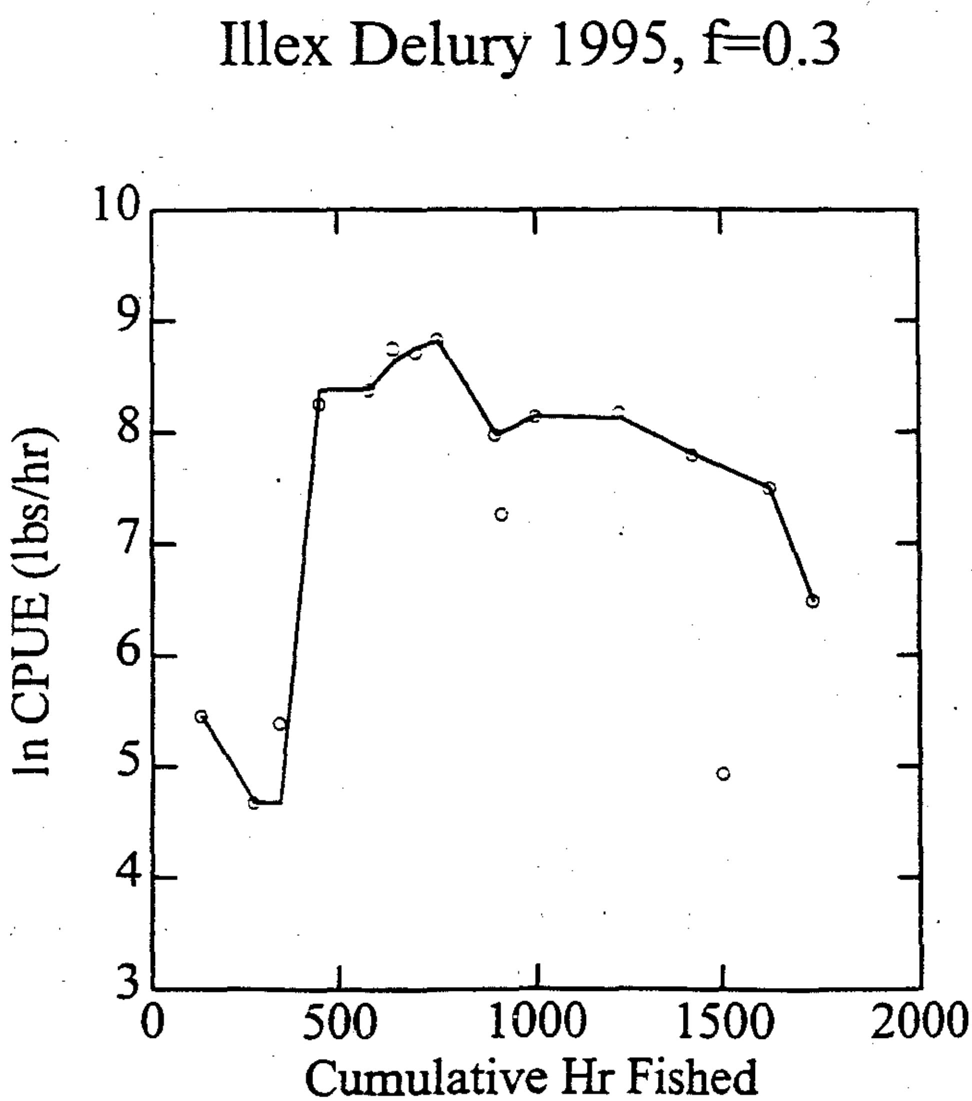



Figure D56. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the 1995 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

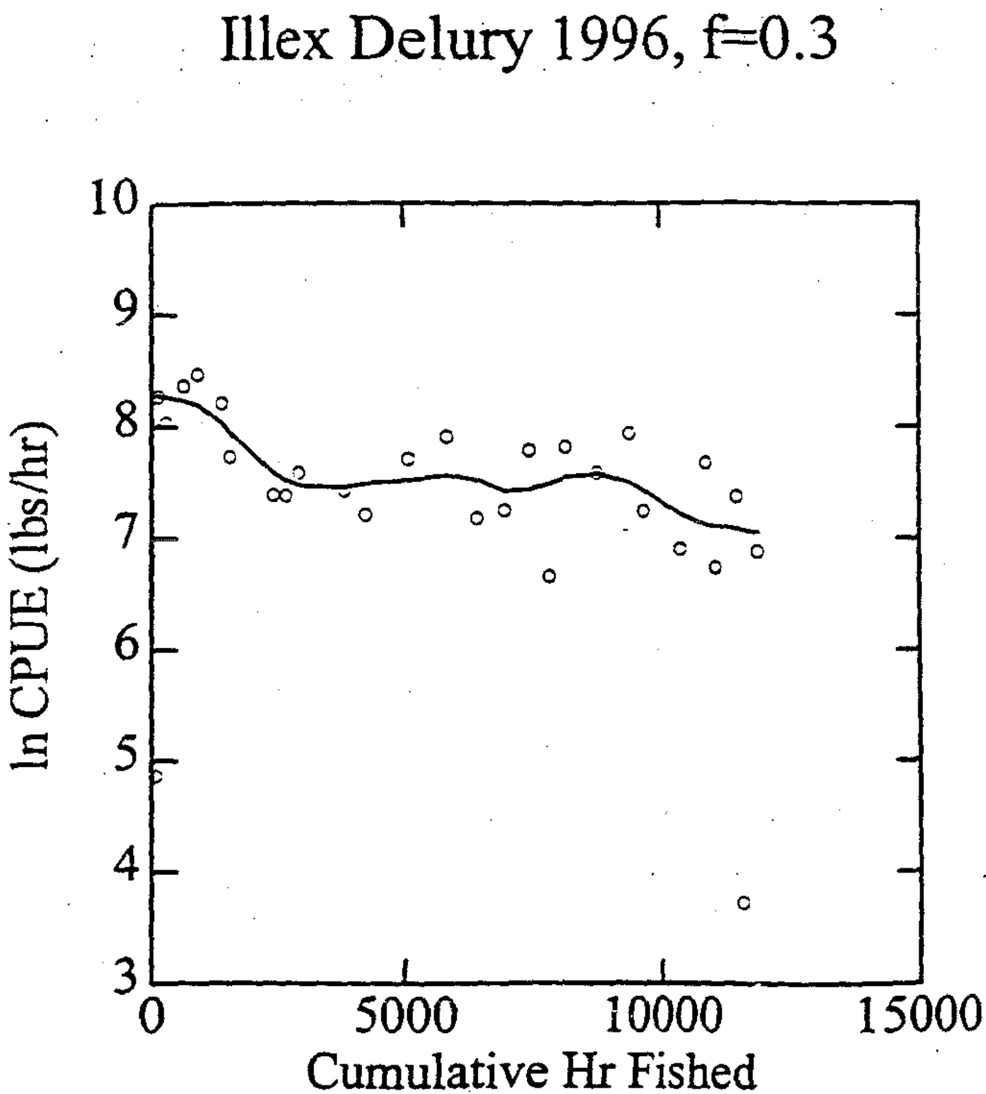



Figure D57. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the 1996 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

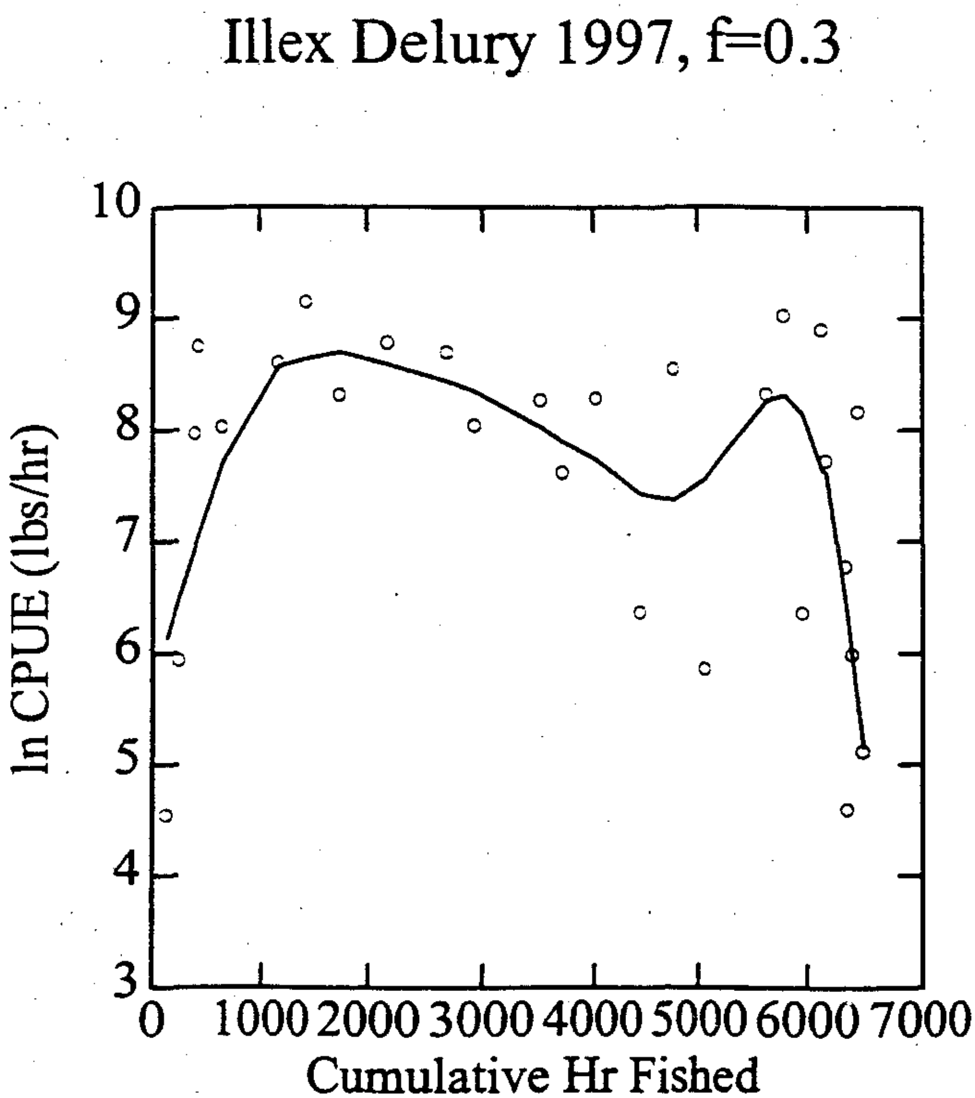



Figure D58. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the 1997 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

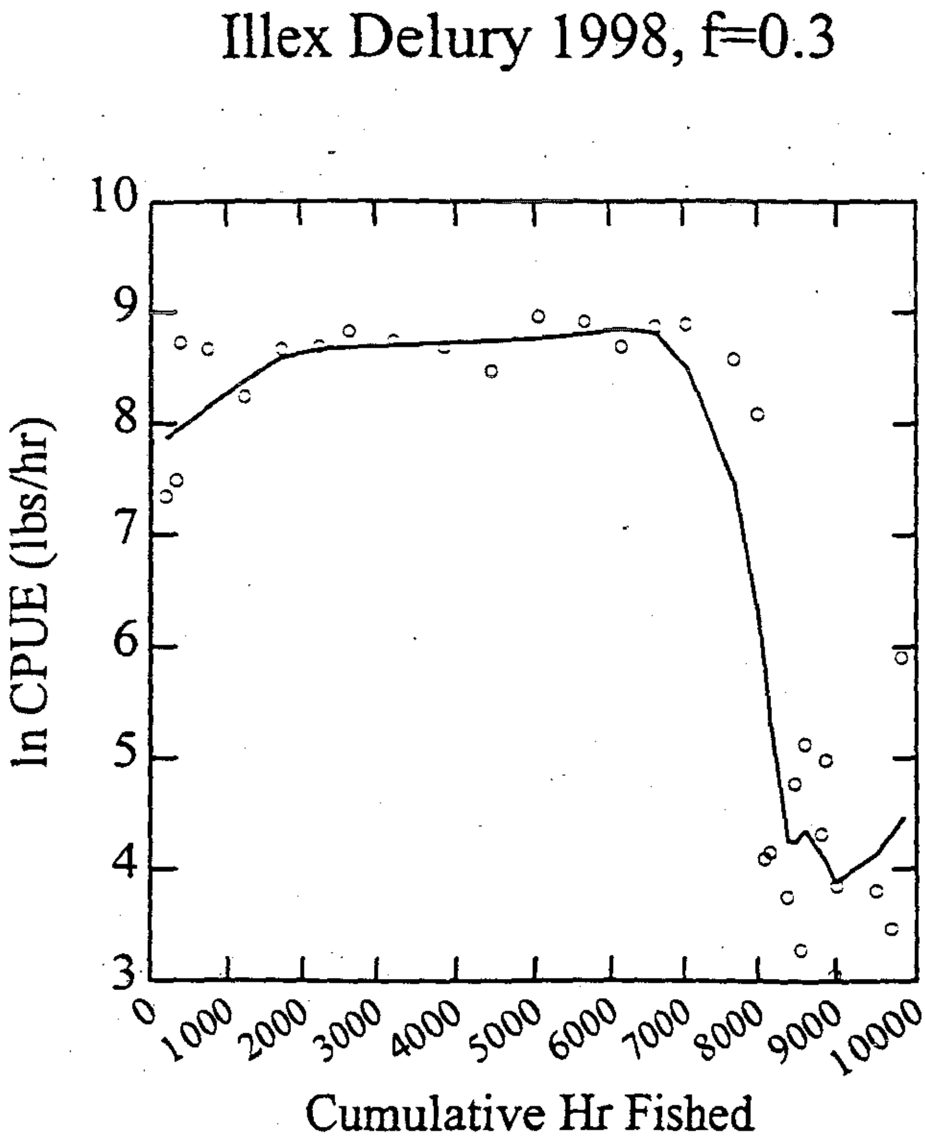



Figure D59. Lowess smooth of log LPUE (lb/hr) vs cumulative catch for the 1998 fishery; tension factor = 0.3. This plot is the graphical depiction of the original Delury estimator of population abundance.

Research Communications Unit
Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
Woods Hole, MA 02543-1026

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# Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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