

**37th Northeast Regional  
Stock Assessment Workshop  
(37th SAW)**

*Stock Assessment  
Review Committee (SARC)  
Consensus Summary of Assessments*

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- 03-11 **Accuracy Enhancement of Microscope Enumeration of Picoplankter *Aureococcus anophagefferens*.** By J.B. Mahoney, D. Jeffress, J. Bredemeyer, and K. Wendling. August 2003.
- 03-12 **A Taxonomy of World Whaling: Operations, Eras, and Data Sources.** By R.R. Reeves and T.D. Smith. August 2003.
- 03-13 **Distribution of the Brown Tide Picoplankter *Aureococcus anophagefferens* in Western New York Bight Coastal Waters.** By J.B. Mahoney, D. Jeffress, C. Zetlin, P.S. Olsen, H. Grebe, and J. Brooks. August 2003.
- 03-14 **Assessment of the Gulf of Maine and Georges Bank Witch Flounder Stock for 2003.** By S.E. Wigley, J.K.T. Brodziak, and L. Col. September 2003.
- 03-15 **Estimates of the Number of Vessels and Quantity of Gear Deployed in the Lobster and Gillnet Fisheries in 1999 off the Northeast Coast of the United States.** By K.D. Bisack. September 2003.

*A Report of the 37th Northeast Regional Stock Assessment Workshop*

**37th Northeast Regional  
Stock Assessment Workshop  
(37th 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 Fisheries Science Center  
Woods Hole, Massachusetts**

September 2003

## Northeast Fisheries Science Center Reference Documents

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## MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) meeting of the 37th Northeast Regional Stock Assessment Workshop (37th SAW) was held at the School of Marine Science and Technology (SMAST, University of Massachusetts Dartmouth) in New Bedford, Massachusetts, June 16-20, 2003. The SARC Chairman was Patrick Cordue, Innovative Solutions, Ltd, New Zealand (CIE). Members of the SARC included scientists from the NEFSC, the NMFS's Northeast Regional Office, the New England and Mid-Atlantic Fishery Management Councils (NEFMC, MAFMC), Atlantic States Marine Fisheries Commission (ASMFC), University of Maine, Massachusetts Department of Marine Fisheries, the SEFSC's Miami laboratory and the UK (Table 1). In addition, 22 other persons attended some or all of the meeting (Table 2). The meeting agenda is presented in Table 3.

**Table 1.** SAW-37th SARC Composition.

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**Patrick Cordue** (Innovative Solutions, New Zealand; CIE), **Chairman**

Northeast Fishery Science Center:

**Chris Legault**

**Paul Nitschke**

**Loretta O'Brien**

Regional Fishery Management Councils:

**Andy Applegate**, NEFMC

**Tom Hoff**, MAFMC

Atlantic States Marine Fisheries Commission/States:

**Yong Chen**, Univ. of ME

**Lydia Munger**, ASMFC

**Gary Nelson**, MA

Other experts:

**Jerome Hermsen**, NMFS, Gloucester

**Mauricio Ortiz**, SEFSC, Miami

**Paul Medley**, UK; CIE

**Erik Williams**, SEFSC, Beaufort

Industry Advisor:

**Maggie Raymond**, NEFMC

**Table 2.** List of Participants

---

Anne Beaudreau, NEFMC	Paul Rago, NEFSC
Laurel Col, NMFS	Anne Richards, NEFSC
Steven Correia, MADMF	Roger Rulifson, East Carolina University
Chad Demarest, NEFMC	Terry Smith, NEFSC
Sonja Fordham, Ocean Conservancy	Katherine Sosebee, NEFSC
Megan Gamble, ASMFCM	Mark Terceiro, NEFSC
Dvora Hart, NEFSC	David Wallace, Industry
Larry Jacobson, NEFSC	James Weinberg, NEFSC
Teresa Johnson, Rutgers	Sue Wigley, NEFSC
Steve Murawski, NEFSC	John Womack, Industry
Jillian Norton, NEFSC	
Eric Powell, Rutgers	

**Table 3. Agenda of the 37th Northeast Regional Stock Assessment Workshop  
(SAW 37) Stock Assessment Review Committee (SARC) Meeting**

School of Marine Science and Technology (SMAST)  
University of Massachusetts Dartmouth  
New Bedford, Massachusetts  
16-20 June, 2003

<b>TOPIC</b>	<b>WORKING GROUP &amp; PRESENTER(S)</b>	<b>SARC LEADER</b>	<b>RAPPORTEUR</b>
<b>MONDAY, 16 June (1:00-5:00 PM)</b> .....			
Opening			
Welcome	Terry Smith, SAW Chairman		
Introduction	Patrick Cordue, SARC Chairman		
Agenda			
Conduct of Meeting			
Witch flounder Stock (A)	S. Wigley	A. Applegate	L. Col
<b>TUESDAY, 17 June (9:00 AM - 5:00 PM)</b> .....			
Spiny dogfish (B)	P. Rago R. Rulifson	P. Medley	M. Gamble
Atlantic hagfish (E)	A. Beaudreau	Y. Chen	C. Demarest
Reception, 6 pm, Library	SMAST		
<b>WEDNESDAY, 18 June (9:00 AM - 5:00 PM)</b> .....			
Illex squid (D)	L. Hendrickson	M. Ortiz	A. Richards
Atlantic surfclam (C)	J. Weinberg	T. Hoff	A. Richards
<b>THURSDAY, 19 June (9:00 AM - 5:00 PM)</b> .....			
Review Advisory Reports and Consensus Summary Sections for the SARC Report			
<b>FRIDAY, 20 June (9:00 AM - 5:00 PM)</b> .....			
SARC comments, research recommendations, and 2nd drafts of Advisory Reports			

## The Process

The Northeast Regional Coordinating Council, which guides the SAW process, is composed of the chief executives of the five partner organizations (NMFS/NEFSC, NMFS/NER, NEFMC, MAFMC, ASMFC). Working groups assemble the data for assessments, decide on methodology, and prepare documents for SARC review. The SARC members have a dual role – panelists are both reviewers of assessments and drafters of management advice. As products of the meeting, the Committee prepares two reports: a summary of the assessments with advice for fishery managers known as the *Advisory Report on Stock Status*; and a more detailed report of the assessment, results, discussions and recommendations known as the *Consensus Summary of Assessments* (this report).

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

**Table 4.** SAW 37 Working Group meetings and participants.

---

<b>Working Group and Participants</b>	<b>Stock/Species</b>	<b>Meeting Date</b>
<u>SAW Northern Demersal Working Group</u>		
R. Bowering, DFO, St. John's Nfld J. Brodziak, NEFSC J. Burnett, NEFSC S. Cadrin, NEFSC L. Col, NEFSC R. Mayo (Chair), NEFSC L. O'Brien, NEFSC P. Rago, NEFSC K. Sosebee, NEFSC S. Sutherland, NEFSC M. Terceiro, NEFSC S. Wigley, NEFSC	<b>Witch flounder</b>	May 14-16, 2003 NEFSC, Woods Hole

**Table 4. (cont.)** SAW 37 Working Group meetings and participants.

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<b>Working Group and Participants</b>	<b>Stock/Species</b>	<b>Meeting Date</b>	
<u>SAW Invertebrate Working Group</u>			
M. Bell, CEFAS, Lowestoft	<b>Illex</b>	April 14 - 15, 2003	
E. Bochanek, Rutgers University		May 12 - 13, 2003	
D. Hart, NEFSC		NEFSC, Woods Hole	
L. Hendrickson, NEFSC			
J. Idoine, NEFSC			
L. Jacobson, NEFSC			
C. Pickett, NEFSC			
E. Powell, Rutgers University			
P. Rago, NEFSC			
J. Ruhle, MAFMC			
R. Seagraves, MAFMC			
M. Bell, CEFAS, Lowestoft		<b>Surfclam</b>	April 16 - 17, 2003
T. Hoff, MAFMC			May 14 - 15, 2003
L. Jacobson, NEFSC	NEFSC, Woods Hole		
S. Murawski, NEFSC			
C. Pickett, NEFSC			
P. Rago, NEFSC			
D. Wallace, Wallace & Assoc.			
J. Weinberg, NEFSC			
J. Womack, Wallace & Assoc.			
<u>ASMFC Spiny Dogfish Technical Committee/SAW Southern Demersal Working Group</u>			
Jim Armstrong, MAFMC	<b>Spiny dogfish</b>	May 12-14, 2003	
Laurel Col, NEFSC		NEFSC, Woods Hole	
Eric Dolan, NERO			
Megan Gamble, ASMFC			
Joe Grist, N. Carolina Div. of Marine Fisheries			
Ralph Mayo, NEFSC			
Steve Murawski, NEFSC			
Loretta O'Brien, NEFSC			
Chris Powell, R.I. Div. of Fish and Wildlife			
Paul Rago, NEFSC			
Jim Ruhle, MAFMC			
Roger Rulifson, E. Carolina University			

**Table 4. (cont.)** SAW 37 Working Group meetings and participants.

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Alexi Sharov, Maryland Dept. of Natural Resources  
Katherine Sosebee, NEFSC  
Mark Terceiro, NEFSC

Ad hoc Atlantic Hagfish Working Group

Anne Beaudreau, NEFMC, Chair	<b>Atlantic hagfish</b>	March 28, 2003
Mark Boulay, F/V Camano		Newburyport, MA
Andrew Cooper, Univ. of New Hampshire		
Chad Demarest, NEFMC		
Larry Jacobson, NEFSC		
Chad Keith, NEFSC		
Chris Kellogg, NEFMC		
Frederic Martini, Univ. of Hawaii		
Steve Nippert, F/V Kristin & Michael		
Mickie Powell, Birmingham-Southern College		
Terry Smith, NEFSC		

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### **Agenda and Reports**

The 37th SARC reviewed assessments for witch flounder, spiny dogfish, Atlantic surfclam and northern short-finned (illex) squid. Witch flounder and illex assessments were last reviewed in 1999 by the 29<sup>th</sup> SARC; spiny dogfish in 1998 by the 26<sup>th</sup> SARC; and surfclam in 2000 by the 30<sup>th</sup> SARC.

The panel also reviewed a working paper on the Atlantic hagfish resource and fishery. The Atlantic hagfish fishery is new to the region, involves relatively few participants and is currently un-managed as there is no FMP nor fishery regulations in place. As the hagfish fishery has developed, questions related to resource abundance, sustainability, and the need for management have emerged.

There are two reports produced subsequent to the meeting of the Stock Assessment Review Committee: one containing the assessments, SARC comments, and research recommendations (SARC Consensus Summary of Assessments - *this report*), and another produced in a pre-specified format which includes standard information on stock status and management advice (SARC Advisory Report). The draft reports were provided to the NEFMC, MAFMC and ASMFC in July and August. Presentations to the Councils occurred in July and August 2003 (NEFMC, 14 July, Portland; MAFMC, 5 August, Baltimore). Following review by the Councils and Commission and the Northeast Regional Coordinating Council, the documents have been finalized and published in the NEFSC Reference Document series as the 37<sup>th</sup> SARC Consensus Summary of Assessments (CRD 03-16) and the 37<sup>th</sup> SAW Advisory Report (CRD 03-17).

The SARC Consensus Summary of Assessments is organized into chapters: A. Witch flounder; B. Spiny dogfish; C. Atlantic surfclam; D. Northern short-finned squid; and E. Atlantic hagfish. As is customary, each chapter concludes with a section summarizing the SARC's discussion and providing a list of research recommendations offered by the panel.

In this report, in addition to these stock-specific sections, the SARC identified a number of overarching research recommendations which apply to all assessments. These recommendations, to be acted upon by the SAW Methods Working Group, appear below.

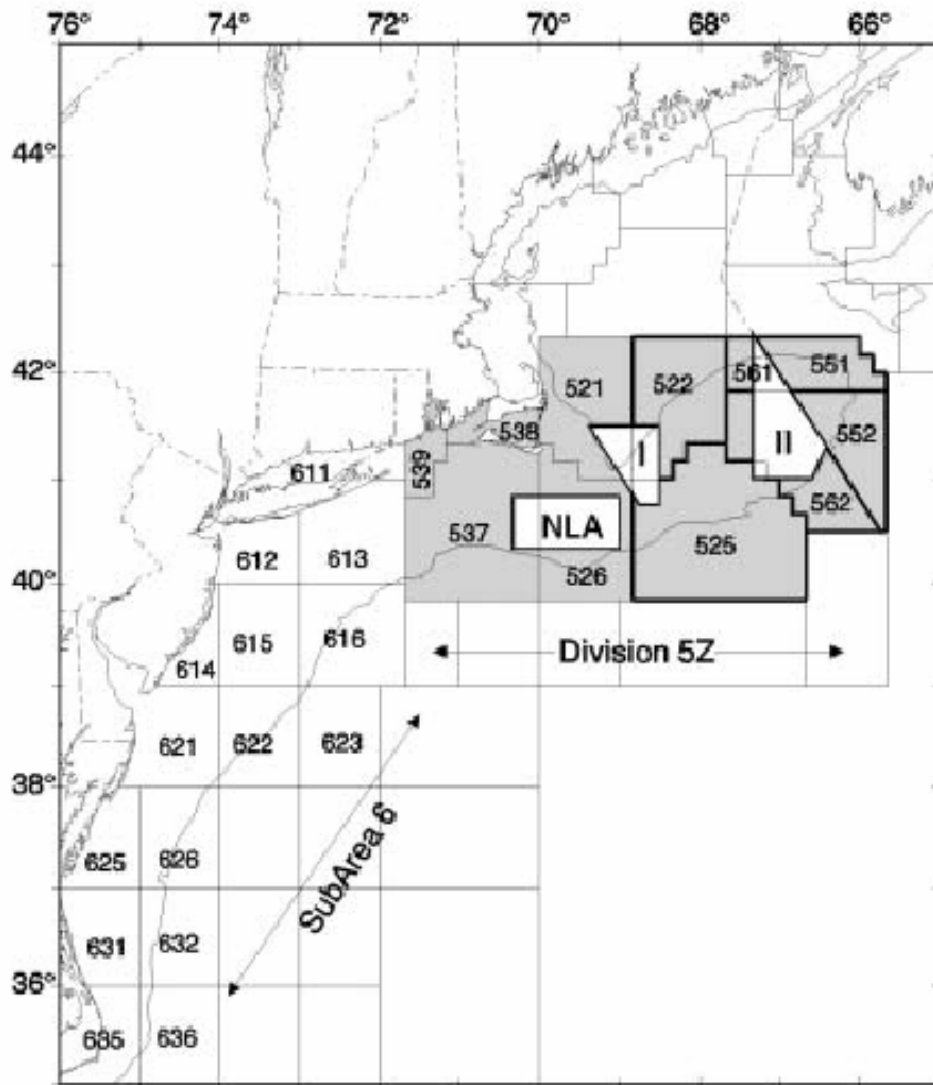
As additional general reference material, a chart of US commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 1 and a chart showing the sampling strata used in NEFSC bottom trawls surveys is presented in Figure 2.

## **RESEARCH RECOMMENDATIONS**

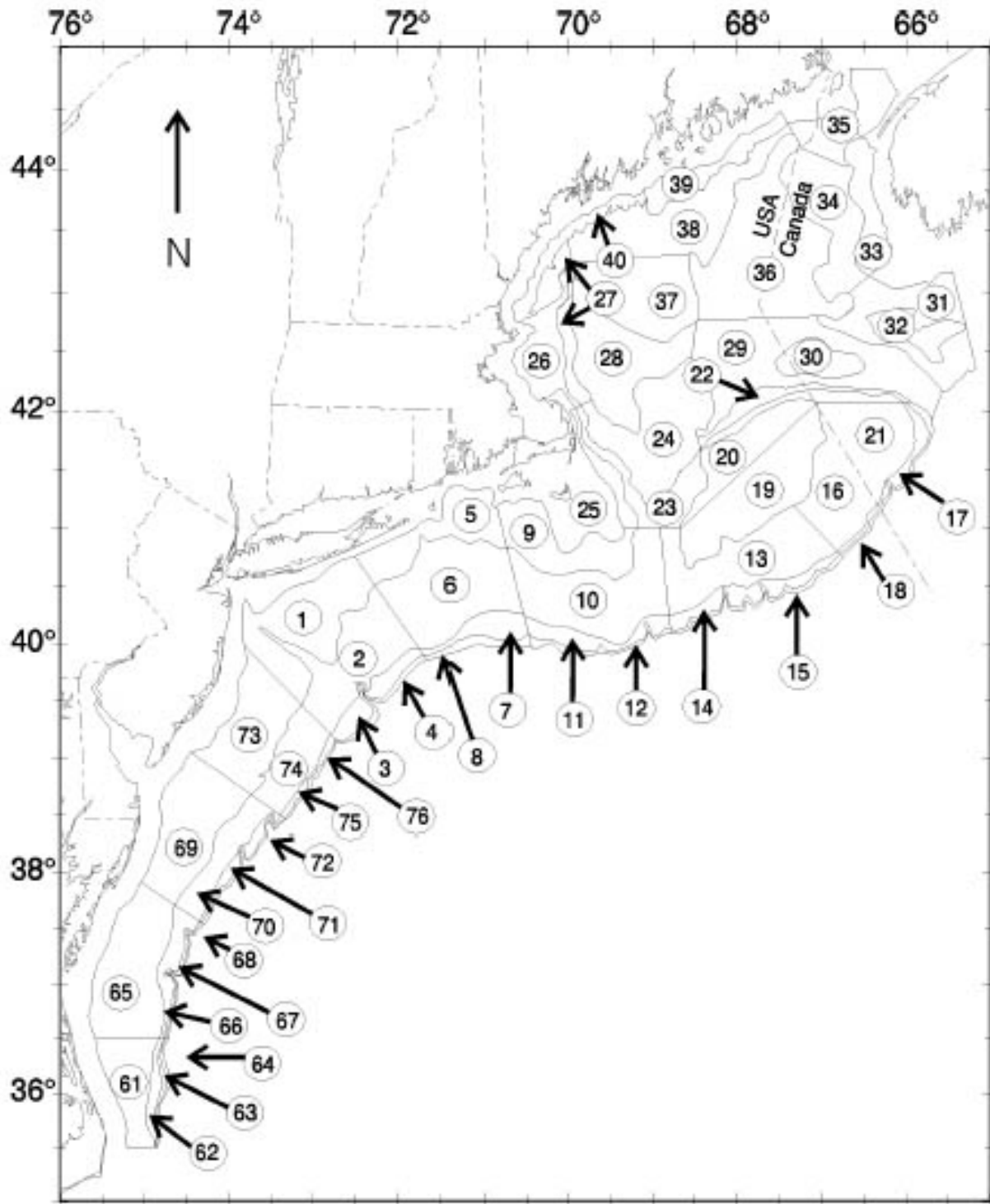
(Generic, for the SAW Methods Working Group)

- ◆ Estimate precision (e.g. the 80% CI) for biological reference points and the parameter values used to evaluate stock status.
- ◆ Explore methods to incorporate sampling uncertainty in bootstrap estimates of precision of VPA estimates of SSB, fishing mortality and recruitment.
- ◆ Explore methods for determining how well the VPA fits the input data, for example, using the Akaike Information Criteria or an overall indicator of the quality of the VPA fit, including the information contained in standardized residual patterns, residual sums of squares and retrospective patterns.

**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

### TERMS OF REFERENCE

1. Characterize the commercial catch (landings and discards) through 2002.
2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for 2002 and characterize the uncertainty of those estimates.
3. Evaluate and either update or re-estimate biological reference points as appropriate.
4. If stock projections are possible,
  - a. provide short term projections (2003-2005) of stock status under various fishing mortality strategies and
  - b. evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.

### 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 1910-1982 averaged 3,000 metric tons (mt), 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 2002 were 3,186 mt.

Previous witch flounder stock assessments were conducted by Burnett and Clark (1983), Wigley and Mayo (1994) and Wigley et al. (1999). An assessment update was conducted for this stock in 2002 and reviewed at Groundfish Assessment Review Meeting (GARM; NEFSC 2002). The GARM assessment indicated average fishing mortality (ages 7-9, unweighted) increased from 0.21 in 1982 to 0.59 in 1985, declined to 0.24 in 1990, increased to 0.96 in 1996, then declined to 0.45 in 2001. Spawning stock biomass declined from 18,000 tons in 1982 to about 4,000 tons in 1995 and then increased to 11,368 mt in 2001. Since 1982, recruitment at age 3 has ranged from approximately 3 million fish (1984 year class) to 84 million fish (1997 year class) with a mean of 22 million fish. In 2001, the SSB was slightly above  $\frac{1}{2}$  SSB<sub>msy</sub> (9,950 mt), the minimum stock size threshold, and fishing mortality ( $F=0.45$ ) was three times higher than  $F_{msy}$ , the maximum fishing mortality threshold; thus, witch flounder was not overfished but overfishing was occurring in 2001.

This assessment of witch flounder in the Gulf of Maine - Georges Bank region and southward (USA Subareas 4, 5 and 6), presents a benchmark analytical assessment for the stock for the 1982-2002 period, estimates 2002 fishing mortality and spawning stock biomass for stock status, and provides short-term projections of median landings, discards and spawning stock biomass for various fishing mortality scenarios. This assessment 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 2002.

Witch flounder is managed under the New England Fishery Management Council's Multi-species Fisheries Management plan since 1987. A brief summary of groundfish management regulations affecting witch flounder is presented in Table A.1. Significant changes in regulations include increased minimum size in 1983 and 1987; increases in mesh size in 1982, 1983, 1994, 1999; effort reductions in 1996 and 2002; and implementation of closed areas in 1994 and 1998 (Figure 2). The western Gulf of Maine area closure, Cashes Ledge area closure and the seasonal rolling closures overlap the witch flounder distribution (Figures A.1 and A.2). Management regulations for the northern shrimp fishery also impact witch flounder (Table A.2); 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.

## **THE FISHERY**

### Recreational Catches

There is no recreational fishery for witch flounder.

### Commercial Landings

USA commercial landings in 2002 totaled 3,186 mt, a 5% increase over 2001 (Table A.3); and 117% higher than in 1990, the lowest value since 1964 (Figure A.3). Canadian landings from the stock have been negligible (32 mt in 2001; Table A.3). 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. Furthermore, samples from the western Scotian Shelf indicate slower growth of witch flounder than in the Gulf of Maine, suggesting a different phenotypic stock.

The western Gulf of Maine (SA 513 and 514) and the central basin (SA 515) provide nearly a third of the USA witch flounder landings (Table A.4); landings from Georges Bank are confined to the deeper waters north of the South Channel (SA 521, 522; Table A.4). Otter trawl catches account for about 98% of witch flounder landings, with sink gillnets comprising the remainder (Table A.5). 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 A.6, Figure A.4). Since the early 1990s, the proportions of witch flounder landings from the peewee and small market categories have steadily increased. In 2002, witch flounder less than 45 cm ('peewee' and 'small' market categories) constituted 87% of total landings (Table A.6, Figure A.4). 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 in Table A.7 (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 (approximately 100 fish per sample) 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 (Tables A.6 and A.7). Sampling intensity during 2001-2002 averaged 39 samples annually, representing 1 sample per 80 mt landed; nonetheless, even with this increased sampling intensity, inadequate numbers of samples were obtained for some market categories and quarter combinations. In 2002, of the 35 samples collected, 15 were small samples (43%), 10 were medium (29%) and 10 were large (29%). Compared with the 2002 market category landings distribution by weight (small 87%; medium: 10%; large: 3%), sampling in 2002 adequately approximated the market category distribution of landings on an annual basis. As in previous years, it was necessary to pool some quarters for some market categories. A summary of pooling procedures by year, market category and quarter is presented in Table A.8.

### Commercial Landings at Age

Commercial age data for the years 1982 to 2002 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 A.9. No discernible changes in growth are evident during the 1982-2002 period; although landings mean weights and mean lengths at ages 6 to 8 declined in 1996-2002, this may be an artifact of poor sampling in recent years.

### Discards

The Fisheries Observer Program (FOP), which began in 1989, has generated various levels of coverage for different fisheries. Prior to the FOP, 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. 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. These estimation procedures were used in the 1994 assessment (Wigley and Mayo 1994), reviewed by the SAW 18 (NEFSC 1994), and extended through 1997 using the same methodology. The ratio of witch flounder discarded (kg) to days fished was calculated using FOP 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 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 A.10). To estimate witch flounder discard rates prior to the FOP, (i.e., 1982-1988), a simple linear regression was employed using 1989-1992 (years in which the Nordmore grate was not required) 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 A.5; Wigley MS 1994).

With no 1998-2002 FOP 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. As used for the years prior to the FOP, a simple linear regression using 1993-1997 (years in which the Nordmore grate was required) 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 four of the points are clustered (Figure A.5).

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 A.11). 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 ALKs. Detailed information on this method is given in Wigley (MS 1994). For 1995-2002, 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.

For the 1982-1997 time period, 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 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 discards-at-age were 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.

Without 1998-2002 FOP sampling, discard length-frequency data were unavailable to partition the 1998-2002 estimated discard weight into numbers at length; thus discarded numbers at age were derived by apportioning discard weight by the average age composition (calendar year) of discards in 1993-1997 and then dividing by the average 1993-1997 discard mean weights at age. The average 1993-1997 mean weights at age from the FOP were consistent with trends in mean weights from the NEFSC survey during the 1998-2002 time period.

Witch flounder discards in the northern shrimp fishery ranged from a low 0.8 mt in 2002 to a high of 34 mt in 1988 and 1995 (Table A.11). Similarly, number of witch flounder discarded ranged from 40,000 fish discarded in 2002 to 1.8 million fish in 1994 (Table A.11). Estimates of age compositions of discarded witch flounder in the shrimp fishery are presented in Table A.12. Discarded witch flounder from the shrimp fishery range from age 0 to 6, with ages 1 to 3 most commonly discarded (Table A.12).

#### *Large-mesh otter trawl fishery*

Discard estimation from the large-mesh otter trawl fishery is confounded by the lack of FOP coverage prior to 1989, sparse coverage in the beginning of the program, and the recent implementation of year-around and seasonal area closures. As a result, three estimation scenarios were examined: 1) utilizing a survey filter method; 2) utilizing the at-sea observer data (Table A.13); and 3) utilizing the Vessel Trip Report data (Table A.14). The estimated discards (in weight and numbers) are presented in Table A.15. Each method is described below.

The method used in previous witch flounder assessments to estimate large-mesh otter trawl discards was 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 nearly knife edged 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. Semi-annual numbers of discard fish at length were apportioned to age using the corresponding season NEFSC ALK. Estimated numbers of discarded witch flounder in the large-mesh otter trawl fishery are presented in Table A.15. Results indicate that in recent years, numbers discarded at sea comprised as much as 54% of the witch flounder landed. The general pattern of discarding appears to be consistent with that expected given strong recruitment during 1979-1981 and the mid-1990's.

Given the distribution of juvenile witch flounder in the western Gulf of Maine and the recent implementation of year-around area closures and seasonal rolling area closures in the western Gulf of Maine, there was some concern regarding the application of the survey filter method to estimate discards in recent years. Since the commercial fishery does not have year-around access to the population estimated by the NEFSC survey, it may be inappropriate to use the survey filter method to estimate discards. For the 1989-2002 period, discard weight to kept weight ratios (D/K ratio) were calculated from FOP data on a semi-annual basis (Table A.13). Total discard weight was derived by multiplying the D/K ratio by the commercial landings. The number of sea sampled trips varied from no trips in the second half of 1992 to 83 trips in the second half of 2002. The D/K ratios ranged between 0.02 and 0.50. Given the limited number of trips, tows and available discard length frequencies, discards at age were derived only for the 1995-2002 time period (Tables A.15).

The Vessel Trip Report data were explored for information on discarding of witch flounder. Reporting of discard information in the logbooks is 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) semi-annually for large-mesh otter trawl gear from 1994 to 2002. Limitations of this analysis are: 1) the dealer data used to expand discard rates to total discard weight do not contain information on mesh size, precluding partitioning of otter trawl fisheries into small and large mesh trips; 2) there is no area information on dealer data to isolate trips from the Gulf of Maine-Georges Bank region. From this analysis, results suggest that discard rates range between 4% and 9% (Table A.14). These estimates should be reviewed cautiously as not all fishermen report discards. Discarded numbers at age were estimated by expanding the FOP length frequencies and applying the survey age/length keys (Table A.15).

For estimates of total catch at age, discards from the large-mesh otter trawl fishery were derived using the survey filter method from 1982-1994 and using the FOP method for 1995-2002 (Table A.16).

#### 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 A.17 and Figure A.6. The age composition data reveal strong 1979-1981 year classes (Table A.17). The 1989

and 1993 year classes also appear to have been strong; however, these cohorts were heavily discarded in both the shrimp and large-mesh otter trawl fisheries (Tables A.12 and A.16). The poor 1984 year class is also evident as well as the truncated age-structure since the early 1990's.

Since witch flounder landings are highest during March-July, the average weights-at-age in the catch approximate mid-year weights. Mean weights at age at the beginning of the year (January 1; Table A.18) were derived from mid-year weights using procedures described by Rivard (1980).

## **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 A.19). 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. Since the early 1990s, LPUE indices have steadily increased and are among the highest in the time series (Table A.19, Figure A.7a). Indices for 40% trips peaked in the early 1980's, then declined to a low in 1994, and have increased slightly in recent years (Table A.19, Figure A.7a). Effort (days fished) associated with all trips and 40% trips increased during the late 1970s and early 1980s, peaked during 1985-1988, and have generally declined since (Figure A.7b). 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 2002 may be underestimated in this report since effort is based upon preliminary VTR data, which do 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.

In September 2002, an offset in the trawl wraps was detected which may have effected the NEFSC bottom trawl surveys conducted from winter 2000 to the spring 2002. Extensive analyses of existing data sets and experimental studies were conducted to evaluate the offset issue (NEFSC 2002). These analyses were reviewed by a panel of experts and they concluded that no adjustments to the survey time series were justified (Groundfish Science Peer Review, 2003).

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 (ASMFC) 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 3); Massachusetts DMF, regions 4 and 5; and northern shrimp, strata 1, 3, 6, and 8.

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 A.1 and A.8). 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 (Figures A.2a and A.2b). Concentrations of witch flounder along the western portion of the Gulf of Maine are observed in the ASMFC shrimp survey. Although this survey has limited spatial coverage (Figure A.9), most of the juvenile range is covered.

In response to a research recommendation from SARC 29, analyses were conducted to examine if the use of additional strata in the NEFSC bottom trawl survey might be appropriate. Burnett and Clark (1983) used NEFSC survey strata set 22,24,26-30, 33-40 in the first witch flounder assessment; however, Burnett (MS 1987) suggested that fish from strata 33, 34 and 35 exhibited different growth rates indicating these fish may be from a different stock inhabiting the western Scotian shelf. Based on this information, Wigley and Mayo (1994) revised the witch flounder survey strata set excluding 33, 34, and 35, and included strata 23 and 25 (Figure A.9). Following a method developed by Cadrin (2003), witch flounder catches for the entire autumn bottom trawl survey time series were examined by individual stratum. The stratified mean number per tow in each stratum was summed over the time period, and the percentage contribution of each stratum was calculated as well as the percentage of annual stratum sampling which produced no catch

(Table A.20). Results indicate that the current strata set (22-30, 36-40) accounts for approximately 93% of the survey catch and that only minor differences exist between the strata sets used in previous assessments. This analysis also indicated that stratum 6 contributed to the overall witch flounder catch. The stratified mean weight (kg) per tow was calculated for three strata sets: set 1 (22-30, 36-40); set 2 (22, 24, 26-30, 36-40); and set 3 (6, 22, 24, 26-30, 36-40). The trends of these biomass indices (and their variance) are indistinguishable (Figures A.10a and A.10b). The inclusion of stratum 6 is not justified due to its geographical discontinuity with the core strata. Since no additional strata were identified as contributing to the total catch, or improved the precision of the estimates of mean weight per tow, the strata set 22-30, 36-40 will continue to be used.

Research vessel survey indices of abundance, biomass, and mean length for NEFSC surveys, Mass. DMF surveys, and ASMFC shrimp surveys are presented in Tables A.21-A.23 and Figures A.11-A.16, respectively. A summary of available age data from NEFSC surveys is given in Table A.24; 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 1980-2002, and preliminary spring 2003 are presented in Table A.25, Figures A.17 and A.18. Mean length and mean weights at age from the NEFSC spring and autumn surveys are given in Tables A.26 and A.27 and Figures A.19 - A.21.

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 A.21, Figures A.11 and A.12); autumn indices declined during the early and mid 1980s, reaching record low levels in 1987. Abundance sharply increased in 1993, due to a large age 0 index (Table A.25, Figure A.12) and has continued to increase to near record high levels in 2002. During the same time, mean length declined (Figures A.15 and A.16). The age structure has been truncated since the late 1980's (Figures A.17 and A.18).

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 (Table A.23). The ASMFC survey data indicate improved recruitment in recent years, corresponding to age 1 fish, during 1991-1994, 1997, and 1999. Significant numbers of small fish were also observed in the NEFSC autumn survey during the same years.

Mean lengths at age from NEFSC spring and autumn surveys are presented in Table A.26 and for ages 4 to 8 in Figures A.19a and A.19b. 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 A.19a and A.19b); however, Von Bertalanffy growth analyses detected no significant changes in resulting growth parameters over the time period.

NEFSC spring and autumn survey mean weights at age are given in Table A.27 and Figures A.20 and A.21. Survey mean weights are variable, however, similar declines in mean weights for ages 6-9 were observed during the mid-1990s to 2002 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). In the previous witch flounder assessment, probit analyses (SAS 1985) of maturity at age data revealed that there have been six maturity stanzas over the assessment period (GARM NEFSC 2002). 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, 1994-1999, and 2000-2002. 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 1980-1982 to 1985-1990, then increasing in 1991-1993, then declining in 1994-1999 and increasing in 2000-2002 similar to 1983-1984 levels. The maturity stanzas used revealed sharp changes in proportion mature, uncharacteristic of the assumed gradual biological process. The maturity stanzas also revealed, in a few instances, biologically infeasible outcomes, i.e. over the life span of a cohort, the proportion mature at age would decrease. Given these issues, a method which has been applied to Georges Bank cod (L. O'Brien, NEFSC, pers. comm.) was employed to minimize the abrupt changes yet still capture the changing trends in maturity over time. This method used logistic regression and a five-year moving time block to estimate annual maturity ogives. For example, the proportion mature in 1982 was estimated using NEFSC spring maturity data from 1980, 1981, 1982, 1983 and 1984. Likewise, the 1983 maturity ogive used maturity data from 1981 to 1985. Annual maturity ogives were derived for 1982 to 2001 using 1980 - 2003 data. The annual 2002 maturity ogive was assumed to be equal to the 2001 ogive (Table A.28, Figure A.22). In addition to the annual maturity ogives, a single ogive using maturity data from the entire time series was also calculated (Table A.28). It was concluded that the moving time block method was appropriate for use in the VPA.

Stratified mean weight per tow of mature (spawning stock) witch flounder was calculated for spring NEFSC research vessel surveys (Table A.29, Figure A.23) using the six maturity stanzas. This analysis will be updated to incorporate the moving time-block maturity estimates in the next assessment update. The spawning stock biomass indices closely track total biomass indices 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, 1994-1997 and 1997-2001. Given the variability in age at full recruitment to the sampling gear observed during the survey time series (Table A.30), 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:

$$\begin{array}{ll} \text{Spring:} & \ln (\text{sum age 7+ for 1982-1985} / \text{sum age 8+ 1983-1986}) \\ \text{Autumn:} & \ln (\text{sum age 6+ for 1981-1984} / \text{sum age 7+ 1982-1985}). \end{array}$$

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 A.30 and Figure A.24a). 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 ranged between 0.34 and 0.71 over the time series (Table A.30). Additionally, annual estimates of total mortality were calculated, and smoothed with a three year moving average (Figure A.24b).

## **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 2003 using catch-at-age estimates (i.e., landings plus discards from the shrimp and large-mesh otter trawl fishery; Table A.17). Estimates of stock sizes, their associated statistics, and F in the terminal year are summarized in the Table A.31.

New VPA software is now available in the NOAA Fisheries Toolbox. To bridge the transition between the software used in the last assessment update (FACT 1.5) and the current software, NFTv2.0.11, the accepted 2002 VPA (NEFSC 2002) formulation and input data was re-run using

the NFTv2.0.11 software. The summary statistics of the two VPAs (RUN 61-f) reveal only slight changes in stock size estimates and fishing mortality (Table A.31), and these minor changes are attributed to the use of the exact catch equation and other improvements in precision.

An initial formulation (RUN 100) based upon the 2002 VPA was performed to estimate 2003 stock sizes for ages 4 to 10 (Table A.31) using a catch-at-age matrix including ages 3-11+ and NEFSC spring and autumn abundance indices for ages 3 to 11+ 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. A flat-top partial recruitment (PR) pattern was assumed, with full fishing mortality on ages 7 and older. 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. Instantaneous rate of natural mortality ( $M$ ) was assumed to be 0.15. Spawning stock biomass (SSB) was calculated at time of spawning (March) and mean weight at age calculated by the Rivard method (Table A.18).

The results of the initial run indicated that coefficients of variation (CV) for estimated ages ranged between 29% and 44% and the CVs for survey catchability coefficients ( $q$ ) were consistent, ranging from 11% to 27%.

Two alternative formulations included: 1) using a total catch at age in which large-mesh otter trawl discards were estimated using the survey filter method for 1982-1994 and Fisheries Observer Program data for 1995 to 2002 [RUN 200]; and 2) estimating age 3 stock size using survey tuning indices [RUN 201]. Results from these alternative formulations provided estimates of stock size,  $F$  and spawning stock biomass consistent with the base run [RUN 100]. RUN 201 stock size for age 3 was poorly estimated (CV = 63%). Based on these runs, the partial recruitment pattern indicated that age 7 was not fully recruited. An alternative formulation (RUN 300) was conducted using a partial recruitment vector where the fully recruited age was increased from 7 to 8. Assuming full recruitment at age 8, the  $F$  on ages 10 and 11+ in the terminal year was estimated as the average of  $F$  on ages 8 and 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 8 through 9. This partial recruitment pattern is consistent with recent mesh regulation changes.

The final formulation (RUN 301-f) included a 3 to 11+ catch at age with large-mesh otter trawl discards estimated using both the survey filter method and FOP data; an updated partial recruitment vector reflecting current management regulations was derived from the 1999-2002  $F$  pattern taken from a penultimate calibration run; annual maturity ogives estimated by the five year moving time block with the 2002 maturity vector assumed to be equal to 2001. Ages 1 and 2 were deleted from the catch at age, this allowed recruitment in 2003 to be estimated using the the geometric mean; there is no difference between 1-11+ vs 3-11+ on VPA results for fishing mortality and spawning stock biomass. Based on the final formulation, two sensitivity analyses were conducted to evaluate the selection of tuning indices. The VPA was tuned with only

NEFSC spring survey indices and then tuned with only NEFSC autumn survey indices (Table A.31). Estimates of F and SSB from analyses using a single tuning series bounded the F and SSB estimated using both spring and autumn tuning indices. Using only the spring tuning series (RUN 301-f-spr), F was slightly higher ( $F = 0.43$ ) and SSB is slightly lower (15,798 mt) than the final run (RUN 301-f). Conversely, using only the autumn tuning indices (RUN 301-f-aut), F is slightly lower ( $F = 0.39$ ) and SSB is slightly higher (21,569 mt; Table A.31) than the final run (RUN 301-f).

#### VPA Estimates of Fishing Mortality, Spawning Stock Biomass and Recruitment

The VPA results, including estimates of F, stock size and spawning stock biomass at age are given in Tables A.32. The mean residual for the VPA calibration was 0.791 and the CV on age 3-10 stock sizes ranged from 31% to 64% while the CVs on the estimates of survey catchabilities were between 13% and 26%. The normalized survey indices and standardized residuals are presented in Figures A.25 And A.26.

The VPA indicates that fishing mortality (ages 8-9, unweighted) increased from 0.26 in 1982 to 0.67 in 1985, declined to 0.22 in 1992, increased to 1.13 in 1996, then declined to 0.41 in 2002 (Table A.33 and Figure A.27). Spawning stock biomass declined from 16,897 mt in 1982 to about 3,800 mt in 1996. With recent increases in recruitment and declines in fishing mortality, SSB has increased to 18,296 mt in 2002 (Table A.33 and Figure A.28). Since 1982 recruitment of age 3 has ranged from approximately 3 million fish (1984 year class) to 67.6 million fish (1997 year class; Table A.33 and Figure A.28). Over the 1982-2002 period, average recruitment of age 3 fish (the 1979 - 2000 year classes) was 19.6 million (the geometric mean equaled 14.4 million fish). The 1995-1999 year classes appear to be above average, and the 1997 year class is the largest in the VPA time series (Table A.33 and Figure A.28).

The relationship between spawning stock biomass and recruitment (age 3) is presented in Figure A.29. The negative stock-recruitment relationship observed in previous assessments continues with the addition of the 2000 year class.

#### 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 2003, the catchability estimates ( $q$ ) of the abundance indices used in calibrating the VPA, and the 2002 fully recruited fishing mortality rate (age 8+). Frequency distributions of the 2002 mean fishing mortality and spawning stock biomass bootstrap estimates were generated and cumulative probability curves produced (Figures A.30 and A.31).

Bootstrap results suggest that the estimates of 2003 abundance had CVs between 32% to 84%, 24% for 2002  $F_{8,9}$  and 15% for 2002 spawning stock biomass. There is an 80% probability that the 2002 F (0.41) lies between 0.31 and 0.56 (Figure A.30), and the 2002 SSB (18,296 mt) lies between 15,603 mt and 22,969 mt (Figure A.31).

### Retrospective Analyses

A retrospective analysis was conducted on the final VPA (Run 301-f) from 2002 to 1992 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 seven years prior to the current assessment. Results indicate that average F was underestimated (Figure A.32a) and spawning stock biomass was consistently overestimated (Figure A.32b). The retrospective analysis indicated that the number of age 3 recruits were generally overestimated, and the 1995-1997 year classes were considerably overestimated (Figure A.32c).

### Statistical Catch-at-age model

A statistical catch-at-age analysis was conducted for the witch flounder stock. An age-structured forward-projection model (a.k.a., age-structured production model) was fit to fishery and survey data during 1937-2002. This model provided an alternative long-term perspective on resource dynamics in comparison to VPA-based analyses that were limited to the period 1982-2002. Age-structured population dynamics of witch flounder were described using forward-projection methods for statistical catch-at-age analyses (Fournier and Archibald 1982, Methot 1990, Ianelli and Fournier 1998, Quinn and Deriso 1999). Models were fit to data with the AD Model builder software for nonlinear optimization (Otter Research 2001).

Six alternative statistical catch-at-age models were developed and fit. Brodziak and Wigley (2003 ms) contains a complete description of the basic model and input data. Common features of the six models were:

- Natural mortality was  $M=0.15$  for all age classes.
- Catch scenario 2 was used (same catch as used in the VPA).
- Fishery selectivity was estimated for historic (1937-1993) and current (1994-present) time periods.
- NEFSC spring and fall survey biomass and numbers at age data were used.
- Emphasis values for likelihood components were: Recruitment  $\lambda_1=10$ , Fishery age composition  $\lambda_2=1$ , NEFSC Fall survey age composition  $\lambda_3=1$ , NEFSC Fall survey biomass index  $\lambda_4=100$ , NEFSC Spring survey age composition  $\lambda_5=1$ , NEFSC Spring survey biomass index  $\lambda_6=100$ , Catch biomass  $\lambda_7=100$ , Fishing mortality  $\lambda_8=1$ , Fishing mortality penalty  $\lambda_9=1$

The primary differences among the six alternative models were:

1. Dome-shaped selectivity possible for fishery, spring, and fall surveys; time frame is 1937-2002.
2. Flat-topped selectivity for fishery, spring, and fall surveys; time frame is 1937-2002.
3. Dome-shaped selectivity possible for fishery, spring, and fall surveys; time frame is 1963-2002.
4. Flat-topped selectivity for fishery, spring, and fall surveys; time frame is 1963-2002.
5. Flat-topped selectivity for fishery and spring survey; Dome-shaped selectivity possible for fall survey; time frame is 1963-2002.

6. Flat-topped selectivity for fishery and spring survey; Dome-shaped selectivity possible for fall survey; time frame is 1937-2002.

Models 1, 2, and 6 were considered to be the primary models, while models 3, 4, and 5 provided sensitivity analyses to the choice of time frame. The Northern Demersal Working Group (WG) reviewed the model diagnostics. In general, the selectivity patterns of models that allowed dome-shaped fishery or survey selectivity appeared to be too sharply domed to be biologically plausible. In contrast, models with the assumption of flat-topped selectivity provided a poorer fit to the data, as measured by the root-mean squared errors for the NEFSC fall and spring survey biomass index and the catch biomass fits to the data. The WG chose to reduce the emphasis on the NEFSC fall and spring survey biomass index and the catch biomass likelihood components to 10 down from 100. This choice alleviated the problem of implausible selectivity patterns in the fishery and the survey. As a result, the WG concluded that Model 1 with reduced emphasis values was the best alternative of the statistical catch-at-age analyses (SCAA). Model results are reported to confirm the basic trends of VPA-based results and show the likely effect of extending the assessment time horizon back to 1937.

Model results showed that current fishery selectivity at age was estimated to be lower at ages 1-6 than historic selectivity (Figure A.33). This was consistent with increases in fishery mesh size and changes in discarding practices (e.g., shrimp fishery) that occurred around 1994. The resulting catch biomass predictions generally matched observed catch biomasses (Figure A.34) with some moderate deviations in the early 1980s.

Model results showed that NEFSC fall survey selectivity was dome-shaped with a peak at age-5 (Figure A.35). The NEFSC spring survey selectivity was flat-topped with full selection occurring at roughly age-7. The resulting predicted NEFSC fall and spring survey indices generally matched the trends in observed indices (Figures A.36 and A.37). Both surveys indicate a longterm decline in biomass from the 1970s through the early 1990s. Biomass increases in the late-1990s differed moderately between the fall and spring surveys

There was general agreement between VPA and SCAA results during 1982-2002. Spawning biomass estimates were very similar during 1989-1999 (Figure A.38, SCAA estimate of 10.5 kt in 2002). The VPA indicates a smaller decrease in spawning biomass during 1982-1988 and a greater increase during 2000-2002. Fishing mortality estimates were also similar (Figure A.39, SCAA estimate of 0.48 in 2002). Both VPA and SCAA estimates increased to roughly the mid-1990s and then declined. Recruitment estimates also exhibited similar patterns (Figure A.40, SCAA estimate of 14.1 million age-1 fish in 2002), although the VPA indicated larger increases in recruitments during the late-1990s. Despite differences in model configuration and estimation approach, the SCAA generally confirmed point estimates and trends in the VPA results.



## BIOLOGICAL REFERENCE POINTS

Yield-per-recruit (Y/R) and spawning stock biomass per recruit (SSB/R) analyses were performed using the Thompson and Bell (1934) method for witch flounder ages 3 to 20. Input vectors for partial recruitment, maturation at age and mean weights at age were all updated since the last assessment. Mean weights at age used in the Y/R analyses were computed as an arithmetic average of catch mean weights at age (Table A.17) over the 1999-2002 period. Mean weights at age for use in the SSB/R analyses were derived by applying the length-weight relationship for witch flounder to predicted lengths at age from von Bertalanffy growth curve analyses of NEFSC survey data from 1980-2002. The maturation ogive from the entire time series (1980-2003) was also used (Table A.28). Given the changes in regulated mesh size in 1999, the exploitation pattern used in the yield and SSB per recruit analyses and short-term projections was computed from the 1999-2002 VPA results. Geometric mean F at age was computed for the 1999-2002 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 8 and older, viz.

Age 3	Age 4	Age 5	Age 6	Age 7	Ages 8+
0.0036	0.0229	0.0703	0.1931	0.5282	1.000

The input data and results for the Y/R and SSB/R analyses are given in Table A.34 and Figure A.41. The reference points were  $F_{0.1} = 0.196$ ,  $F_{\max} = 0.545$ , and  $F_{40\%} = 0.230$ .

The biological reference points were updated by applying the approach used to estimate MSY proxies for witch flounder (NEFSC 2002).  $F_{msy}$  is approximated as  $F_{40\%}$  (0.23), the  $SSB_{msy}$  proxy is 25,248 mt, the product of 40%MSP (1.2882 kg spawning biomass) and average long-term recruitment (19.6 million). The MSY proxy is 4,375 mt, the product of yield per recruit at  $F_{40\%}$  (0.2232 kg) and average recruitment.

In 2002, spawning stock biomass was slightly greater than  $\frac{1}{2}$   $SSB_{msy}$  (12,624 mt), the minimum stock size threshold, and fishing mortality in 2002 was nearly double  $F_{msy}$ , the maximum fishing mortality threshold; therefore, witch flounder was not overfished but overfishing was occurring in 2002 (Figure A.42).

To evaluate the effects of simultaneous changes in the three input vectors described above (i.e. partial recruitment, maturation and mean weights) on  $F_{40\%}$ , Y/R, SSB/R and the  $SSB_{msy}$  proxy, a decomposition analysis (P.Rago, NEFSC, pers. comm.) was conducted. This analysis is analogous to decomposing a sum of squares in an analysis of variance (decomposing the total resulting difference into its components).

For  $F_{40\%}$ , Y/R and SSB/R:

Total effect = effect of vector 1 + effect of vector 2 + effect of vector 3 + interaction terms.

For  $SSB_{MSY}$ :

Total effect = SSB/R effect + Recruit effect + interaction term.

The effect is the difference between the former YPR estimate and the current YPR estimate, for F40%, Y/R, SSB/R and for  $SSB_{MSY}$ .

To accomplish this, the former YPR analysis (Run 0) was re-run using ages 3-20 to coincide with the ages used in the current YPR analysis (Run 1). Then, YPR analyses were conducted where each former vector was replaced with a current vector (Runs 2 through 7), until all vectors were replaced with current vectors (Run 8). The resultant F, Y/R and SSB/R at 40%MSP from each run (Runs 0 to 8) are reported in Table A.35. The total effect of changing all three vectors at once equals Run 1 - Run 8.

Results of the decomposition analysis (Table A.35) indicate that changes in F40% were effected most by new partial recruitment vector. Changes in Y/R resulted from the interaction of all three new input vectors while changes in the SSB/R resulted from the interaction between the mean weights and maturity vectors. Changes in  $SSB_{msy}$  were effected most by changes in new mean age 3 recruitment.

## SHORT-TERM PROJECTIONS FOR 2004 AND 2005

Short-term stochastic projections were performed to estimate landings, discards and SSB during 2003-2005 under various F scenarios using bootstrapped VPA calibrated stock sizes in 2002. The partial recruitment, maturity ogive, and mean weights at age were the same as described in the yield and SSB per recruit section (Table A.36). Recruitment (age 3) in 2003-2005 was derived by re-sampling the cumulative density function based on the empirical observations during 1982-2002 (1979-2000 year classes). Fishing mortality was apportioned among landings and discards based on the proportion observed landed at age during 1999-2002. The proportion of F and M which occurs before spawning equals 0.1667 (March 1); M was assumed to be 0.15. Spawning stock biomass in 2002 was estimated to be 18,296 mt. The F scenarios are: status quo  $F_{2003} = 0.41$ ,  $F_{msy} = 0.230$ , 75% of  $F_{msy} = 0.17$  and  $landings_{2003} = landings_{2002}$  ( $F = 0.199$ ). Fishing at the status quo F (0.41) or at the target ( $F_{msy} = 0.23$ ) in 2003 - 2005 is expected to allow biomass to increase above  $SSB_{msy}$  and initiate rebuilding of the age structure (Table A.36). Comparison of the current age structure and the age structure under MSY conditions are given in Figure A.43.

## CONCLUSIONS

Based on the ADAPT VPA, the witch flounder stock was not overfished, but overfishing was occurring in 2002. Fully recruited fishing mortality in 2002 was 0.41, nearly double  $F_{msy}$  (0.23), and spawning stock biomass was estimated to be 18,296 mt in 2002, 72% of  $SSB_{msy}$  (25,248 mt). Recent year classes appear to be above average. Although the spawning stock

biomass has increased, the age structure still remains truncated. Fishing mortality should be reduced to  $F_{msy}$  or below to allow the age structure to rebuild.

## **WORKING GROUP DISCUSSION**

The Working Group noted the truncated age structure in the landings during the 1990s, and concluded that the 11+ group was appropriate for this species. The Working Group discussed the survey filter method and its potential to overestimate discards when closed area exists. The Working Group concurred that the survey filter method should be used only when Fisheries Observer Program data are not available or insufficient to characterize discards. The Working Group accepted the large-mesh otter trawl discards which had been estimated using both the survey filter method for the 1982-1994 period and the FOP data for the 1995-2002 period.

The maturity analyses and limitations of using multiple maturity stanzas was also discussed. The Working Group examined the annual estimates of  $A_{50}$  over time relative to the six stanzas and agreed that, while time trends in  $A_{50}$  were evident, the multi-year moving time block method used to estimate annual maturity ogives was appropriate.

The Working Group pointed out that very few witch flounder are caught during the NEFSC bottom trawl surveys. In most years, the stratified mean number per tow of witch flounder is less than five fish. During the late 1980's and early 1990's, the abundance of witch flounder may have gone below detectable levels with one or less than one fish per tow.

The Working Group pointed out that the recent, above-average year classes may be poorly determined, and based on the retrospective pattern for recruitment, these year classes may be overestimated.

## **SARC DISCUSSION**

The effect of low sampling intensity of witch flounder in commercial landings was discussed. It was noted that in recent years, the sampling ratio has decreased especially in the small market category (87% percent of commercial landings), and it was recommended that the commercial sampling be allocated appropriately to the landings of each market category.

The SARC noted that there has been a recent increase in the proportion of smaller witch flounder in the NMFS survey, as well as the truncation of older age classes. The truncation of the age structure in the survey is consistent with high fishing mortality in the 1990s. Since full recruitment is estimated to occur at age eight, there is concern that age truncation could have a serious effect on the future reproductive potential. However, since the 1997 and 1998 above average recruitment events, the age structure is starting to expand compared to the early 1990s when fishing mortality was high and recruitment of the 1983 and 1984 year classes was very poor.

The SARC discussed the difference between survey selectivity estimates in the VPA and SCAA models. In the SCAA, there appears to be a flat-top pattern for the spring and a dome-shaped pattern for the autumn NEFSC survey. The VPA model indicates that the two surveys have similar selectivity. The SARC noted the recent decrease in mean length per tow of witch flounder, which is more apparent in the autumn compared to the spring survey. The greater inter-annual variability of mean length per tow in the autumn survey may be magnifying the discrepancy between the two models. Alternatively, the differences in selectivity and mean weights between the surveys could be a manifestation of seasonal pre-spawning aggregations of witch flounder that differentially affect the availability of older or younger witch flounder to the surveys.

The SARC discussed the decline in the mean weights at age, since declines in mean weight are counter-intuitive compared to the usual response of stocks to overfishing. There were three possible hypotheses: 1) a fishery effect; 2) a density dependent effect or 3) an environmental effect. Fishery effects on mean weights at age can occur when a fishery tends to catch larger fish of a cohort as often occurs for partially-recruited age classes. The declining mean weights at age occurred in fully-recruited year classes, however. Changes in mean weight at age are also commonly observed as a response to year class strength, a density-dependent effect. On the other hand, the year class strength was low for the older year classes where declining mean weights were observed. The other possibility, suggested by the SARC, is that environmental effects may have caused changes in large fish distribution or in growth rates which may or may not reverse as the stock size increases.

Also noted was the peculiar stock-recruitment pattern for witch flounder, where the strongest year classes were spawned when SSB was lowest, and vice versa. The SARC thought that further investigation was needed to evaluate the productivity of witch flounder and the value of biomass targets derived from assumptions about the estimated relationship between spawning biomass and recruitment. It was recommended that a longer time series of data from the SCAA results be explored as well as examining the relationship with trends in abundance of primary predators identified in the food habits data base or other factors to identify possible causes for the observed recruitment pattern. SARC analyses of NEFSC food habits data revealed that witch flounder occurred as prey items in 64 predators (13 species) during the 1978 to 2000 period.

There were several methodological issues raised by the SARC. The SARC commented that estimation uncertainty for input parameters were not included in the YPR analysis. Concerning the ability to compare and evaluate different model formulations and methods, the SARC recommended using an overall statistic (e.g. AIC statistic) for this purpose.

For the accepted VPA formulation, the SARC noted that the CVs are within acceptable ranges and residuals do not show strong patterns that would indicate the model's lack of fit to the data, although in older ages, there may be some positive bias in the earlier years of the time series. It was noted that the uncertainty of the assumptions associated with the model were not addressed since the 80% CI estimates only reflect uncertainty of the model fit and does not incorporate all

sources of uncertainty. The SARC also discussed the justification for using F40% as the basis for estimating a SSB proxy as a substitute for Bmsy. It was concluded that using F40% was an acceptable parameter to use for a slow-growing, late-maturing, flatfish species. Changes in the SSBmsy proxy value were attributed mainly to the addition of new recruitment data that included the strong 1995 - 2000 year classes occurring during 1998 to 2002.

The SARC considered an alternative statistical catch at age model (SCAA) for comparison with the VPA results. The SCAA approach can potentially account for uncertainty in the catch and incorporate information when the full catch-at-age data are not available (e.g. historical landings). The SARC agreed to accept the VPA assessment, although the SCAA model is under development and is giving comparable estimates. The SARC commented that the projections using the terminal year estimates of numbers at age may be optimistic given the retrospective patterns of the VPA. Uncertainties in the discard estimates may also be contributing to the observed retrospective pattern. The SCAA model avoids this problem because it accounts for errors in the catch.

The SARC also noted the landings were comprised of small fish, the age-structure of the population was truncated, and the changes in growth and maturity were occurring. There is concern that average recruitment from the VPA time series may overestimate average recruitment over all stock sizes in the projections. The SARC was also concerned about the reliability of projections since the SSB includes young spawning fish and that the retrospective patterns tend to be optimistic. It was noted that the VPA estimated higher stock biomass in recent years than those estimated by the SCAA model.

## **SOURCES OF UNCERTAINTY**

- The research bottom trawl survey catches very few witch flounder; in most years, the stratified mean number per tow of witch flounder is less than 5 fish. Abundance of witch flounder in the late 1980s and early 1990's may have gone below levels that provide reliable estimates of trends in abundance and biomass.
- Low sampling intensity of commercial length samples across market category and quarter, especially seen in the recent decreased ratio of small market category sampling, results in imprecise mean weights at age and estimates of numbers at age.
- The VPA calibration may be confounded because survey-based estimates of discards use the same information as that used as tuning indices. Survey information was used to estimate discards for the large-mesh otter trawl fishery during 1982 to 1994, as a substitute for the lack of FOP data prior to 1989 and sparse FOP coverage through 1994.
- Retrospective patterns suggest that 2002 SSB may be overestimated (i.e. future assessments may provide lower estimates of 2002 SSB) and fishing mortality may be underestimated (i.e. future assessments may provide higher estimates of F).

- Various factors including selectivity ogives, mean length of discards, and sampling frequency, introduce uncertainties in the VPA that are not appropriately treated because the VPA assumes that catches are known without error.

## RESEARCH RECOMMENDATIONS

- Continue to develop alternative models to the VPA, focusing on those that incorporate sampling error and uncertainties in input parameters. While the statistical catch-at-age model is a useful approach, it is still at the developmental stage; further work is needed to examine the sensitivity of the model's weighting factors.
- Investigate the sensitivity of SSB estimates to the number of years used to calculate annual proportion mature at age using a multiple year time block.
- Explore the sensitivity of the assessment models to discard at age estimates, especially with respect to retrospective patterns and other diagnostics.
- Explore the usefulness of the Maine Department of Marine Resources inshore survey for estimating trends in relative abundance and biomass, and for use as assessment tuning indices.
- Improve the biological sampling of all market categories. Sampling should be proportion to landings.

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Table A.1. Significant changes in management regulations governing the USA commercial fishery for witch flounder (adapted from O'Brien and Brown, 1996), updated by Tom Nies, NEFMC (pers. comm., 2003).

<u>1953-1977</u>		<u>ICNAF era</u>
1953		Minimum mesh in body and codend 4 ½ inches.
1970		Areas 1(A) and 2(B) closed during haddock spawning, from March - April.
1972-1974		Areas 1(A) and 2(B) closure extended to March - May.
1975		Areas 1(A) and 2(B) closures extended to February - May.
<u>1977 - Present</u>		<u>Extended Jurisdiction and National Management</u>
1977		USA Fishery Conservation and Management Act of 1976 (FCMA) in effect.
1977-1982		Fishery Management Plan (FMP) for Atlantic groundfish: Seasonal spawning closures for haddock (Areas 1 and 2), quotas for haddock, etc
1982		<b>Mesh size 5 1/8 inches (130 mm).</b>
1982-1985		The 'Interim Plan' for Atlantic groundfish: Eliminated all catch controls, retained closed area and mesh size regulations, implemented minimum landing sizes.
1983		Mesh size increased to 5 ½ inches (140 mm). <b>Witch flounder minimum size 33 cm.</b>
1984	October	Hague Line separating USA and Canadian fishing zones in the Gulf of Maine and Georges Bank region.
1985		Fishery Management Plan for the Multispecies Fishery.
1987		<b>Witch flounder minimum size increased to 36 cm.</b>
1991		Amendment 4 established overfishing definitions for witch flounder in terms of Fmed (F20%) replacement levels.
1993		Area 2 closure is extended from January 1 - June 30.
1994	January May December	Amendment 5 implemented: expanded Area 2, Area 1 closure not in effect. 6 inch (152 mm) mesh restriction implemented (delayed from March 1). Square or diamond mesh allowed. Area 1, Area 2 and Nantucket Lightship Area closed year-around.
1996	July	Amendment 7 implemented: <b>Days-at-sea (DAS) restrictions.</b> Haddock trip limits Raised to 1000 pounds
1997	May	Additional scheduled DAS restrictions from Amendment 7 accelerated.
1998	May	Western Gulf of Maine Closure Area adopted: Jeffery's Ledge area closed to all groundfishing. Rolling closures in the western Gulf of Maine.
	October	Amendment 9: revised overfishing definitions as required by Sustainable Fisheries Act.
1999	May	<b>Codend mesh regulations changed to 6-inch diamond mesh, 6 1/2-inch square mesh.</b> Additional rolling closures adopted in the western Gulf of Maine Cashes Ledge seasonal closure adopted Roller gear limited to a maximum of 12 inches in an area of the western Gulf of Maine. Gulf of Maine cod trip limit ranged from 30 to 400 lbs. in this fishing year.

Table A.1 continued. Significant changes in management regulations.

2000	May	May closure implementation on northern Georges Bank. Changes to large mesh permit category, granting additional DAS to vessels using larger than 6-inch diamond / 6-inch square mesh.
2002	June 1	Additional restrictions adopted during this fishing year (result of lawsuit over FW33): Vessels limited to 25% of allocated DAS May to July; Increase in minimum mesh size for trawl vessel to 6 ½ inch diamond/ 6 ½ inch square; Reduced number of rolling closures in the western Gulf of Maine (effective in January 2003, with result there were additional rolling closures in calendar year 2002 compared to calendar year 2001); Cashes Ledge seasonal closure expanded to year-around closure; Increase in GOM cod trip limit to 500 lbs. per day/4,000 lbs per trip; Increase in mesh size for large mesh permit category.
2002	August 1	Reduction in allocated DAS based on past history of use for each permit; Front-loading of DAS clock prohibited; Additional restrictions on number and deployment of gillnets.

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Table A.2. Significant changes in management regulations governing the USA northern shrimp fishery in the Gulf of Maine.

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1972	Adoption of mesh regulations, Establishment of count/pound limits, Establishment of closed areas.
1973	Adoption of interim minimum mesh regulations; mesh size not less than 1.5 inches (38 mm).
1975	<b>Minimum mesh regulations increased to 1.75 inches (44 mm).</b> Harvest restricted to 4,200 mt (9.2 million pounds). Fishery closure from July - September.
1976	Harvest restricted to 2,300 mt (5 million pounds) by season closure and quota management. Open season: January 1 - April 15 1976.
1977	Harvest restricted to 1,600 mt (3.5 million pounds). Open season: January 1 - May 15 1977.
1978	<b>Closure of fishery.</b>
1979	Open season: February 1 - March 31, 1979
1980	Open season: February 15 - May 31, 1980
1981	Open season: February 15 - May 31, 1981
1982	Open season: January 1 - April 15, 1982
1983	Open season:
1984	Open season:
1985	Open season:
1986 - 1991	Open season: 183 days, by-catch limit of 10% by weight of groundfish allowed.
1992 April	<b>Nordmore grate regulation</b> (max 25 mm space); no bycatch of groundfish allowed, no Sunday fishing
1993	Open season: Dec 15 - May 15, no Sundays, separator gear Dec 15 - Mar 15; grate Apr-May15
1994	Open season: December 15 - April 15
1995	Open season: December 1 - May 31 with 1 day off per week.
1996	Open season: December 1 - May 31 with 1 week off.
1997	Open season: December 1 - May 27 with 4 or 5 day block off per month.
1998	Open season: December 8 - May 22 with 3 weekends of no fishing
1999	Open season: December 1 - May 30, no weekend fishing.
2000	Open season: (51 day season)
2001	Open season: Jan 9 - March17; April 16-30 and no days off (83 day season)
2002	Open season: February 15 - March 11 (25 day season)
2003	Open season: Jan 15 - Feb 27 no Friday fishing (38 day season)

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Table A.3. Witch flounder landings, discards and catch (metric tons, live) by country, 1937-2002  
 [1937-1959 provisional landings reported in Lange and Lux, 1978; 1960-1963 reported to  
 ICNAF/NAFO (Burnett and Clark, 1983)].

Year	LANDINGS						USA Discards	USA Catch
	USA Subarea 4, 5 & 6	USA Subarea 3	USA Total	CAN	Other	Total		
1937			5000			5000		
1938			3600			3600		
1939			3100			3100		
1940			3000			3000		
1941			2000			2000		
1942			1800			1800		
1943			1000			1000		
1944			1000			1000		
1945			1000			1000		
1946			1500			1500		
1947			1500			1500		
1948			1000			1000		
1949			3600			3600		
1950			3000			3000		
1951			2600			2600		
1952			3700			3700		
1953			4200			4200		
1954			4000			4000		
1955			2400			2400		
1956			2000			2000		
1957			1000			1000		
1958			1000			1000		
1959			1000			1000		
1960	1255		1255			1255		
1961	1022		1022	2		1024		
1962	976		976	1		977		
1963	1226		1226	27	121	1374		
1964	1381		1381	37		1418		
1965	2140		2140	22	502	2664		
1966	2935		2935	68	311	3314		
1967	3370		3370	63	249	3682		
1968	2807		2807	56	191	3054		
1969	2542		2542		1310	3852		
1970	3112		3112	19	130	3261		
1971	3220		3220	35	2860	6115		
1972	2934		2934	13	2568	5515		
1973	2523		2523	10	629	3162		
1974	1839		1839	9	292	2140		
1975	2127		2127	13	217	2357		
1976	1871		1871	5	6	1882		
1977	2469		2469	11	13	2493		
1978	3501		3501	18	6	3525		
1979	2878		2878	17		2895		
1980	3128		3128	18	1	3147		
1981	3442		3442	7		3449		

continued

Table A.3 continued. Witch flounder landings, discards and catch (metric tons, live).

Year	LANDINGS							
	USA Subarea 4, 5 & 6	USA Subarea 3	USA Total	CAN	Other	Total	USA Discards	USA Catch
1982	4906		4906	9		4915	48	4954
1983	6000		6000	45		6045	162	6162
1984	6660		6660	15		6675	100	6760
1985	6130	255	6385	46		6431	61	6191
1986	4610	539	5149	67		5216	25	4635
1987	3450	346	3796	23		3819	47	3497
1988	3262	358	3620	45		3665	60	3322
1989	2068	297	2365	13		2378	133	2201
1990	1465	2	1467	12		1479	184	1649
1991	1777		1777	7		1784	95	1872
1992	2227		2227	7		2234	171	2398
1993	2601		2601	10		2611	376	2977
1994	2665		2665	34		2699	422	3087
1995	2209		2209	11		2220	193	2402
1996	2087		2087	10		2097	254	2341
1997	1771		1771	7		1778	300	2071
1998	1848		1848	10		1858	286	2134
1999	2121		2121	19		2140	213	2334
2000	2439		2439	53		2492	115	2554
2001	3019		3019	32		3051	224	3243
2002	3186		3186			3186	279	3465

Table A.4. Percentage of USA commercial witch flounder landings (mt) by Statistical Area, 1973 - 2002.

YEAR	Statistical Areas																							TOTAL		
	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
1973	-	1.1	-	0.8	-	-	-	4.0	9.4	18.6	13.8	1.5	-	10.5	16.3	0.8	2.9	7.6	10.7	-	1.0	0.0	0.2	-	0.6	100.0
1974	-	2.7	-	0.1	0.2	-	-	1.0	4.1	17.3	11.6	1.3	-	18.2	16.0	0.9	5.7	7.9	10.4	-	2.2	0.1	0.1	-	0.2	100.0
1975	-	0.7	-	0.8	0.0	-	-	0.8	7.1	16.9	13.6	4.3	-	17.4	11.2	0.5	7.5	13.2	4.9	-	0.6	0.0	0.1	-	0.2	100.0
1976	-	1.2	-	0.3	0.1	-	-	1.3	7.5	25.1	19.5	2.0	-	14.9	11.2	1.3	4.3	7.7	2.7	-	0.6	0.1	0.1	-	0.2	100.0
1977	-	0.2	-	0.2	0.1	-	-	0.6	7.8	30.6	27.6	4.1	-	10.4	10.1	0.8	2.5	2.9	1.2	-	0.5	0.1	0.2	-	0.1	100.0
1978	-	0.3	-	0.1	-	-	-	0.2	9.5	39.1	18.3	4.7	-	10.5	8.7	2.4	2.5	1.1	1.3	-	0.6	0.2	0.1	-	0.3	100.0
1979	-	0.2	-	0.0	-	-	-	2.3	9.4	35.6	14.5	4.2	-	12.8	13.7	3.4	1.2	0.5	1.0	-	0.7	0.0	0.1	-	0.5	100.0
1980	-	0.1	-	0.2	-	-	-	1.4	8.9	42.2	12.3	8.2	-	10.1	7.4	2.1	0.8	1.2	3.5	-	0.6	0.0	0.2	-	0.5	100.0
1981	-	0.2	-	1.0	-	-	-	1.9	9.2	41.0	12.2	9.4	-	11.3	5.3	2.0	1.8	1.4	1.2	-	1.1	0.0	0.3	-	0.8	100.0
1982	-	0.4	-	0.7	-	-	0.0	3.1	15.5	29.2	8.7	15.5	-	11.4	5.9	2.4	1.1	1.4	2.0	-	1.0	0.1	0.2	-	1.3	100.0
1983	-	0.5	-	2.4	-	-	-	4.2	20.6	24.3	8.0	17.4	-	9.3	5.4	2.0	0.8	1.1	1.7	-	1.5	0.0	0.2	-	0.7	100.0
1984	-	0.2	-	2.2	-	-	-	2.4	11.3	23.5	11.8	19.8	-	12.0	6.5	2.3	1.0	1.8	2.7	-	1.5	0.0	0.1	-	0.9	100.0
1985	4.0	0.1	-	1.1	-	-	-	3.7	11.8	23.1	10.3	19.8	-	11.5	7.3	2.0	1.0	1.6	1.7	-	0.5	0.0	0.0	-	0.6	100.0
1986	10.5	0.2	-	1.3	0.0	-	-	4.0	14.9	23.6	9.1	15.3	-	9.3	5.8	1.9	0.4	0.6	1.5	-	0.6	0.0	0.0	-	1.0	100.0
1987	9.1	0.1	-	0.4	-	-	-	2.7	11.6	27.4	9.6	19.0	-	9.1	5.6	1.4	0.5	0.7	1.2	-	0.4	0.0	0.0	-	1.1	100.0
1988	9.9	-	-	0.3	-	-	-	2.6	8.0	26.5	9.7	17.0	-	12.4	5.7	1.5	1.0	2.7	1.3	-	0.4	0.0	0.0	-	1.1	100.0
1989	12.5	0.0	-	0.1	-	-	-	1.3	7.4	21.8	9.4	16.1	-	12.8	5.7	1.6	1.2	2.2	5.4	-	0.9	0.1	0.0	-	1.3	100.0
1990	0.1	0.3	-	0.1	-	-	-	1.6	9.1	29.0	12.4	12.7	-	11.1	5.5	2.4	2.4	3.7	5.2	-	2.6	0.0	0.1	-	1.6	100.0
1991	-	0.1	-	0.1	-	-	-	1.1	9.3	26.1	11.0	15.6	-	8.1	7.7	2.4	3.0	2.0	4.8	-	4.7	0.1	0.1	-	3.7	100.0
1992	-	0.0	-	-	-	-	-	0.6	10.5	23.2	10.1	14.8	-	6.8	8.4	2.0	1.7	2.8	9.8	-	6.4	0.0	0.2	-	2.8	100.0
1993	-	0.5	-	-	-	-	-	0.5	6.7	22.3	16.1	16.2	-	6.9	10.4	3.1	2.5	3.6	5.1	-	3.8	0.0	0.1	-	2.2	100.0
1994*	-	-	0.1	-	-	0.4	0.3	1.7	13.1	15.5	15.5	13.5	0.1	14.3	12.2	2.6	1.5	2.1	1.6	0.1	2.7	0.4	0.1	0.2	1.8	100.0
1995*	-	-	0.5	0.5	-	0.6	0.2	1.1	6.8	14.1	15.2	20.6	0.3	17.3	15.0	1.9	0.7	1.5	0.6	0.2	1.1	0.2	0.0	0.1	1.6	100.0
1996*	-	-	0.1	0.1	-	0.8	1.2	1.7	6.3	18.1	13.8	20.9	1.2	13.7	14.1	2.1	0.4	2.2	0.3	0.0	1.3	0.4	0.1	0.1	1.0	100.0
1997*	-	-	-	0.1	-	1.1	0.7	0.7	9.3	16.5	12.6	21.9	0.6	11.0	16.1	2.7	0.5	3.2	0.7	-	1.2	0.3	0.1	-	0.8	100.0
1998*	-	-	-	0.1	-	1.2	0.1	0.7	8.3	14.5	11.1	21.8	0.2	15.1	16.2	3.5	1.3	2.5	0.5	0.1	1.1	0.6	0.3	0.1	0.5	100.0
1999*	-	-	-	0.1	-	0.4	0.1	0.7	8.2	12.0	11.9	15.8	1.5	17.7	20.9	2.9	1.3	3.0	0.5	-	1.8	-	0.1	-	1.1	100.0
2000*	-	-	-	0.1	-	0.3	0.1	1.0	5.6	12.4	14.5	12.9	0.2	22.8	20.6	2.5	1.0	2.4	0.3	-	0.8	0.2	0.3	0.1	2.0	100.0
2001*	-	-	0.1	0.1	-	-	0.1	1.7	5.2	14.1	15.6	11.2	-	24.8	18.0	4.8	0.5	1.5	0.4	-	0.8	0.1	0.2	-	0.8	100.0
2002*	-	-	-	0.1	-	-	-	1.5	5.5	15.3	23.0	10.5	-	18.4	16.9	3.2	1.6	2.2	0.5	-	0.2	0.3	0.2	0.1	0.5	100.0

<sup>1</sup>Note: USA portions of SA 523 and 524 were renamed 561 and 562, respectively, in 1985.

\* 1994-2002 spatial distribution based upon Vessel Trip Report data, considered provisional.

Table A.5. Percentage of annual USA commercial witch flounder landings by gear type, 1973-2002.

Year	Otter Trawl	Shrimp Trawl	Other	Total
1973	98.7	-	1.3	100.0
1974	99.7	-	0.3	100.0
1975	97.3	2.5	0.2	100.0
1976	98.8	0.9	0.3	100.0
1977	97.4	1.5	1.1	100.0
1978	98.1	-	1.9	100.0
1979	97.9	0.2	1.9	100.0
1980	96.6	0.6	2.8	100.0
1981	97.3	0.8	1.9	100.0
1982	96.8	0.9	2.3	100.0
1984	96.4	0.4	3.2	100.0
1985	95.1	1.0	3.9	100.0
1986	95.9	1.1	3.0	100.0
1987	95.5	1.1	3.4	100.0
1988	96.0	0.8	3.2	100.0
1989	95.3	0.4	4.3	100.0
1990	92.8	0.6	6.6	100.0
1991	95.1	0.5	4.4	100.0
1992	96.2	0.1	3.7	100.0
1993	94.2	0.0	5.8	100.0
1994	96.2	0.0	3.8	100.0
1995	96.1	0.0	3.9	100.0
1996	96.7	0.0	3.3	100.0
1997	96.9	0.0	3.1	100.0
1998	97.5	0.0	2.5	100.0
1999	97.4	0.0	2.6	100.0
2000	97.5	0.0	2.5	100.0
2001	97.5	0.0	2.5	100.0
2002	97.8	0.0	2.2	100.0



Table A.6. Percentage of annual USA commercial witch flounder landings by market category, 1973 - 2002.

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
1999	10.1	74.3	10.1	4.6	0.0	0.9	100.0
2000	8.1	76.6	9.7	3.6	0.0	2.0	100.0
2001	9.0	77.9	9.1	2.9	0.0	1.1	100.0
2002	8.2	78.5	9.7	2.6	0.0	0.9	100.0

Table A.7. Summary of USA commercial witch flounder landings (mt), number of length samples (n), number of fish measured (len) and number of age samples (age) by market category and quarter for all gear types, 1981 - 2002. The sampling ratio represents the amount of landings per length sample.

Year	Quarter 1			Quarter 2			Quarter 3			Quarter 4			Sampling	
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	All	Ratio
1981 mt	260	7	517	269	32	694	242	13	607	230	0	453	3324	
n	.	.	.	.	1	1	.	1	.	1	.	1	5	
len	.	.	.	.	101	103	.	89	.	105	.	100	498	
age	.	.	.	.	.	26	.	25	.	25	.	25	101	
1982 mt	348	1	726	342	73	886	287	170	739	278	201	669	4720	
n	5	2	6	1	2	2	2	2	6	3	4	2	37	128
len	527	194	626	126	209	216	189	210	514	307	393	189	3700	
age	128	55	150	30	55	50	50	50	150	81	105	50	954	
1983 mt	475	250	910	471	286	1037	298	154	758	257	169	613	5678	
n	5	2	3	5	1	5	8	3	8	6	3	.	49	116
len	680	232	265	685	96	520	1008	123	981	677	344	.	5611	
age	135	30	55	131	16	125	152	0	159	180	75	.	1058	
1984 mt	462	322	1036	513	393	1000	403	248	653	429	286	586	6331	
n	5	9	4	7	1	7	8	1	2	4	2	1	51	124
len	804	1112	400	970	117	775	1045	106	191	615	243	91	6469	
age	154	250	76	186	25	180	210	28	53	105	44	25	1336	
1985 mt	465	377	613	697	453	850	526	291	553	433	310	408	5976	
n	12	1	2	5	4	7	7	7	6	8	2	4	65	92
len	1530	105	229	657	426	698	795	800	684	824	264	349	7361	
age	319	29	50	106	77	153	97	138	113	161	25	29	1297	
1986 mt	384	309	356	654	421	595	375	238	354	312	212	238	4448	
n	6	3	5	5	4	5	4	3	4	5	3	2	49	90
len	662	307	515	558	410	413	302	364	406	416	337	233	4923	
age	123	60	89	106	97	129	63	75	100	87	75	52	1056	

Table A.7 continued.

Year	Quarter 1			Quarter 2			Quarter 3			Quarter 4			All	Sampling Ratio
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large		
1987 mt	349	211	228	432	317	387	296	203	247	298	203	202	3373	69
n	1	1	2	4	2	3	5	5	4	2	3	2	34	
len	85	145	200	323	228	316	354	583	400	204	261	178	3277	
age	25	25	50	77	47	76	78	113	95	48	64	51	749	
1988 mt	424	304	271	436	393	389	184	176	208	140	140	131	3196	65
n	5	4	5	5	5	3	5	4	3	3	4	3	49	
len	335	407	465	344	544	429	396	359	295	229	402	356	4561	
age	70	89	106	71	110	77	70	100	75	61	95	69	993	
1989 mt	230	174	148	255	264	251	98	145	156	85	107	103	2016	112
n	1	2	2	2	2	1	2	2	1	1	2	.	18	
len	94	201	222	230	236	27	150	206	100	125	202	.	1793	
age	25	50	49	50	46	25	40	51	25	25	47	.	433	
1990 mt	113	125	107	147	168	147	100	119	129	84	79	85	1403	40
n	1	2	3	6	3	1	6	2	2	7	2	.	35	
len	134	199	199	335	296	100	349	247	145	381	201	.	2586	
age	15	40	45	81	70	25	69	41	50	103	48	.	587	
1991 mt	71	56	58	219	151	167	192	142	184	168	108	121	1637	40
n	5	2	3	7	2	1	4	2	3	5	4	3	41	
len	262	224	401	537	239	125	212	165	249	300	410	274	3398	
age	53	50	80	93	45	25	49	49	52	66	97	58	717	
1992 mt	180	86	82	466	163	174	205	115	138	212	97	116	2034	68
n	4	2	2	7	1	2	7	1	1	2	.	1	30	
len	259	241	185	501	125	235	477	121	117	129	.	46	2436	
age	42	46	52	78	25	25	86	25	25	27	.	23	454	
1993 mt	350	112	110	442	192	161	263	122	150	331	96	106	2435	76
n	7	1	.	7	1	1	9	1	5	.	.	.	32	
len	830	100	.	741	107	100	728	85	499	.	.	.	3190	
age	55	25	.	56	27	26	74	.	73	.	.	.	336	

Table A.7. continued.

Year	Quarter 1			Quarter 2			Quarter 3			Quarter 4			Sampling	
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	All	Ratio
1994 mt	403	143	98	505	183	154	390	122	117	383	91	80	2670	
n	.	.	.	3	5	6	5	5	1	5	3	4	37	72
len	.	.	.	560	532	749	356	648	105	342	368	407	4067	
age	.	.	.	59	104	134	44	113	26	56	60	82	678	
1995 mt	336	91	77	586	117	100	399	61	70	304	48	40	2212	
n	3	3	3	6	3	5	.	.	.	2	.	1	26	85
len	208	348	347	459	367	517	.	.	.	217	.	94	2557	
age	53	84	89	81	75	135	.	.	.	27	.	25	569	
1996 mt	313	57	36	545	86	60	458	56	44	363	42	28	2088	
n	5	2	3	5	2	1	5	4	4	5	3	3	42	50
len	504	218	292	331	240	127	494	464	468	343	277	348	4106	
age	59	45	78	53	50	26	59	86	101	60	70	69	756	
1997 mt	313	40	25	478	86	41	398	55	27	265	31	16	1775	
n	6	3	3	9	4	3	9	3	1	9	1	1	52	34
len	557	350	351	812	418	309	783	308	107	505	128	50	4678	
age	77	68	70	108	73	77	98	81	20	73	18	23	786	
1998 mt	372	39	19	587	79	31	380	40	20	239	26	14	1849	80
n	5	2	1	4	1	1	5	3	1	.	.	.	23	
len	339	206	128	238	88	135	484	186	100	.	.	.	1904	
age	45	50	19	30	.	29	47	22	.	.	.	.	242	
1999 mt	386	48	19	616	79	31	436	67	30	353	38	18	2121	51
n	3	.	.	4	.	.	17	2	3	11	1	.	41	
len	282	.	.	308	.	.	1110	201	306	775	109	.	3091	
age	15	.	.	62	.	.	143	.	32	91	16	.	359	
2000 mt	477	53	17	583	93	27	555	89	28	451	50	16	2439	21
n	31	2	.	47	.	.	17	1	.	5	5	2	110	
len	2253	91	.	2445	.	.	994	105	.	308	558	217	6971	
age	390	10	.	460	.	.	224	20	.	67	92	51	1314	

Table A.7 continued.

Year	Quarter 1			Quarter 2			Quarter 3			Quarter 4			Sampling	
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	All	Ratio
2001 mt	583	71	17	824	99	30	699	98	28	507	50	13	3019	70
n	8	4	2	3	3	2	8	2	3	5	3	.	43	
len	744	422	134	237	352	159	594	209	213	313	232	.	3609	
age	125	63	42	47	48	64	126	34	46	61	48	.	704	
2002 mt	740	79	18	774	103	26	849	114	29	400	45	9	3186	91
n	4	1	2	3	5	3	5	2	3	3	2	2	35	
len	312	121	107	212	518	209	389	150	194	262	226	115	2815	
age	73	14	44	65	68	63	86	32	62	49	30	49	635	

Table A.8. The data pooling to apply age and length frequency samples to landings by market category and quarter to estimate numbers at age of witch flounder from 1982-2002.

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 =>	

Table A.8. Continued.

Year	Mkt. Cat.	Quarter 1	Quarter 2	Quarter 3	Quarter 4
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 ===>			
1999	Small	<=Pooled =>		X	X
	Med.	<===Pooled ===>			
	Large	<===Pooled ===>			
2000	Small	X	X	X	X
	Med.	<===Pooled ===>			
	Large	<===Pooled ===>			
2001	Small	X	X	X	X
	Med.	<=Pooled =>		<=Pooled =>	
	Large	<===Pooled ===>			
2002	Small	X	X	X	X
	Med.	<=Pooled =>		<=Pooled =>	
	Large	<=Pooled =>		<=Pooled =>	

Table A.9. USA commercial landings at age in numbers, weight (thousands of fish; mt) and mean weight (kg) and mean length (cm) at age of witch flounder, 1982 - 2002.

Year	Age															TOTAL	11+
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+		
<b>USA Commercial Landings in Numbers (1000's) at Age</b>																	
1982	0.0	0.0	0.0	117.9	826.6	1119.9	1454.3	665.2	656.0	399.5	239.4	201.0	356.3	183.7	837.4	7057.2	1578.4
1983	0.0	0.0	0.0	219.8	768.6	1033.7	1567.3	1590.2	977.8	737.7	510.4	366.0	287.3	289.1	733.1	9081.0	1675.5
1984	0.0	0.0	0.0	90.6	1012.4	1808.7	1734.3	1486.5	1497.5	696.7	375.1	279.5	356.4	261.3	821.6	10420.0	1718.8
1985	0.0	0.0	0.0	0.0	985.1	2026.8	1933.8	1524.9	1247.9	606.0	400.4	261.2	221.5	170.7	705.8	10084.0	1359.2
1986	0.0	0.0	0.0	6.3	298.5	1441.6	2772.6	1566.9	834.9	412.7	222.8	188.2	157.0	137.0	276.0	8314.5	758.2
1987	0.0	0.0	0.0	0.0	81.5	321.6	1276.0	1574.7	870.9	480.6	252.4	132.4	90.8	62.1	204.1	5347.1	489.4
1988	0.0	0.0	0.0	0.0	50.8	176.0	654.7	1382.7	1154.1	401.5	266.7	124.1	94.0	71.9	307.5	4684.0	597.5
1989	0.0	0.0	0.0	0.0	7.3	49.7	314.3	759.4	882.1	349.7	123.4	73.2	61.1	56.7	157.1	2833.8	349.0
1990	0.0	0.0	0.0	0.0	181.6	574.3	255.6	273.9	471.1	333.9	81.4	43.1	38.5	19.1	76.9	2349.2	179.1
1991	0.0	0.0	0.0	0.0	179.5	732.9	519.4	235.8	244.6	292.1	313.6	51.8	44.0	22.5	139.5	2775.6	260.8
1992	0.0	0.0	0.0	0.0	509.3	839.4	935.5	717.0	201.6	177.9	120.0	217.6	46.3	26.5	86.5	3877.7	380.2
1993	0.0	0.0	0.0	0.0	422.2	1022.8	917.7	597.2	585.6	218.8	278.5	113.9	32.6	103.6	140.4	4433.2	391.1
1994	0.0	0.0	0.0	0.0	201.3	1429.4	1286.2	826.9	196.7	539.2	113.5	71.4	40.2	132.3	80.4	4917.4	324.9
1995	0.0	0.0	0.0	0.0	23.7	763.0	1597.4	848.7	267.5	97.2	269.5	55.0	43.9	8.1	49.9	4023.8	157.1
1996	0.0	0.0	0.0	0.0	45.8	467.7	1263.8	1430.4	263.2	215.5	57.1	78.8	3.6	13.0	18.2	3857.2	113.7
1997	0.0	0.0	0.0	0.0	212.2	527.9	1049.4	1014.0	591.3	83.1	49.8	17.9	36.6	2.2	13.4	3597.8	70.2
1998	0.0	0.0	0.0	0.0	18.1	488.0	1213.5	1583.0	370.5	141.4	15.5	37.2	5.6	19.9	7.7	3900.2	70.3
1999	0.0	0.0	0.0	0.0	185.2	585.7	1391.7	1178.3	763.2	251.3	31.6	40.8	0.0	0.0	13.5	4441.3	54.4
2000	0.0	0.0	0.0	0.0	75.4	266.2	1062.1	1611.1	1027.6	623.7	94.8	174.3	6.2	5.0	27.4	4973.9	212.8
2001	0.0	0.0	0.0	0.0	18.8	382.2	940.5	1669.0	1459.4	634.3	425.4	95.8	163.5	8.6	38.8	5836.3	306.7
2002	0.0	0.0	0.0	0.0	173.2	644.9	1242.7	2098.3	1274.4	632.1	96.4	102.7	11.0	65.6	25.3	6366.6	202.6



Table A.9. continue. USA commercial landings.

Year	Age														TOTAL	11+	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13			14+
<b>USA Commercial Landings Mean Weight (kg) at Age</b>																	
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
1999	0.000	0.000	0.000	0.000	0.325	0.355	0.406	0.516	0.584	0.628	0.917	0.683	-	-	1.442	0.477	0.872
2000	0.000	0.000	0.000	0.000	0.319	0.327	0.376	0.450	0.533	0.633	0.677	0.834	1.167	1.298	1.379	0.490	0.925
2001	0.000	0.000	0.000	0.000	0.291	0.325	0.384	0.469	0.550	0.646	0.647	0.718	0.816	1.016	1.206	0.517	0.840
2002	0.000	0.000	0.000	0.000	0.354	0.344	0.416	0.477	0.554	0.651	0.824	0.844	0.716	0.993	1.120	0.501	0.919
mean																	
1982-02	0.000	0.000	0.000	0.034	0.287	0.345	0.421	0.535	0.654	0.807	0.934						1.237
1999-02	0.000	0.000	0.000	0.000	0.322	0.338	0.396	0.478	0.555	0.640	0.766						0.889

Table A.9 continued. USA commercial landings.

Year	Age														TOTAL	11+	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13			14+
<b>USA Commercial Landings Mean Length (cm) at Age</b>																	
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	39.9	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	57.9	57.9	43.8	56.5
1992	0.0	0.0	0.0	0.0	37.0	38.7	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	53.1	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	40.9	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
1999	0.0	0.0	0.0	0.0	36.6	37.5	39.0	41.8	43.3	44.3	49.4	45.2	-	-	56.4	40.7	48.0
2000	0.0	0.0	0.0	0.0	36.4	36.7	38.2	40.2	42.2	44.2	45.2	47.7	53.0	54.6	55.3	40.9	49.0
2001	0.0	0.0	0.0	0.0	35.5	36.6	38.4	40.7	42.5	44.6	44.5	45.9	47.7	50.8	53.3	41.6	47.9
2002	0.0	0.0	0.0	0.0	37.4	37.2	39.3	40.9	42.7	44.6	47.9	48.2	45.8	50.5	52.2	41.6	49.3

Table A.10. Discard rates (kg/day fished) by fishing zone<sup>1</sup> obtained from a ratio estimator (kg of witch flounder discarded to days fished) using Fisheries Observer 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 seasons.

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

<sup>1</sup> 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 A.11. Witch flounder discard rates (kg/df), days fished (df), discarded metric tons (mt), numbers of discarded fish (in thousands) in the northern shrimp fishery during 1982-2002.

Year	Shrimp Season Disc. Rate	Calendar Year			mt	Numbers (‘000)
		Days Fished				
		Jan-Apr	Dec.	Total		
1982	5.7025	970.1	35.6	1005.7	5.90	62.14
1983	10.4523	1121.3	141.7	1263	12.56	131.67
1984	5.9234	1612.3	237.6	1849.9	10.93	110.94
1985	5.8129	1843.8	272.8	2116.6	12.12	91.32
1986	5.1502	2122.3	428.9	2551.2	13.14	98.80
1987	5.1502	3279.3	380.4	3659.7	21.79	235.99
1988	12.8824	2434.8	426.9	2861.7	33.95	723.95
1989	6.0626	2412.6	491.9	2904.5	18.93	219.81
1990	8.7512	2712.7	377.6	3090.3	28.53	468.56
1991	12.6856	2210.1	172.3	2382.4	29.46	443.85
1992	8.2343	2141.0	113.2	2254.2	18.13	384.45
1993	4.4485	1789.0	161.7	1950.7	8.86	356.77
1994	5.6004	1820.6	530.8	2351.4	16.06	1891.71
1995	11.0492	2844.9	547.6	3392.5	33.80	1176.37
1996	4.3130	2695.3	645.2	3340.5	13.75	250.46
1997	3.2915	3016.0	361.4	3377.4	13.27	304.52
1998	9.2437	1842.6	96.9	1939.5	18.04	873.52
1999	10.3851	1120.5	0	1120.5	11.64	563.50
2000	9.8775	792.9	0	792.9	7.83	379.26
2001	6.6415	672.8	0	672.8	4.47	216.38
2002	3.5325	238	0	238	0.84	40.68

Note: 1982-1988 discard rates were derived from a linear regression using 1989-1993 discard rates and NEFSC autumn age 3 abundance indices.

1998-2002 discard rates were derived from a linear regression using 1989-1993 discard rates and NEFSC autumn age 3 abundance indices.

Table A.12. Witch flounder discards at age in numbers, weight (thousands of fish; mt) and mean weight (kg) and mean length (cm) at age in the shrimp fishery, 1982 - 2002.

Year	Age															TOTAL
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	
<b>Shrimp Fishery Discards in Numbers (1000's) at Age</b>																
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
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
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
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
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
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
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
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
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
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
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
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
1994	8.06	1368.46	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	1891.71
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	1176.37
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
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
1998	49.78	391.44	264.72	132.04	30.13	4.78	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	873.52
1999	32.11	252.51	170.76	85.18	19.44	3.09	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	563.50
2000	21.61	169.95	114.93	57.33	13.08	2.08	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	379.26
2001	12.33	96.96	65.57	32.71	7.46	1.19	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	216.38
2002	2.32	18.23	12.33	6.15	1.4	0.22	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.68

Note: 1998-2002 estimated using 1993-1997 Fisheries Observer Program data.

Table A.12 continued. Discards in the shrimp fishery.

Year	Age														TOTAL
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	
<b>Shrimp fishery Mean Weight (kg) at Age</b>															
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	0.003	0.006	0.023	0.042	0.100	0.184	0.286								0.021
1999	0.003	0.006	0.023	0.042	0.100	0.184	0.286								0.021
2000	0.003	0.006	0.023	0.042	0.100	0.184	0.286								0.021
2001	0.003	0.006	0.023	0.042	0.100	0.184	0.286								0.021
2002	0.003	0.006	0.023	0.042	0.100	0.184	0.286								0.021
Mean															
1982-02	0.004	0.011	0.027	0.050	0.110	0.197	0.267								0.058

Noe:1998-2002 estimated using 1993-1997 Fisheries Observer Program data.

Table A.12 continued. Discards in the shrimp fishery.

Year	Age														TOTAL	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13		14+
<b>Shrimp fishery Mean Length (cm) at Age</b>																
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									28.3
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	9.4	10.4	16.8	20.3	26.4	31.5	36.1									14.9
1999	9.4	10.4	16.8	20.3	26.4	31.5	36.1									14.9
2000	9.4	10.4	16.8	20.3	26.4	31.5	36.1									14.9
2001	9.4	10.4	16.8	20.3	26.4	31.5	36.1									14.9
2002	9.4	10.4	16.8	20.3	26.4	31.5	36.1									14.9

Note: 1998-2002 estimated using 1993-1997 Fisheries Observer Program data.

Table A.13 . Summary of number of trips, tows, kept and discard pounds of witch flounder, discard: kept ratio observed in the large-mesh otter trawl fishery in the Georges Bank - Gulf of Maine area (observed tows only; excluding trips targeting loligo) from the Fisheries Observer Program, 1989 - 2002.

Year	January - June								July- December								Annual mt
	Trips	Tows	Fish in disc l-f	Pounds kept	discard	D/K ratio	metric tons Landing Disc.		Trips	Tows	fish in disc lf	Pounds kept Disc	D/K ratio	metric tons landings discard			
1989	3	17	68	850	14	0.016	1298.64	20.78	4	19	411	427	142	0.333	663.58	220.97	241.75
1990	2	2	20	50	1	0.020	795.25	15.91	1	12	10	535	48	0.090	573.98	51.66	67.56
1991	4	45	15	1655	49	0.030	757.7	22.73	6	52	148	1882	159	0.084	947.63	79.60	102.33
1992	4	80	31	1896	222	0.117	1273.78	149.03	0	0	0	0	0	<b>0.117</b>	884.62	103.50	252.53
1993	3	37	428	1607	806	0.502	1411.03	708.34	2	24	229	1665	125	0.075	1041.84	78.14	786.48
1994	5	70	63	7298	332	0.045	1427.92	64.26	5	126	125	3794	157	0.041	1139.81	46.73	110.99
1995	31	640	1500	35968	2561	0.071	1244.48	88.36	11	199	571	8240	669	0.081	878.28	71.14	159.50
1996	17	267	272	14016	1387	0.099	1049.86	103.94	1	13	75	638	90	0.141	968.59	136.57	240.51
1997	9	203	593	10907	1831	0.168	945.2	158.79	7	134	77	4518	750	0.166	772.52	128.24	287.03
1998	7	93	200	3786	595	0.157	1095.59	172.01	2	14	3	277	37	0.134	705.15	94.49	266.50
1999	3	46	5	3663	454	0.124	1149.74	142.57	15	148	225	10057	644	0.064	914.79	58.55	201.11
2000	29	211	101	25343	666	0.026	1218.38	31.68	30	266	134	26149	1711	0.065	1159.65	75.38	107.06
2001	34	332	48	36279	1864	0.051	1596.02	81.40	45	383	459	35016	3581	0.102	1356.47	138.36	219.76
2002	27	298	795	36836	2439	0.066	1678.73	110.80	83	500	2361	44451	5268	0.119	1408.75	167.64	278.44
average						0.107								0.115			

Note: in 1993, one 'dirty' trip' during Jan-June; if excluded, d/k ratio = 0.132.; dis mt = 186.3 mt

1999 and 1998 annual discard length frequencies were used due to low numbers of fish in each half year.



Table A.14. Number of trips, witch flounder kept and discarded weight (mt), discard:kept ratio from the Vessel Trip Reports, and commercial landings and estimated total discard weight.

Year	Qtr 1+2	Qtr 3+4	Total	Year	Qtr 1+2	Qtr 3+4	Total
1994 VTR trips	1228	2487		1999 VTR trips	1417	1655	
VTR kept (mt)	209.13	631.67		VTR kept (mt)	389.71	334.3	
VTR disc. (mt)	20.07	36.98		VTR disc. (mt)	18.75	17.11	
<b>Ratio (d/k)</b>	<b>0.09597</b>	<b>0.05854</b>		<b>Ratio (d/k)</b>	<b>0.04811</b>	<b>0.05118</b>	
Landings (mt)	1427.29	1139.81	2567.1	Landings (mt)	1149.74	914.79	2064.5
Discards (mt)	136.976	66.7282	203.7	Discards (mt)	55.3171	46.8204	102.1
1995 VTR trips	2674	1801		2000 VTR trips	1421	1608	
VTR kept (mt)	603.17	331.91		VTR kept (mt)	397.84	369.31	
VTR disc. (mt)	32.25	17.41		VTR disc. (mt)	21.84	19.76	
<b>Ratio (d/k)</b>	<b>0.05347</b>	<b>0.05245</b>		<b>Ratio (d/k)</b>	<b>0.0549</b>	<b>0.05351</b>	
Landings (mt)	1244.48	878.28	2122.8	Landings (mt)	1218.38	1159.65	2378.0
Discards (mt)	66.5393	46.0693	112.6	Discards (mt)	66.8847	62.0473	128.9
1996 VTR trips	2216	1662		2001 VTR trips	1327	1165	
VTR kept (mt)	469.79	411.2		VTR kept (mt)	531.92	410.55	
VTR disc. (mt)	21.62	22.93		VTR disc. (mt)	24.28	19.91	
<b>Ratio (d/k)</b>	<b>0.04602</b>	<b>0.05576</b>		<b>Ratio (d/k)</b>	<b>0.04565</b>	<b>0.0485</b>	
Landings (mt)	1049.86	968.59	2018.5	Landings (mt)	1596.02	1356.47	2952.5
Discards (mt)	48.3151	54.0121	102.3	Discards (mt)	72.8519	65.7833	138.6
1997 VTR trips	1906	1360		2002 VTR trips	791	1227	
VTR kept (mt)	355.61	302.67		VTR kept (mt)	494.02	388.52	
VTR disc. (mt)	16.39	17.22		VTR disc. (mt)	23.78	16.15	
<b>Ratio (d/k)</b>	<b>0.04609</b>	<b>0.05689</b>		<b>Ratio (d/k)</b>	<b>0.04814</b>	<b>0.04157</b>	
Landings (mt)	945.2	772.52	1717.7	Landings (mt)	1678.73	1408.75	3087.5
Discards (mt)	43.5641	43.9515	87.5	Discards (mt)	80.8068	58.5589	139.4
1998 VTR trips	1645	1129					
VTR kept (mt)	320.93	223.35					
VTR disc. (mt)	17.06	11.82					
<b>Ratio (d/k)</b>	<b>0.05316</b>	<b>0.05292</b>					
Landings (mt)	1095.59	705.15	1800.7				
Discards (mt)	58.2394	37.3175	95.6				

Table A.15. Numbers and weight (mt) of discarded witch flounder in the large-mesh otter trawl fishery derived by three scenarios: 1) Vessel trip reports (VTR), 2) Fisheries Observer Program (FOP), and 3) survey filter method.

Year	VTR	FOP	Survey filter method
Numbers (1000's)			
1982			359.01
1983			1062.39
1984			599.49
1985			320.94
1986			78.75
1987			136.47
1988			202.67
1989			733.52
1990			959.82
1991			455.22
1992			988.11
1993			2171.25
1994	832.65		2155.99
1995	639.95	906.50	1302.62
1996	543.51	1277.79	2432.13
1997	489.12	1604.49	2071.03
1998	549.41	1541.34	1722.55
1999	520.04	1024.35	1932.76
2000	668.38	555.11	3022.89
2001	695.16	1102.21	3820.86
2002	701.19	1400.56	3475.61
Weight (mt)			
1982			42.44
1983			149.04
1984			88.81
1985			48.75
1986			12.00
1987			25.68
1988			26.55
1989		241.8	113.86
1990		67.6	155.75
1991		102.3	65.41
1992		252.5	153.31
1993		786.45	367.77
1994	203.7	110.99	406.30
1995	112.6	159.50	231.23
1996	102.3	240.51	439.88
1997	87.5	287.03	379.83
1998	95.6	266.50	316.89
1999	102.1	201.11	342.33
2000	128.9	107.05	546.34
2001	138.6	219.76	700.93
2002	139.4	278.44	645.23

Table A.16. Large-mesh otter trawl discards at age in numbers (thousands of fish), mean weight (kg) and mean length (cm) at age of witch flounder, 1982 - 2002, estimated using a **survey filter method 1982-1994) and FOP data (1995-2002).**

Year	Age															TOTAL	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+		
<b>Large-mesh Otter Trawl Fishery Discards in Numbers (1000's) at Age</b>																	
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	0.00	359.01
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	0.00	1062.39
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	0.00	599.49
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	0.00	320.94
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	0.00	78.75
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	0.00	136.47
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	0.00	202.67
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	0.00	733.52
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	0.00	959.82
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	0.00	455.22
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	0.00	988.11
1993	1.70	6.96	22.01	378.54	1371.00	391.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2171.25
1994	0.00	0.02	0.94	22.35	800.5	1330.43	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2155.99
1995	0.00	0.00	25.41	147.96	334.33	278.03	116.71	2.65	1.09	0.31	0.00	0.00	0.00	0.00	0.00	0.00	906.50
1996	0.00	0.00	0.00	22.43	419.44	737.88	98.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1277.79
1997	0.00	0.00	0.00	48.80	822.57	480.73	243.46	5.05	2.47	1.41	0.00	0.00	0.00	0.00	0.00	0.00	1604.49
1998	0.00	1.45	29.48	199.19	508.67	571.00	201.32	28.61	0.93	0.70	0.00	0.00	0.00	0.00	0.00	0.00	1541.34
1999	0.00	0.43	23.69	75.74	321.49	506.95	69.80	22.80	2.19	1.25	0.00	0.00	0.00	0.00	0.00	0.00	1024.35
2000	0.00	0.00	4.58	46.17	197.98	187.57	95.56	18.26	4.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	555.11
2001	0.00	0.00	0.85	37.22	316.95	557.06	157.64	32.29	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.00	1102.21
2002	0.00	2.01	5.09	34.81	574.48	577.81	161.64	33.89	6.61	2.47	1.04	0.00	0.00	0.00	0.00	0.00	1400.56

Table A.16 continued. Discards in the large-mesh otter trawl fishery ( **survey filter method (1982-1994) and FOP data (1995-2002)** ).

Year	Age														TOTAL	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13		14+
<b>Large-mesh Otter Trawl Fishery Discards Mean Weight (kg) at Age</b>																
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				0.105	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			0.059	0.095	0.152	0.221	0.252	0.473	0.595	0.702						0.176
1996				0.077	0.145	0.208	0.251									0.188
1997				0.108	0.157	0.185	0.242	0.495	0.471	0.702						0.179
1998		0.008	0.041	0.089	0.165	0.200	0.219	0.225	0.355	0.370						0.174
1999		0.021	0.037	0.097	0.162	0.218	0.281	0.406	0.447	0.505						0.196
2000			0.066	0.096	0.155	0.198	0.280	0.313	0.403							0.193
2001			0.070	0.130	0.171	0.208	0.230	0.258	0.309	0.309						0.199
2002		0.018	0.054	0.122	0.180	0.205	0.234	0.264	0.414	0.577	0.566					0.199
Mean 1982-02	0.001	0.009	0.037	0.102	0.155	0.180	0.236	0.264	0.428	0.528	0.566					

Table A.16 continued. Discard in the large-mesh otter trawl fishery ( survey filter method (1982-1994) and FOP data (1995-2002) .

Year	Age														TOTAL	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13		14+
<b>Large-mesh Otter Trawl Fishery Discards Mean Length (cm) at Age</b>																
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			22.7	25.9	29.9	33.5	34.8	41.8	44.7	47.0						30.8
1996				24.6	29.5	32.9	34.8									31.7
1997				27.1	30.3	31.8	34.4	42.4	41.6	47.0						31.3
1998		12.3	20.3	25.6	30.7	32.5	33.3	33.4	38.5	39.0						30.9
1999		17.0	19.7	26.1	30.5	33.3	35.9	40.0	41.1	42.7						31.9
2000			23.5	26.1	30.0	32.3	35.8	36.7	39.7							31.7
2001			23.9	28.5	31.0	32.9	33.9	35.1	37.0	37.0						32.4
2002		16.0	21.9	27.7	31.4	32.7	34.0	35.1	40.1	44.2	44.0					32.3

Table A.17. **Total USA commercial catch** [landings + shrimp trawl discards + large-mesh otter trawl discards using survey filter and FOP] in numbers, (thousands of fish), mean weight (kg) and mean length (cm) at age of witch flounder, 1982 - 2002.

Year	Age															TOTAL	11+
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+		
<b>USA Commercial Catch in Numbers (1000's) at Age</b>																	
1982	0.03	0.06	1.72	190.5	1064.5	1207.7	1475.4	665.2	656.0	399.5	239.4	201.0	356.3	183.7	837.4	7478.4	1578.4
1983	0.00	0.02	4.28	337.1	1346.2	1520.8	1575.1	1590.2	977.8	737.7	510.4	366.0	287.3	289.1	733.1	10275.1	1675.5
1984	0.00	0.33	0.88	146.6	1466.3	2002.7	1739.6	1486.5	1497.5	696.7	375.1	279.5	356.4	261.3	821.6	11131.0	1718.8
1985	0.00	0.34	3.47	123.6	1176.1	2118.2	1936.2	1524.9	1247.9	606.0	400.4	261.2	221.5	170.7	705.8	10496.4	1359.2
1986	0.00	0.53	3.86	23.0	377.1	1516.8	2775.4	1566.9	834.9	412.7	222.8	188.2	157.0	137.0	276.0	8492.1	758.2
1987	2.08	18.92	79.93	22.3	181.3	467.1	1280.1	1574.7	870.9	480.6	252.4	132.4	90.8	62.1	204.1	5719.6	489.4
1988	0.42	14.66	130.29	600.3	139.9	264.3	658.3	1382.7	1154.1	401.5	266.7	124.1	94.0	71.9	307.5	5610.6	597.5
1989	0.85	10.69	50.32	447.1	436.3	65.2	314.3	759.4	882.1	349.7	123.4	73.2	61.1	56.7	157.1	3787.2	348.0
1990	1.46	6.29	95.30	343.9	634.1	1103.2	255.6	273.9	471.1	333.9	81.4	43.1	38.5	19.1	76.9	3777.6	177.5
1991	3.06	17.90	23.26	441.8	405.8	863.7	575.4	235.8	244.6	292.1	313.6	51.8	44.0	22.5	139.5	3674.7	257.8
1992	2.84	44.35	159.43	399.5	1255.6	859.2	936.0	717.0	201.6	177.9	120.0	217.6	46.3	26.5	86.5	5250.3	377.0
1993	113.76	85.80	129.59	417.2	1807.3	1419.0	918.1	597.2	585.6	218.8	278.5	113.9	32.6	103.6	140.4	6961.3	390.5
1994	8.06	1368.48	496.44	42.0	1001.8	2759.9	1288.0	826.9	196.7	539.2	113.5	71.4	40.2	132.3	80.4	8965.1	324.3
1995	2.68	49.95	655.51	628.8	370.3	1041.2	1714.5	851.4	268.5	97.5	269.5	55.0	43.9	8.1	49.9	6106.7	156.8
1996	5.21	32.68	50.83	121.9	524.4	1207.7	1362.9	1430.5	263.2	215.5	57.1	78.8	3.6	13.0	18.2	5385.5	113.6
1997	8.68	74.91	102.92	135.3	1058.5	1016.0	1293.4	1019.1	593.8	84.6	49.8	17.9	36.6	2.2	13.4	5506.9	70.1
1998	49.78	392.89	294.20	331.2	556.9	1063.7	1415.5	1611.6	371.4	142.1	15.5	37.2	5.6	19.9	7.7	6315.1	70.3
1999	32.11	252.94	194.45	160.9	526.1	1095.8	1462.0	1201.1	765.3	252.5	31.6	40.8	0.0	0.0	13.5	6029.2	54.4
2000	21.61	169.95	119.51	103.5	286.5	455.9	1158.0	1629.4	1032.6	623.7	94.8	174.3	6.2	5.0	27.4	5908.3	212.8
2001	12.33	96.96	66.42	69.9	343.2	940.4	1098.3	1701.3	1459.6	634.4	425.4	95.8	163.5	8.6	38.8	7154.9	306.7
2002	2.32	20.24	17.42	41.0	749.1	1222.9	1404.4	2132.2	1281.1	634.6	97.5	102.7	11.0	65.6	25.3	7807.9	205.2

Table A.17 continued. **Total USA commercial catch** (landings + shrimp trawl discards + LM otter trawl discards) .

Year	Age															TOTAL	11+
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+		
<b>USA Commerical Mean Weight (kg) at Age</b>																	
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		0.017	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	0.581	1.358
1990	0.004	0.012	0.029	0.062	0.186	0.257	0.438	0.586	0.688	0.849	1.049	1.213	1.262	1.521	1.669	0.437	1.454
1991	0.004	0.014	0.035	0.062	0.199	0.344	0.420	0.578	0.702	0.836	0.974	1.099	1.369	1.537	1.536	0.509	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	0.457	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	0.344	1.266
1995	0.005	0.007	0.024	0.051	0.158	0.328	0.435	0.561	0.690	0.910	0.974	1.101	1.203	1.411	1.406	0.393	1.243
1996	0.004	0.019	0.031	0.060	0.149	0.265	0.422	0.554	0.708	0.856	0.974	1.114	1.401	1.440	1.558	0.435	1.232
1997	0.004	0.023	0.033	0.070	0.189	0.274	0.376	0.495	0.627	0.868	1.037	1.168	1.196	1.687	1.659	0.376	1.293
1998	0.003	0.006	0.024	0.070	0.163	0.260	0.359	0.487	0.584	0.869	0.978	1.115	1.132	1.261	1.557	0.338	1.206
1999	0.003	0.006	0.024	0.068	0.217	0.291	0.400	0.514	0.584	0.627	0.917	0.683			1.442	0.387	0.872
2000	0.003	0.006	0.024	0.066	0.196	0.273	0.368	0.448	0.532	0.633	0.677	0.834	1.167	1.298	1.379	0.432	0.925
2001	0.003	0.006	0.023	0.089	0.176	0.256	0.362	0.465	0.550	0.646	0.647	0.718	0.816	1.016	1.206	0.453	0.840
2002	0.003	0.007	0.032	0.110	0.220	0.278	0.395	0.474	0.553	0.651	0.821	0.844	0.716	0.993	1.120	0.444	0.918
Mean																	
1982-02	0.0040	0.0106	0.0287	0.0914	0.1984	0.2984	0.4131	0.5344	0.6534	0.8066	0.9339						1.2372
1999-02	0.0031	0.0063	0.0258	0.0830	0.2021	0.2746	0.3813	0.4752	0.5548	0.6393	0.7656						0.8887

Table A.17 continued. **Total USA commercial catch** (landings+ shrimp trawl discards + LM otter trawl discards) .

Year	Age															TOTAL	11+
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+		
<b>USA Commerical Mean Length (cm) at Age</b>																	
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		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	39.9	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	57.9	57.9	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	53.1	53.4	57.8	33.0	54.1
1995	10.9	11.6	17.3	21.1	30.1	36.7	39.8	42.8	45.4	49.3	50.1	52.0	53.4	56.0	55.8	35.7	53.8
1996	10.0	15.3	18.4	22.5	29.5	34.7	39.4	42.7	45.8	48.4	50.1	52.2	55.8	56.2	57.6	38.6	53.6
1997	10.2	16.1	18.9	23.3	31.4	34.8	38.2	41.3	44.2	48.5	51.1	52.9	53.3	59.0	58.7	36.9	54.4
1998	9.4	10.4	17.1	23.5	30.5	34.5	37.6	41.1	43.3	48.6	50.5	52.3	52.7	54.1	57.6	34.6	53.4
1999	9.4	10.4	17.2	23.0	32.5	35.6	38.9	41.8	43.3	44.3	49.4	45.2			56.4	36.8	48.0
2000	9.4	10.4	17.1	22.9	31.5	34.8	38.0	40.1	42.1	44.2	45.2	47.7	53.0	54.6	55.3	38.4	49.0
2001	9.4	10.4	16.9	24.7	31.1	34.4	37.7	40.5	42.5	44.6	44.5	45.9	47.7	50.8	53.3	39.3	47.9
2002	9.4	11.0	18.3	26.6	32.8	35.1	38.7	40.8	42.6	44.6	47.9	48.2	45.8	50.5	52.2	39.7	49.3



Table A.18. Mean weights at age (kg) at the beginning of the year (January 1) for witch flounder, 1982-2002. Values derived from catch mean weight-at-age data using procedures described by Rivard (1980).

Year	Age										
	1	2	3	4	5	6	7	8	9	10	11+
1982	0.0005	0.0193	0.1316	0.2287	0.2951	0.3789	0.5210	0.6952	0.8437	0.9332	1.4056
1983	0.0042	0.0090	0.0755	0.1753	0.2552	0.3670	0.4667	0.5806	0.7602	0.9304	1.3575
1984	0.0143	0.0191	0.0763	0.1848	0.2577	0.3371	0.4696	0.5865	0.7077	0.8561	1.3393
1985	0.0137	0.0199	0.0719	0.1893	0.2639	0.3751	0.4880	0.6103	0.7477	0.8875	1.3255
1986	0.0121	0.0208	0.0456	0.1623	0.2663	0.3525	0.4781	0.6180	0.7677	0.9061	1.3209
1987	0.0142	0.0236	0.0456	0.1300	0.2477	0.3602	0.4783	0.6047	0.7481	0.9143	1.3031
1988	0.0027	0.0161	0.0384	0.1284	0.2438	0.3598	0.4829	0.6122	0.7496	0.9008	1.3256
1989	0.0076	0.0145	0.0457	0.0874	0.2554	0.3636	0.4992	0.6057	0.7392	0.8904	1.3577
1990	0.0066	0.0187	0.0457	0.1510	0.2092	0.3752	0.4990	0.6284	0.7609	0.9263	1.4542
1991	0.0103	0.0202	0.0426	0.1108	0.2533	0.3286	0.5032	0.6414	0.7584	0.9094	1.4198
1992	0.0033	0.0190	0.0604	0.1192	0.2745	0.3974	0.5081	0.6536	0.7596	0.8587	1.2431
1993	0.0062	0.0135	0.0563	0.1445	0.2703	0.4046	0.4955	0.6395	0.8073	0.9170	1.3353
1994	0.0019	0.0130	0.0434	0.1571	0.2380	0.3698	0.4802	0.6080	0.7444	0.8954	1.2656
1995	0.0036	0.0105	0.0308	0.1050	0.2572	0.3491	0.4909	0.6068	0.7931	0.9002	1.2426
1996	0.0142	0.0151	0.0382	0.0868	0.2048	0.3719	0.4907	0.6301	0.7683	0.9416	1.2316
1997	0.0229	0.0251	0.0465	0.1061	0.2021	0.3154	0.4569	0.5895	0.7840	0.9422	1.2930
1998	0.0030	0.0239	0.0483	0.1069	0.2215	0.3135	0.4279	0.5378	0.7381	0.9215	1.2061
1999	0.0030	0.0120	0.0406	0.1233	0.2180	0.3226	0.4293	0.5333	0.6055	0.8924	0.8721
2000	0.0031	0.0120	0.0399	0.1150	0.2436	0.3272	0.4236	0.5231	0.6078	0.6517	0.9247
2001	0.0026	0.0118	0.0463	0.1076	0.2237	0.3145	0.4137	0.4967	0.5864	0.6400	0.8403
2002	0.0038	0.0138	0.0504	0.1395	0.2213	0.3179	0.4140	0.5072	0.5982	0.7283	0.9179
mean											
1982-2002	0.0073	0.0167	0.0533	0.1361	0.2439	0.3525	0.4722	0.5956	0.7322	0.8735	1.2372
1999-2002	0.0031	0.0124	0.0443	0.1214	0.2267	0.3206	0.4202	0.5151	0.5995	0.7281	0.8888

Table A.19. USA commercial witch flounder landings (L), days fished (DF), and landings per day fished (L/DF), by vessel tonnage class, for otter trawl trips which any witch flounder were landed, and for otter trawl trips in which 40% or more of the total catch consisted of witch flounder, in the Gulf of Maine-Georges Bank region (SA 51, 52, 56), 1973 - 2002. *Note: in 1994-2002, Vessel Trip Report data were used.*

YEAR	CLASS 2			CLASS 3			CLASS 4			TOTAL		
	L	DF	L/DF	L	DF	L/DF	L	DF	L/DF	L	DF	L/DF
<b>ALL TRIPS</b>												
1973	802	2620	0.31	1284	6236	0.21	234	859	0.27	2320	9715	0.25
1974	497	2478	0.20	1029	7092	0.15	157	1004	0.16	1683	10574	0.16
1975	679	2354	0.29	1126	7728	0.15	153	1178	0.13	1957	11260	0.19
1976	756	2826	0.27	913	6373	0.14	97	860	0.11	1765	10059	0.19
1977	1074	3183	0.34	1070	6025	0.18	157	872	0.18	2302	10080	0.25
1978	1372	4033	0.34	1658	7053	0.24	277	1225	0.23	3307	12310	0.28
1979	946	4465	0.21	1467	6757	0.22	283	1570	0.18	2696	12792	0.21
1980	1062	4932	0.22	1428	7120	0.20	376	1997	0.19	2866	14049	0.20
1981	1069	3748	0.29	1637	7015	0.23	423	2595	0.16	3129	13358	0.24
1982	1162	4430	0.26	2346	8626	0.27	905	3559	0.25	4413	16615	0.27
1983	1203	3930	0.31	2796	9581	0.29	1308	4544	0.29	5307	18056	0.29
1984	1281	4069	0.31	3245	12157	0.27	1423	4769	0.30	5949	20994	0.28
1985	1195	3794	0.31	2765	12664	0.22	1600	5530	0.29	5560	21988	0.26
1986	806	3289	0.25	2031	10525	0.19	1177	5287	0.22	4015	19101	0.21
1987	647	2833	0.23	1623	9593	0.17	845	5035	0.17	3114	17461	0.18
1988	560	2986	0.19	1463	8948	0.16	951	4871	0.20	2973	16805	0.18
1989	283	2269	0.12	959	8538	0.11	618	4292	0.14	1860	15099	0.12
1990	265	2649	0.10	661	7736	0.09	347	4172	0.08	1274	14557	0.09
1991	316	3135	0.10	830	9076	0.09	383	4681	0.08	1529	16892	0.09
1992	352	3589	0.10	1148	10720	0.11	414	5005	0.08	1914	19314	0.10
1993	380	3321	0.11	1347	10872	0.12	530	4711	0.11	2257	18904	0.12
1994	261	2067	0.13	581	5126	0.11	302	2384	0.13	1143	9578	0.12
1995	291	2784	0.10	852	7328	0.12	462	3911	0.12	1605	14023	0.11
1996	369	2647	0.14	908	6992	0.13	399	3200	0.12	1677	12839	0.13
1997	371	2666	0.14	731	5084	0.14	277	2395	0.12	1379	10145	0.14
1998	393	2641	0.15	694	4697	0.15	255	1867	0.14	1342	9205	0.15
1999	407	2316	0.18	682	4387	0.16	288	1675	0.17	1378	8377	0.17
2000	555	2665	0.21	993	5431	0.18	398	2564	0.16	1946	10660	0.18
2001	321	1349	0.24	771	3750	0.21	396	2115	0.19	1488	7213	0.21
2002	320	875	0.37	446	1781	0.25	185	988	0.19	951	3644	0.28

Table A.19 continued.

YEAR	CLASS 2			CLASS 3			CLASS 4			TOTAL		
	L	DF	L\DF	L	DF	L\DF	L	DF	L\DF	L	DF	L\DF
<b>40% TRIPS</b>												
1973	306	208	1.47	392	271	1.45	96	58	1.66	793	536	1.48
1974	134	99	1.34	169	112	1.50	21	16	1.25	323	228	1.42
1975	292	171	1.71	208	168	1.24	4	4	1.09	504	343	1.51
1976	211	144	1.47	137	90	1.54	3	1	3.38	352	234	1.51
1977	151	93	1.62	129	84	1.53	1	4	0.26	281	182	1.57
1978	214	162	1.33	197	82	2.39	7	2	3.58	418	246	1.87
1979	93	79	1.17	103	69	1.49	7	2	3.45	203	151	1.41
1980	93	82	1.14	107	40	2.66	54	25	2.17	254	147	2.00
1981	101	54	1.87	239	108	2.21	22	13	1.69	362	175	2.08
1982	172	112	1.53	289	136	2.13	55	31	1.75	516	279	1.89
1983	183	140	1.30	519	279	1.86	48	30	1.59	750	450	1.70
1984	234	210	1.12	705	595	1.18	176	98	1.80	1115	903	1.27
1985	266	277	0.96	465	580	0.80	177	143	1.24	909	1000	0.93
1986	185	236	0.78	499	785	0.64	127	169	0.75	811	1190	0.69
1987	155	195	0.79	377	569	0.66	86	109	0.78	617	873	0.71
1988	137	176	0.78	517	905	0.57	202	254	0.79	856	1335	0.66
1989	45	67	0.67	128	256	0.50	77	112	0.69	250	435	0.59
1990	36	57	0.63	49	85	0.58	9	16	0.54	94	158	0.60
1991	35	76	0.46	55	106	0.52	1	1	0.83	92	183	0.50
1992	42	65	0.65	181	382	0.48	25	7	3.32	248	454	0.79
1993	76	140	0.54	266	538	0.49	30	42	0.71	372	720	0.52
1994	95	221	0.43	90	225	0.40	17	22	0.77	202	468	0.45
1995	90	237	0.38	155	323	0.48	28	53	0.54	274	613	0.45
1996	139	309	0.45	169	378	0.45	40	60	0.67	348	746	0.47
1997	98	238	0.41	158	311	0.51	17	36	0.48	273	585	0.47
1998	154	327	0.47	172	263	0.65	5	6	0.90	331	596	0.57
1999	164	370	0.44	140	240	0.59	17	14	1.18	321	624	0.54
2000	212	329	0.64	164	200	0.82	21	14	1.49	396	543	0.76
2001	97	117	0.83	138	143	0.96	8	7	1.28	244	267	0.92
2002	132	127	1.05	104	91	1.14	0	0	0.00	236	217	1.09

Table A.20. The sum of the 1963-2001 NEFSC autumn stratified mean number per tow by stratum (Stratum sum), the percentage of annual stratum sampling which produced no catch (% Zero Catch), and the percentage of stratum contribution (all years) to the total (% Total).

Strata	Stratum sum	% Zero Catch	% Total
1	0.00	100.0	0.0
2	0.70	84.6	0.1
3	0.22	92.3	0.0
4	2.88	76.9	0.3
5	0.23	97.4	0.0
6	19.30	48.7	1.8
7	0.43	94.9	0.0
8	2.51	64.1	0.2
9	0.53	92.3	0.0
10	8.54	56.4	0.8
11	1.23	92.3	0.1
12	2.01	86.8	0.2
13	7.80	43.6	0.7
14	0.68	89.7	0.1
15	4.26	69.2	0.4
16	0.98	74.4	0.1
17	1.12	92.3	0.1
18	7.40	74.4	0.7
19	0.00	100.0	0.0
20	0.02	97.4	0.0
21	1.43	89.7	0.1
22	73.23	5.1	6.8
23	5.75	66.7	0.5
24	85.01	2.6	7.9
25	0.61	94.9	0.1
26	73.21	5.1	6.8
27	94.59	0.0	8.8
28	22.08	15.4	2.1
29	18.72	7.7	1.7
30	8.93	56.4	0.8
33	6.88	61.5	0.6
34	55.51	2.6	5.2
351	93.13	8.3	8.7
36	48.86	0.0	4.5
37	109.01	0.0	10.2
38	185.36	0.0	17.3
39	38.84	5.1	3.6
40	85.47	10.3	8.0
61	0.00	100.0	0.0
62	0.00	100.0	0.0
63	0.10	97.1	0.0
64	0.60	90.6	0.1
65	0.00	100.0	0.0
66	0.00	100.0	0.0
67	0.05	97.1	0.0
68	1.10	75.8	0.1

Strata	Stratum sum	% Zero Catch	% Total
69	0.02	97.1	0.0
70	0.00	100.0	0.0
71	0.00	100.0	0.0
72	3.35	81.8	0.3
73	0.00	100.0	0.0
74	0.00	100.0	0.0
75	0.05	97.1	0.0
76	1.20	80.0	0.1
Total	1073.89		100.0

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Strata set 22-30,36-40 92.5

Strata set 6,22-30,36-40 93.9

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Strata set 22,24,26-30,36-40 91.8

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Table A.21. Stratified mean number, weight (kg), length (cm), and individual weight (kg) 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), 1963-2003.

Year	SPRING				AUTUMN			
	Number per tow	Weight per tow	Length per tow	Ave. wt. per tow	Number per tow	Weight per tow	Length per tow	Ave. wt. per tow
1963	-	-	-	-	5.52	3.46	39.7	0.627
1964	-	-	-	-	2.89	2.00	44.2	0.691
1965	-	-	-	-	3.94	2.27	40.6	0.577
1966	-	-	-	-	7.80	4.56	41.2	0.584
1967	-	-	-	-	3.01	2.02	43.7	0.673
1968	4.83	3.35	42.3	0.695	4.82	3.49	44.8	0.724
1969	3.74	2.53	45.3	0.676	5.81	4.40	43.5	0.757
1970	6.39	4.49	44.7	0.702	4.89	3.71	45.0	0.760
1971	2.70	2.04	46.5	0.756	4.32	2.95	42.1	0.683
1972	5.35	4.01	45.8	0.749	3.24	2.42	43.9	0.747
1973	8.20	6.21	44.8	0.758	3.18	2.05	43.6	0.646
1974	6.23	3.62	39.3	0.581	2.38	1.58	41.0	0.666
1975	3.72	2.75	43.9	0.739	1.66	1.03	39.8	0.621
1976	5.50	3.70	42.3	0.673	1.34	0.94	41.9	0.699
1977	4.20	1.96	37.2	0.467	5.06	3.38	42.0	0.669
1978	3.87	2.56	41.7	0.662	4.04	2.94	42.8	0.727
1979	2.91	1.71	38.2	0.587	1.94	1.62	45.2	0.838
1980	8.46	3.89	36.0	0.460	2.62	2.04	43.7	0.777
1981	8.14	4.05	38.0	0.497	3.66	2.19	40.4	0.600
1982	3.64	1.87	37.2	0.513	0.99	0.83	44.7	0.842
1983	6.41	2.74	36.3	0.427	4.72	2.12	36.7	0.448
1984	3.00	1.66	39.9	0.554	4.37	2.34	39.7	0.534
1985	5.18	2.75	40.3	0.531	2.76	1.59	41.9	0.577
1986	2.07	1.35	44.1	0.650	1.59	1.09	43.3	0.683
1987	1.01	0.65	43.4	0.646	0.48	0.37	43.9	0.774
1988	1.43	0.85	42.3	0.590	1.38	0.57	35.2	0.414
1989	1.95	0.74	35.8	0.382	0.89	0.38	31.4	0.423
1990	0.63	0.24	35.2	0.378	2.00	0.40	24.7	0.200
1991	1.68	0.57	31.5	0.341	2.08	0.54	29.2	0.258
1992	1.26	0.48	34.8	0.383	0.94	0.24	29.5	0.254
1993	1.47	0.36	30.3	0.245	5.15	0.54	17.0	0.105
1994	3.13	0.53	27.4	0.170	2.21	0.42	24.9	0.191
1995	1.88	0.47	30.6	0.248	4.74	0.62	25.7	0.132
1996	1.36	0.28	30.5	0.204	5.38	1.02	29.7	0.189
1997	2.22	0.43	31.0	0.195	5.11	0.77	24.9	0.150
1998	4.27	0.77	29.0	0.179	3.70	0.47	24.2	0.127
1999	3.15	0.48	28.1	0.153	5.92	0.88	26.3	0.148
2000	3.45	0.52	27.3	0.151	6.63	1.11	27.1	0.167
2001	4.41	0.75	29.5	0.171	7.94	1.71	32.3	0.216
2002	8.10	1.62	31.4	0.199	4.31	1.06	33.2	0.247
2003	5.20	1.30	34.2	0.250				

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 A.22. Stratified mean number, weight (kg), length (cm) per tow of witch flounder in Massachusetts Division of Marine Fisheries inshore spring and autumn surveys in the Cape Cod Bay and Mass. Bay region (Regions 4 and 5), 1978-2002.

Year	SPRING			AUTUMN		
	Number per tow	Weight per tow	Length per tow	Number per tow	Weight per tow	Length per tow
1978	2.98	2.15	45.3	2.47	2.41	48.2
1979	1.36	1.41	47.9	1.39	1.09	44.4
1980	1.49	1.44	46.0	1.66	1.77	48.2
1981	3.74	3.18	43.7	0.36	0.23	42.3
1982	1.23	0.97	46.1	1.24	0.76	40.3
1983	2.15	1.29	38.9	3.79	2.68	45.9
1984	1.50	1.01	41.6	0.62	0.45	44.7
1985	1.12	0.82	43.9	0.83	0.57	44.2
1986	0.90	0.83	47.1	0.32	0.27	46.3
1987	1.45	1.10	44.7	0.26	0.20	45.7
1988	0.36	0.29	46.1	0.39	0.24	40.8
1989	0.17	0.07	35.9	0.21	0.13	42.2
1990	0.40	0.32	45.0	0.06	0.03	37.5
1991	0.17	0.08	37.4	0.37	0.22	41.5
1992	0.34	0.24	41.3	0.45	0.25	41.3
1993	0.03	0.01	33.0	0.39	0.19	40.2
1994	0.00	0.00	-	0.53	0.21	34.9
1995	0.08	0.05	36.6	2.17	0.46	28.7
1996	0.02	<0.01	21.0	0.05	0.02	40.0
1997	0.04	0.01	31.5	1.20	0.36	36.0
1998	0.00	0.00	-	0.44	0.15	35.7
1999	0.01	<0.01	11.0	1.38	0.38	34.9
2000	0.95	0.11	24.4	1.28	0.43	34.4
2001	0.16	0.04	33.0	0.66	0.20	34.8
2002	0.11	0.03	32.5	2.40	0.79	37.1

Table A.23. Stratified mean number, weight (kg), length (cm), and individual weight (kg) per tow of witch flounder in the ASMFC summer shrimp surveys in the Gulf of Maine (Strata set 1,3,6,8), 1984 - 2002.

Year	Number per tow	Weight per tow	Length per tow	Individual Weight per tow
1984	4.68	1.60	33.9	0.341
1985	6.19	2.52	36.2	0.408
1986	2.05	0.74	35.9	0.362
1987	4.87	1.50	26.5	0.307
1988	2.53	0.60	25.8	0.238
1989	2.92	0.31	22.8	0.105
1990	6.66	1.02	24.5	0.154
1991	14.94	1.20	19.6	0.080
1992	24.28	1.91	20.5	0.079
1993	21.42	0.50	12.8	0.023
1994	36.36	2.20	19.1	0.061
1995	17.95	1.48	22.6	0.082
1996	15.45	1.95	25.2	0.126
1997	23.20	1.42	19.1	0.061
1998	7.35	0.52	21.9	0.071
1999	110.07	5.93	18.7	0.054
2000	32.43	3.09	24.2	0.095
2001	41.52	5.57	27.2	0.134
2002	45.25	7.05	28.8	0.156



Table A.24. 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 - 2002.

Year	Spring				Autumn			
	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	187	138	73.8	10	556	244	43.9	10
2000	231	141	61.0	10	411	224	54.5	12
2001	315	197	62.5	10	475	234	49.3	10
2002	568	289	50.9	21	339	201	59.3	12

Table A.25. Stratified mean number per tow at age of witch flounder in NEFSC bottom trawl spring and autumn surveys (Strata 22-30, 36-40), 1980-2002, preliminary spring 2003.

SPRING	Age															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +	
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	0.99	8.40
1982	0.00	0.04	0.04	0.61	0.48	0.38	0.24	0.61	0.36	0.09	0.26	0.17	0.03	0.03	0.29	3.64
1983	0.00	0.00	0.07	0.53	1.26	1.29	0.54	0.72	0.63	0.48	0.21	0.17	0.08	0.05	0.38	6.41
1984	0.00	0.00	0.10	0.01	0.31	0.78	0.40	0.31	0.20	0.20	0.11	0.17	0.12	0.02	0.27	3.00
1985	0.00	0.00	0.00	0.02	0.46	1.06	1.20	0.91	0.41	0.15	0.15	0.04	0.07	0.03	0.69	5.18
1986	0.00	0.00	0.00	0.00	0.04	0.24	0.53	0.41	0.17	0.19	0.08	0.04	0.06	0.05	0.25	2.07
1987	0.00	0.00	0.00	0.00	0.06	0.11	0.13	0.26	0.19	0.01	0.06	0.02	0.00	0.00	0.16	1.01
1988	0.00	0.02	0.02	0.06	0.00	0.07	0.30	0.38	0.24	0.14	0.09	0.08	0.03	0.00	0.00	1.43
1989	0.00	0.02	0.01	0.04	1.00	0.11	0.07	0.08	0.33	0.08	0.02	0.06	0.06	0.02	0.06	1.95
1990	0.00	0.01	0.00	0.04	0.09	0.32	0.00	0.04	0.01	0.05	0.02	0.01	0.01	0.00	0.03	0.63
1991	0.00	0.04	0.00	0.78	0.11	0.09	0.21	0.03	0.10	0.08	0.14	0.02	0.02	0.00	0.06	1.68
1992	0.00	0.05	0.01	0.19	0.37	0.09	0.11	0.15	0.04	0.15	0.02	0.02	0.05	0.00	0.02	1.26
1993	0.00	0.15	0.11	0.14	0.47	0.32	0.06	0.09	0.00	0.02	0.02	0.00	0.07	0.00	0.04	1.47
1994	0.00	0.11	0.70	0.54	0.64	0.81	0.16	0.03	0.03	0.07	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	0.12	0.11	0.04	0.00	0.04	0.03	0.00	0.00	1.88
1996	0.00	0.02	0.04	0.24	0.39	0.35	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	0.69	0.62	0.44	0.08	0.08	0.01	0.00	0.00	0.00	0.00	0.00	2.22
1998	0.00	0.11	1.08	0.71	0.39	0.80	0.71	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	0.97	0.80	0.48	0.16	0.18	0.03	0.01	0.02	0.00	0.00	0.00	0.00	3.15
2000	0.00	0.01	0.25	1.19	0.69	0.66	0.24	0.25	0.12	0.00	0.04	0.00	0.00	0.00	0.00	3.45
2001	0.00	0.11	0.10	0.71	1.48	1.02	0.40	0.29	0.16	0.11	0.03	0.00	0.00	0.00	0.00	4.41
2002	0.00	0.02	0.06	0.90	2.63	2.26	0.82	0.68	0.35	0.19	0.10	0.01	0.00	0.03	0.04	8.10
2003	0.00	0.00	0.00	0.16	0.78	1.57	1.08	0.81	0.43	0.23	0.05	0.07	0.00	0.02	0.01	5.20

Table A.25 continued. Stratified mean number per tow at age of witch flounder in NEFSC bottom trawl spring and autumn surveys (Strata 22-30, 36-40), 1980-2002.

AUTUMN	Age															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +	
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	0.03	0.08	0.24	0.13	0.01	0.03	0.03	0.01	0.04	0.30	0.99
1983	0.00	0.01	0.01	0.51	1.60	0.76	0.55	0.44	0.08	0.14	0.07	0.11	0.02	0.00	0.41	4.72
1984	0.00	0.00	0.00	0.09	0.94	0.99	0.60	0.53	0.31	0.15	0.13	0.07	0.04	0.13	0.38	4.37
1985	0.00	0.00	0.01	0.06	0.08	0.61	0.68	0.48	0.27	0.10	0.12	0.03	0.01	0.09	0.22	2.76
1986	0.01	0.00	0.00	0.00	0.05	0.27	0.35	0.31	0.16	0.11	0.01	0.01	0.02	0.05	0.24	1.59
1987	0.00	0.00	0.02	0.00	0.01	0.02	0.05	0.19	0.07	0.00	0.01	0.00	0.00	0.02	0.08	0.48
1988	0.00	0.01	0.00	0.72	0.05	0.01	0.04	0.21	0.05	0.05	0.05	0.08	0.01	0.04	0.05	1.38
1989	0.17	0.02	0.02	0.08	0.30	0.01	0.02	0.02	0.08	0.08	0.02	0.00	0.03	0.00	0.04	0.89
1990	0.48	0.09	0.14	0.38	0.51	0.22	0.02	0.02	0.02	0.03	0.00	0.00	0.01	0.05	0.03	2.00
1991	0.22	0.02	0.18	0.66	0.33	0.29	0.14	0.07	0.06	0.03	0.05	0.03	0.00	0.00	0.00	2.08
1992	0.10	0.03	0.11	0.26	0.22	0.05	0.06	0.00	0.00	0.02	0.01	0.02	0.00	0.02	0.04	0.94
1993	2.54	0.67	0.15	0.54	0.78	0.22	0.06	0.02	0.08	0.00	0.02	0.04	0.00	0.01	0.01	5.15
1994	0.43	0.16	0.29	0.53	0.17	0.40	0.04	0.11	0.00	0.04	0.01	0.00	0.01	0.00	0.04	2.21
1995	0.51	0.20	0.76	1.62	0.86	0.47	0.23	0.00	0.00	0.01	0.05	0.00	0.00	0.00	0.01	4.74
1996	0.23	0.09	0.26	0.79	1.99	1.39	0.44	0.07	0.06	0.04	0.00	0.03	0.00	0.00	0.00	5.38
1997	0.89	0.34	0.98	0.52	0.87	0.77	0.38	0.33	0.00	0.00	0.00	0.00	0.02	0.00	0.00	5.10
1998	0.64	0.08	0.52	1.36	0.47	0.30	0.17	0.11	0.04	0.01	0.00	0.00	0.00	0.00	0.00	3.70
1999	0.32	0.52	1.18	1.51	1.04	0.60	0.36	0.28	0.05	0.04	0.01	0.00	0.00	0.00	0.00	5.91
2000	0.94	0.10	0.72	1.41	1.75	0.67	0.59	0.23	0.15	0.05	0.00	0.00	0.03	0.00	0.00	6.63
2001	0.00	0.04	0.21	0.95	3.16	1.89	0.81	0.61	0.16	0.06	0.06	0.00	0.00	0.00	0.00	7.94
2002	0.00	0.00	0.27	0.43	1.48	1.00	0.53	0.33	0.15	0.07	0.00	0.05	0.01	0.00	0.00	4.31

Table A.26. Witch flounder mean length (cm) at age in spring and autumn NEFSC bottom trawl surveys (Strata 22-30, 36-40), 1980-2002, preliminary 2003.

SPRING	Age														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +
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	-	7.9	15.0	20.7	27.2	32.8	36.1	41.0	44.1	48.2	50.7	51.3	58.0	53.0	58.1
1983	-	-	17.9	20.9	26.5	31.2	35.5	40.2	43.7	47.4	52.5	54.9	50.0	55.6	56.1
1984	-	-	17.4	19.0	29.4	32.6	37.5	42.2	43.0	46.0	51.3	50.6	54.2	54.3	57.4
1985	-	-	-	19.5	28.8	33.5	36.6	41.2	44.4	46.9	49.3	49.3	48.5	55.0	56.3
1986	-	-	-	-	27.3	35.0	38.5	41.7	45.8	49.1	51.8	52.3	54.2	56.1	57.9
1987	-	-	-	-	28.0	34.4	40.9	40.8	44.1	46.0	51.5	48.0	-	-	56.7
1988	-	9.0	15.0	19.5	-	33.1	39.2	43.0	46.0	50.2	54.2	51.2	58.3	-	-
1989	-	7.0	15.0	20.6	28.5	33.0	39.8	44.0	44.9	50.5	50.2	53.1	58.3	47.0	60.7
1990	-	9.0	-	19.8	28.3	32.4	-	40.9	49.0	49.8	51.5	52.0	53.0	-	54.9
1991	-	7.5	-	20.4	27.4	35.3	37.2	43.1	48.2	48.2	52.7	53.0	54.0	-	52.4
1992	-	8.5	11.0	21.7	29.3	35.0	38.4	42.5	45.7	49.3	46.0	51.0	57.3	-	56.0
1993	-	7.9	17.9	23.5	30.0	34.5	38.1	40.5	-	50.0	50.0	-	50.3	-	60.1
1994	-	10.8	17.9	21.5	29.4	33.7	38.1	41.2	46.0	48.2	48.0	-	-	57.0	57.0
1995	-	9.7	17.3	22.4	27.1	34.3	37.2	43.7	45.7	50.3	-	54.0	58.7	-	-
1996	-	9.4	19.6	22.3	28.1	32.5	37.1	40.6	0.0	-	-	56.3	-	-	-
1997	-	10.8	15.9	22.2	29.5	31.4	36.3	42.3	43.9	48.0	-	-	-	-	-
1998	-	11.0	20.3	24.6	29.9	33.3	35.7	39.1	42.6	45.2	-	-	-	51.7	-
1999	-	10.0	19.5	25.0	28.5	34.0	37.2	40.6	45.5	44.0	50.0	-	-	-	-
2000	-	9.0	18.1	20.9	27.3	31.2	36.5	38.5	41.1	-	50.3	-	-	-	-
2001	-	7.4	15.9	23.5	27.0	32.4	36.0	38.2	40.8	41.5	45.3	-	-	-	-
2002	-	11.0	18.0	20.2	29.0	32.2	34.7	37.8	42.1	44.3	45.1	42.0	-	45.3	54.8
2003	-	-	-	22.4	27.7	31.9	34.9	38.1	40.8	42.7	43.6	45.4	-	47.5	49.5

Table A.26 continued. Witch flounder mean length (cm) at age in spring and autumn NEFSC bottom trawl surveys (Strata 22-30, 36-40), 1980-2002.

AUTUMN	Age														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
<b>1980</b>	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	5.0	0.0	0.0	22.0	28.5	29.2	36.4	41.9	42.8	47.3	50.2	49.1	51.0	52.0	56.8
1983	0.0	14.0	19.0	24.7	30.1	34.7	39.2	42.2	45.0	48.5	52.0	50.9	51.0	0.0	58.8
1984	0.0	0.0	0.0	25.1	30.7	34.2	38.2	42.8	45.2	46.6	50.2	51.3	54.8	53.5	58.6
1985	0.0	0.0	20.0	26.0	29.7	34.6	38.8	42.7	46.8	49.1	50.8	53.3	55.0	53.1	58.7
1986	6.0	0.0	0.0	0.0	29.7	35.5	38.2	42.4	45.4	49.4	51.0	51.3	49.0	53.9	57.7
1987	0.0	0.0	16.0	0.0	28.0	36.0	39.1	41.6	43.8	0.0	49.0	0.0	0.0	55.0	60.9
1988	0.0	10.0	0.0	25.4	31.5	38.0	42.0	42.9	45.6	48.6	50.0	54.3	56.0	55.1	56.8
1989	5.7	15.0	18.5	24.1	31.1	36.0	44.0	45.0	46.7	49.9	52.0	0.0	54.8	0.0	64.2
1990	6.2	16.3	17.6	26.7	29.8	36.2	40.0	43.0	47.0	50.9	0.0	0.0	58.0	51.2	58.9
1991	5.7	14.9	20.8	26.3	30.5	36.8	41.9	46.4	47.6	46.6	53.5	55.0	0.0	0.0	0.0
1992	5.9	15.8	23.1	27.7	32.1	37.7	37.9	0.0	0.0	46.0	50.0	47.0	0.0	49.0	56.5
1993	5.6	14.2	22.2	28.8	32.2	36.4	42.3	43.6	46.2	0.0	55.0	51.0	0.0	63.0	57.0
1994	5.7	16.0	20.9	23.5	32.7	36.6	43.5	44.0	0.0	54.2	50.0	0.0	51.0	0.0	57.2
1995	6.6	16.7	22.0	26.5	29.9	35.5	39.2	0.0	0.0	54.0	50.6	0.0	0.0	0.0	56.0
1996	5.5	14.2	18.7	25.0	29.6	33.8	39.6	42.1	47.4	50.5	0.0	53.0	0.0	0.0	0.0
1997	6.3	16.3	19.8	25.8	30.6	35.1	38.0	42.0	0.0	0.0	0.0	0.0	47.1	0.0	0.0
1998	5.9	15.7	22.0	25.7	30.7	35.0	39.3	41.9	44.9	43.0	0.0	0.0	0.0	0.0	0.0
1999	5.5	15.6	20.4	26.1	30.2	34.6	38.2	41.6	41.6	45.1	45.0	0.0	0.0	0.0	0.0
2000	6.1	15.6	22.6	26.3	31.0	33.4	38.0	42.3	44.1	46.3	0.0	0.0	51.0	0.0	0.0
2001	0.0	14.6	18.9	28.0	30.6	33.1	36.7	39.9	41.9	41.0	46.4	0.0	0.0	0.0	0.0
2002	0.0	0.0	22.7	26.0	31.3	34.3	37.2	41.7	41.9	44.6	0.0	50.5	51.0	0.0	0.0

Table A.27. Mean weight (kg) at age of witch flounder from the Gulf of Maine-Georges Bank region, derived from NEFSC spring and autumn bottom trawl survey, (strata 22-30, 36-40), 1982 - 2002, and preliminary spring 2003.

SPRING	Age														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +
1982	0.0000	0.0018	0.0155	0.0479	0.1220	0.2350	0.3174	0.4939	0.6395	0.8643	1.0226	1.0519	1.5952	1.1711	1.6152
1983	0.0000	0.0000	0.0291	0.0494	0.1069	0.1861	0.2878	0.4433	0.5885	0.7790	1.0889	1.2747	0.9215	1.3281	1.4180
1984	0.0000	0.0000	0.0261	0.0342	0.1540	0.2234	0.3539	0.5318	0.5647	0.7143	1.0398	0.9979	1.2606	1.2534	1.5434
1985	0.0000	0.0000	0.0000	0.0368	0.1424	0.2349	0.3247	0.4841	0.6268	0.7516	0.8984	0.8858	0.8318	1.2805	1.4087
1986	0.0000	0.0000	0.0000	0.0000	0.1115	0.2604	0.3592	0.4737	0.6481	0.8299	0.9880	1.0206	1.1601	1.3053	1.4627
1987	0.0000	0.0000	0.0000	0.0000	0.1278	0.2542	0.4637	0.4615	0.6012	0.6891	1.0154	0.7974	0.0000	0.0000	1.4347
1988	0.0000	0.0025	0.0142	0.0364	0.0000	0.2177	0.3875	0.5340	0.6686	0.8996	1.1689	0.9765	1.5001	0.0000	0.0000
1989	0.0000	0.0010	0.0139	0.0408	0.1255	0.2039	0.3869	0.5537	0.5946	0.8807	0.8600	1.0413	1.4373	0.6851	1.6452
1990	0.0000	0.0026	0.0000	0.0392	0.1328	0.2150	0.0000	0.4708	0.8717	0.9235	1.0370	1.0687	1.1408	0.0000	1.2886
1991	0.0000	0.0014	0.0000	0.0429	0.1244	0.2784	0.3348	0.5487	0.8060	0.8278	1.0986	1.1110	1.1845	0.0000	1.0707
1992	0.0000	0.0024	0.0050	0.0519	0.1449	0.2641	0.3635	0.5224	0.6620	0.8765	0.6694	0.9535	1.4308	0.0000	1.3139
1993	0.0000	0.0016	0.0256	0.0661	0.1507	0.2395	0.3347	0.4116	0.0000	0.8459	0.8459	0.0000	0.8667	0.0000	1.6168
1994	0.0000	0.0051	0.0274	0.0524	0.1481	0.2352	0.3566	0.4681	0.6750	0.7940	0.7810	0.0000	0.0000	1.4078	1.4078
1995	0.0000	0.0032	0.0233	0.0572	0.1089	0.2378	0.3138	0.5452	0.6325	0.8816	0.0000	1.1302	1.5043	0.0000	0.0000
1996	0.0000	0.0037	0.0351	0.0563	0.1252	0.2024	0.3170	0.4300	0.0000	0.0000	0.0000	1.3229	0.0000	0.0000	0.0000
1997	0.0000	0.0046	0.0183	0.0532	0.1400	0.1733	0.2840	0.4763	0.5430	0.7288	0.0000	0.0000	0.0000	0.0000	0.0000
1998	0.0000	0.0053	0.0403	0.0777	0.1507	0.2179	0.2770	0.3836	0.5071	0.6355	0.0000	0.0000	0.0000	0.9754	0.0000
1999	0.0000	0.0040	0.0347	0.0816	0.1278	0.2311	0.3126	0.4251	0.6275	0.5562	0.8621	0.0000	0.0000	0.0000	0.0000
2000	0.0000	0.0025	0.0284	0.0464	0.1155	0.1806	0.3075	0.3789	0.4746	0.0000	0.9379	0.0000	0.0000	0.0000	0.0000
2001	0.0000	0.0015	0.0199	0.0654	0.1052	0.1957	0.2810	0.3412	0.4287	0.4549	0.6114	0.0000	0.0000	0.0000	0.0000
2002	0.0000	0.0046	0.0255	0.0388	0.1307	0.1867	0.2401	0.3232	0.4634	0.5493	0.5910	0.4552	0.0000	0.5938	1.1331
2003	0.0000	0.0000	0.0000	0.0588	0.1141	0.1833	0.2461	0.3324	0.4183	0.4860	0.5191	0.5881	0.0000	0.6712	0.7743

Table A.27 continued. Mean weight (kg) at age of witch flounder from the Gulf of Maine-Georges Bank region, derived from NEFSC spring and autumn bottom trawl survey, (strata 22-30, 36-40), 1982 - 2002.

AUTUMN	AGE														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14 +
1982	0.0004	0.0000	0.0000	0.0604	0.1486	0.1591	0.3462	0.5470	0.5905	0.8193	1.0054	0.9316	1.0589	1.1331	1.5423
1983	0.0000	0.0123	0.0350	0.0883	0.1728	0.2794	0.4271	0.5435	0.6757	0.8757	1.1119	1.0501	1.0340	0.0000	1.7009
1984	0.0000	0.0000	0.0000	0.0905	0.1817	0.2639	0.3836	0.5656	0.6852	0.7623	0.9759	1.0446	1.3091	1.2035	1.6588
1985	0.0000	0.0000	0.0391	0.0969	0.1536	0.2592	0.3875	0.5341	0.7256	0.8551	0.9579	1.1245	1.2535	1.1205	1.5848
1986	0.0007	0.0000	0.0000	0.0000	0.1614	0.3015	0.3832	0.5534	0.6969	0.9241	1.0232	1.0493	0.8921	1.2559	1.5656
1987	0.0000	0.0000	0.0195	0.0000	0.1327	0.3141	0.4168	0.5181	0.6258	0.0000	0.9040	0.0000	0.0000	1.3432	1.9129
1988	0.0000	0.0036	0.0000	0.0900	0.1876	0.3540	0.5152	0.5472	0.6645	0.8253	0.9117	1.2061	1.3376	1.2693	1.4267
1989	0.0007	0.0155	0.0326	0.0791	0.1893	0.3111	0.6190	0.6686	0.7652	0.9710	1.0973	0.0000	1.3101	0.0000	2.2664
1990	0.0008	0.0210	0.0275	0.1135	0.1642	0.3173	0.4439	0.5688	0.7716	1.0181	0.0000	0.0000	1.5867	1.0437	1.7592
1991	0.0006	0.0155	0.0502	0.1083	0.1791	0.3388	0.5257	0.7467	0.8148	0.7657	1.2266	1.3420	0.0000	0.0000	0.0000
1992	0.0006	0.0181	0.0651	0.1236	0.2044	0.3524	0.3850	0.0000	0.0000	0.6915	0.9203	0.7444	0.0000	0.8587	1.3961
1993	0.0006	0.0133	0.0591	0.1416	0.2104	0.3147	0.5233	0.5872	0.7075	0.0000	1.2822	0.9898	0.0000	2.0425	1.4493
1994	0.0006	0.0187	0.0459	0.0707	0.2116	0.3133	0.5605	0.5893	0.0000	1.1912	0.9017	0.0000	0.9650	0.0000	1.4443
1995	0.0008	0.0207	0.0533	0.1000	0.1503	0.2703	0.3794	0.0000	0.0000	1.1259	0.9099	0.0000	0.0000	0.0000	1.2754
1996	0.0005	0.0124	0.0315	0.0828	0.1488	0.2328	0.4005	0.4964	0.7359	0.9408	0.0000	1.0769	0.0000	0.0000	0.0000
1997	0.0008	0.0195	0.0402	0.0950	0.1704	0.2700	0.3529	0.5031	0.0000	0.0000	0.0000	0.0000	0.7415	0.0000	0.0000
1998	0.0006	0.0185	0.0552	0.0928	0.1695	0.2669	0.3936	0.4937	0.6344	0.5333	0.0000	0.0000	0.0000	0.0000	0.0000
1999	0.0005	0.0176	0.0452	0.1021	0.1671	0.2672	0.3707	0.4932	0.4978	0.6581	0.6407	0.0000	0.0000	0.0000	0.0000
2000	0.0007	0.0163	0.0591	0.0993	0.1743	0.2248	0.3510	0.5116	0.5813	0.6765	0.0000	0.0000	0.9435	0.0000	0.0000
2001	0.0000	0.0131	0.0347	0.1227	0.1673	0.2179	0.3122	0.4124	0.4878	0.4468	0.6933	0.0000	0.0000	0.0000	0.0000
2002	0.0000	0.0000	0.0587	0.0959	0.1831	0.2442	0.3225	0.4775	0.4920	0.5955	0.0000	0.9261	0.9391	0.0000	0.0000

Table A.28. Proportion mature at age for female witch flounder derived from logistic regression analysis using a 5-year moving average of NEFSC spring bottom trawl surveys, 1980 - 2003.

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
2	0.00	0.00	0.00	0.00	0.00	0.03	0.13	0.03	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.03
3	0.01	0.01	0.02	0.01	0.02	0.12	0.32	0.12	0.08	0.07	0.06	0.04	0.04	0.03	0.02	0.01	0.04	0.05	0.06	0.07
4	0.04	0.06	0.07	0.05	0.09	0.37	0.60	0.36	0.22	0.18	0.18	0.14	0.13	0.13	0.13	0.07	0.14	0.15	0.15	0.16
5	0.14	0.20	0.24	0.24	0.37	0.71	0.83	0.70	0.47	0.39	0.42	0.35	0.34	0.42	0.45	0.37	0.39	0.37	0.33	0.35
6	0.40	0.51	0.59	0.68	0.76	0.91	0.94	0.91	0.74	0.64	0.70	0.65	0.64	0.78	0.82	0.81	0.71	0.67	0.59	0.59
7	0.73	0.82	0.86	0.93	0.95	0.98	0.98	0.98	0.90	0.84	0.88	0.86	0.86	0.95	0.96	0.97	0.91	0.87	0.81	0.79
8	0.92	0.95	0.97	0.99	0.99	0.99	0.99	0.99	0.97	0.94	0.96	0.95	0.95	0.99	0.99	1.00	0.97	0.96	0.93	0.91
9	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.99	0.99	0.99	1.00	1.00	1.00	0.99	0.99	0.97	0.97
10	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
11+	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Number of fish																				
mature	108	153	204	203	186	177	145	111	104	89	80	85	76	81	132	123	127	148	186	191
immature	98	112	115	102	47	24	11	37	60	88	107	139	139	139	190	198	205	247	301	248
total	206	265	319	305	233	201	156	148	164	177	187	224	215	220	322	321	332	395	487	439

Long-term (non-averaged) proportion mature at age for female witch flounder from NEFSC spring bottom trawl surveys, 1980-2003.

Age	1980- 2003
1	0.00
2	0.00
3	0.01
4	0.04
5	0.14
6	0.40
7	0.73
8	0.92
9	0.98
10	0.99
11+	1.00



Table A.29. Stratified mean weight (kg) per tow of mature witch flounder (spawning stock biomass) in the NEFSC spring bottom trawl survey in Gulf of Maine-Georges Bank region (strata 22-30, 36-40), 1968-2002.

Year	Mature weight (kg) per tow
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	0.323
1995	0.377
1996	0.174
1997	0.249
1998	0.498
1999	0.251
2000	0.228
2001	0.331
2002	0.782
2003	0.751

Note: 1977-1982, 1983-1984, 1985-1990, 1991-1993, 1994-1999, 2000-2002 ogives were used;  
 No maturity at length data before 1977; the 1977-1982 period was applied to the 1963-1976 period.

Table A.30. Estimates of instantaneous total mortality (Z) for witch flounder in the Gulf of Maine-Georges Bank region, 1980-2002, derived from NEFSC spring and autumn bottom trawl survey data.

YEAR	3+	4+	5+	6+	7+	8+				Geometric
Spring										
1980	8.18	7.23	5.71	4.99	3.79	2.77	Times period	Spring	Autumn	mean
1981	8.31	7.49	6.56	4.56	3.54	2.78				
1982	3.56	2.95	2.46	2.09	1.85	1.24	1982-1985	0.48	0.23	0.34
1983	6.34	5.80	4.54	3.25	2.71	1.99	1986-1989	0.77	0.65	0.71
1984	2.90	2.89	2.58	1.80	1.40	1.09	1990-1993	0.59	0.61	0.60
1985	5.18	5.17	4.71	3.65	2.45	1.54	1994-1997	0.53	0.36	0.44
1986	2.07	2.07	2.03	1.79	1.26	0.85	1998-2001	0.52	0.60	0.56
1987	1.01	1.01	0.95	0.83	0.70	0.44				
1988	1.39	1.33	1.33	1.25	0.95	0.57				
1989	1.91	1.87	0.87	0.76	0.69	0.61				
1990	0.62	0.58	0.49	0.17	0.17	0.13				
1991	1.64	0.86	0.75	0.67	0.46	0.42				
1992	1.20	1.01	0.64	0.55	0.44	0.29				
1993	1.21	1.07	0.60	0.28	0.22	0.14				
1994	2.32	1.78	1.14	0.33	0.17	0.14				
1995	1.72	1.14	0.83	0.65	0.33	0.22				
1996	1.31	1.06	0.67	0.32	0.10	0.03				
1997	2.08	1.93	1.24	0.62	0.18	0.10				
1998	3.08	2.37	1.98	1.19	0.47	0.26				
1999	2.67	1.69	0.90	0.41	0.25	0.07				
2000	3.19	2.00	1.30	0.64	0.40	0.15				
2001	4.21	3.49	2.02	1.00	0.60	0.30				
2002	8.02	7.12	4.49	2.23	1.41	0.73				
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	0.87	0.80	0.56				
1983	4.70	4.19	2.60	1.84	1.29	0.85				
1984	4.37	4.28	3.34	2.34	1.74	1.21				
1985	2.75	2.70	2.62	2.01	1.33	0.84				
1986	1.58	1.58	1.53	1.26	0.91	0.60				
1987	0.46	0.46	0.45	0.43	0.38	0.19				
1988	1.37	0.64	0.59	0.58	0.54	0.33				
1989	0.68	0.60	0.30	0.29	0.27	0.25				
1990	1.30	0.92	0.41	0.19	0.17	0.15				
1991	1.66	1.00	0.67	0.38	0.24	0.17				
1992	0.70	0.45	0.22	0.17	0.11	0.11				
1993	1.79	1.24	0.47	0.25	0.19	0.17				
1994	1.33	0.80	0.64	0.24	0.21	0.10				
1995	3.26	1.63	0.78	0.30	0.07	0.07				
1996	4.80	4.02	2.03	0.64	0.20	0.14				
1997	2.89	2.37	1.50	0.73	0.35	0.02				
1998	2.46	1.10	0.63	0.33	0.17	0.05				
1999	3.89	2.38	1.34	0.74	0.37	0.10				
2000	4.87	3.47	1.72	1.05	0.46	0.23				
2001	7.69	6.74	3.58	1.70	0.88	0.27				
2002	4.04	3.61	2.13	1.13	0.60	0.27				

Table A.31. Parameter estimates (with associated statistics) and estimates of terminal F from alternative ADAPT VPA formulations; stock sizes in '000s.

	Run 61-f	Run 61-f	Run 100	Run 200	Run 201	Run 300	Run 301-f	Run 301f-spr	Run 301f-aut
Software	FACT 1.5	NFTv2011	NFTv2011	NFTv2011	NFTv2011	NFTv2011	NFTv2011	NFTv2011	NFTv2011
CAA	1982-2001 1-11+	1982-2001 1-11+	1982-2002 1-11+	1982-2002 1-11+	1982-2002 1-11+	1982-2002 1-11+	1982-2002 3-11+	1982-2002 3-11+	1982-2002 3-11+
Est.Ages	4-10	4-10	4 - 10	4 - 10	3-10	3-10	3-10	3-10	3-10
NMFS-s	3-11+	3-11+	3 - 11+	3 - 11+	3-11+	3-11+	3-11+	3-11+	-
NMFS-a	3-11+	3-11+	3 - 11+	3 - 11+	3-11+	3-11+	3-11+	-	3-11+
Notes:	GARM VPA	Re-Run of GARM VPA	LM discards (sf method)	LM discards (sf & FOP)	LM discards (sf & FOP)	LM discards (sf & FOP)	LM discards (sf and FOP)	LM discards (sf and FOP)	LM discards (sf and FOP)
M.S.R.	.7673	.7289	.7469	.7485	.7459	.792	.791	.603	1.00
N3 (cv)					19.621 (.63)	19.703 (.64)	19.759 (.64)	11.429 (.79)	34.449 (1.03)
N4 (cv)	5.76e4 (.45)	57.321 (.44)	25.111 (.44)	24.755 (.44)	25.291 (.44)	25.373 (.45)	25.441 (.45)	36.289 (.56)	17.944 (.73)
N5 (cv)	6.08e4 (.38)	60.440 (.36)	41.902 (.37)	41.897 (.37)	42.456 (.37)	42.628 (.37)	42.739 (.37)	94.857 (.46)	40.928 (.60)
N6 (cv)	2.91e4 (.34)	28.936 (.33)	40.091 (.33)	41.003 (.32)	41.370 (.32)	41.550 (.33)	41.657 (.33)	36.267 (.41)	48.035 (.52)
N7 (cv)	1.67e4 (.32)	16.563 (.31)	19.965 (.31)	20.937 (.30)	21.063 (.30)	21.145 (.31)	21.203 (.31)	16.900 (.38)	26.672 (.48)
N8 (cv)	4.73e3 (.37)	3.844 (.35)	11.861 (.29)	12.420 (.28)	12.261 (.28)	10.122 (.32)	10.370 (.32)	8.067 (.41)	13.403 (.49)
N9 (cv)	1.56e3 (.44)	1.744 (.42)	2.547 (.38)	2.511 (.38)	2.283 (.40)	3.842 (.34)	3.903 (.33)	3.323 (.43)	4.742 (.51)
N10 (cv)	1.06e3 (.44)	1.197 (.42)	1.017 (.43)	972 (.44)	809 (.47)	754 (.47)	791 (.45)	795 (.57)	787 (.72)
Age 3 in T+1	22,643	23,362	6,268	8,026	19,620	19,707	19,760	11,429	34,449
F 1	0.00	0.0004	0.0000	0.0003	0.0004	0.0003	-	-	-
F 2	0.00	0.0026	0.0020	0.0002	0.0008	0.008	-	-	-
F 3	0.00	0.0026	0.0017	0.0015	0.0015	0.0015	0.0015	0.0010	0.0021
F 4	0.02	0.0205	0.0347	0.0164	0.0162	0.0162	0.0161	0.0154	0.0168
F 5	0.07	0.0725	0.0513	0.0273	0.0270	0.0269	0.0268	0.0308	0.0233
F 6	0.07	0.0725	0.0688	0.0603	0.0599	0.0597	0.0595	0.0741	0.0476
F 7	0.28	0.3375	0.1575	0.1474	0.1492	0.1780	0.1741	0.2186	0.1373
F 8	0.62	0.5716	0.3795	0.3857	0.4169	0.2685	0.2648	0.3045	0.2229
F 9	0.44	0.3985	0.4527	0.4706	0.5435	0.5734	0.5526	0.5508	0.5550
F10	0.45	0.4358	0.3299	0.3346	0.3699	0.3339	0.4087	0.4277	0.03890
F11+	0.45	0.4358	0.3299	0.3346	0.3699	0.3339	0.4087	0.4277	0.3890
Ave F 7-9	0.45	0.4358	0.3299	0.3346	0.3699	-	-	-	-
Ave F 8-9						0.3339	0.4087	0.4277	0.3890
SSB ('000 mt)	11,368	11,267	15,331	16,548	16,242	16,212	18,296	15,798	21,569

Table A.32. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality and spawning stock biomass (mt) for witch flounder estimated from virtual population analysis, 1982-2002.

Stock Numbers (Jan 1) in thousands

<b>Age</b>	<b>1982</b>	<b>1983</b>	<b>1984</b>	<b>1985</b>	<b>1986</b>	<b>1987</b>	<b>1988</b>	<b>1989</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>
3	15404	17700	16340	7650	5414	3001	9740	6214	6670	8831	14342
4	12174	13082	14922	13928	6470	4639	2562	7827	4934	5422	7192
5	9563	9493	10014	11486	10899	5220	3825	2076	6333	3660	4291
6	7830	7114	6765	6768	7929	7978	4060	3047	1726	4431	2353
7	4289	5375	4668	4216	4039	4267	5683	2886	2332	1249	3281
8	2752	3077	3160	2647	2224	2034	2222	3615	1783	1754	857
9	2102	1763	1746	1344	1132	1146	949	853	2297	1100	1283
10	1101	1440	839	862	599	594	544	448	413	1668	677
11+	7260	4728	3844	2926	2039	1151	1218	1263	900	1371	2127
<b>Total</b>	<b>62476</b>	<b>63772</b>	<b>62297</b>	<b>51828</b>	<b>40746</b>	<b>30029</b>	<b>30804</b>	<b>28229</b>	<b>27388</b>	<b>29487</b>	<b>36404</b>

<b>Age</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>
3	9670	13610	12671	15878	20226	29659	42904	67651	58704	29603	19760
4	11974	7936	11675	10324	13554	17283	25221	36778	58131	50462	25441
5	5029	8635	5904	9706	8400	10686	14360	21220	31390	49716	42739
6	2900	3019	4887	4119	7237	6290	8213	11345	17842	26146	41658
7	1164	1649	1414	2627	2289	5033	4106	5717	8693	14340	21204
8	2162	453	660	438	949	1033	2846	2426	3417	5910	10370
9	552	1320	209	321	136	274	547	1743	1138	1599	3903
10	940	274	640	91	80	39	105	239	926	398	792
11+	1318	782	373	180	112	179	181	536	667	655	603
<b>Total</b>	<b>35708</b>	<b>37679</b>	<b>38434</b>	<b>43683</b>	<b>52982</b>	<b>70476</b>	<b>98483</b>	<b>147655</b>	<b>180909</b>	<b>178829</b>	<b>166470</b>

Table A.32. continued.

## Fishing Mortality

<b>Age</b>	<b>1982</b>	<b>1983</b>	<b>1984</b>	<b>1985</b>	<b>1986</b>	<b>1987</b>	<b>1988</b>	<b>1989</b>	<b>1990</b>	<b>1991</b>	
3	0.013	0.021	0.010	0.018	0.005	0.008	0.069	0.081	0.057	0.055	
4	0.099	0.117	0.112	0.095	0.065	0.043	0.061	0.062	0.149	0.084	
5	0.146	0.189	0.242	0.221	0.162	0.101	0.077	0.034	0.207	0.292	
6	0.226	0.271	0.323	0.366	0.470	0.189	0.191	0.118	0.173	0.150	
7	0.182	0.381	0.417	0.490	0.536	0.503	0.303	0.332	0.135	0.227	
8	0.295	0.416	0.705	0.700	0.514	0.612	0.807	0.304	0.333	0.162	
9	0.228	0.593	0.556	0.657	0.495	0.595	0.602	0.577	0.170	0.335	
10	0.266	0.477	0.650	0.685	0.507	0.606	0.741	0.350	0.238	0.226	
11+	0.266	0.477	0.650	0.685	0.507	0.606	0.741	0.350	0.238	0.226	
<b>Age</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
3	0.030	0.048	0.003	0.055	0.008	0.007	0.012	0.004	0.002	0.001	0.002
4	0.208	0.177	0.146	0.035	0.056	0.088	0.035	0.023	0.008	0.006	0.016
5	0.242	0.360	0.419	0.210	0.144	0.139	0.113	0.086	0.023	0.033	0.027
6	0.554	0.414	0.609	0.471	0.438	0.213	0.276	0.212	0.116	0.069	0.060
7	0.267	0.793	0.766	1.023	0.868	0.646	0.420	0.376	0.365	0.236	0.174
8	0.291	0.343	0.623	0.571	1.021	1.093	0.486	0.340	0.607	0.610	0.265
9	0.161	0.552	0.574	0.688	1.244	1.085	0.805	0.679	0.483	0.900	0.553
10	0.211	0.382	0.586	0.598	1.109	1.092	0.545	0.388	0.553	0.675	0.409
11+	0.211	0.382	0.586	0.598	1.109	1.092	0.545	0.388	0.553	0.675	0.409

Table A.32. continued.

## Spawning Stock Biomass ( mt)

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3	20	13	24	5	5	16	115	33	24	25
4	107	132	185	127	91	216	191	238	156	104
5	376	458	580	684	1019	880	745	360	587	336
6	1115	1241	1243	1584	1916	2471	1297	964	454	886
7	1543	1883	1715	1720	1636	1794	2494	1303	999	496
8	1634	1544	1559	1388	1218	1072	1148	2010	1003	1004
9	1632	1172	1088	878	780	757	628	559	1640	754
10	949	1207	628	665	487	479	422	367	358	1411
11+	9521	5781	4505	3374	2414	1323	1392	1577	1227	1829
Total	16897	13431	11528	10425	9567	9008	8433	7410	6447	6844

Age	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
3	50	21	23	11	12	9	56	85	158	186	102
4	145	229	154	155	113	97	251	453	618	975	1096
5	463	437	636	601	852	599	883	1114	1657	2384	3739
6	582	694	630	1200	1139	1740	1304	1671	2095	3192	4736
7	1369	424	585	542	1044	888	1782	1405	1800	2664	4443
8	500	1210	230	352	225	455	485	1343	1040	1361	2545
9	916	392	862	144	196	87	171	286	925	544	825
10	547	789	217	509	69	61	32	86	137	511	262
11+	2490	1610	875	409	180	118	192	145	441	489	548
Total	7063	5806	4212	3922	3828	4053	5156	6587	8871	12305	18296

Table A.33. Summary of witch flounder catch (mt), spawning stock biomass (mt), fully recruited fishing mortality, recruitment (age 3, thousands of fish) and the year class.

Year	Catch (mt)	SSB (mt)	Ave F 8-9	Recruits	
				Age 3 ('000)	Year class
1982	4954	16897	0.262	15.404	1979
1983	6159	13431	0.505	17.700	1980
1984	6759	11527	0.631	16.340	1981
1985	6192	10425	0.679	7.650	1982
1986	4636	9566	0.504	5.414	1983
1987	3494	9008	0.604	3.001	1984
1988	3320	8432	0.704	9.740	1985
1989	2199	7411	0.440	6.214	1986
1990	1645	6448	0.252	6.670	1987
1991	1870	6845	0.249	8.831	1988
1992	2395	7062	0.226	14.342	1989
1993	2973	5806	0.447	9.670	1990
1994	3073	4212	0.598	13.610	1991
1995	2386	3923	0.629	12.671	1992
1996	2338	3830	1.132	15.878	1993
1997	2065	4054	1.089	20.226	1994
1998	2124	5156	0.645	29.659	1995
1999	2327	6588	0.510	42.904	1996
2000	2551	8871	0.545	67.651	1997
2001	3241	12306	0.755	58.704	1998
2002	3466	18296	0.409	29.603	1999
2003				19.760	2000
min	1645	3830	0.226	3.001	
max	6759	18296	1.132	67.651	
mean	3341	8576	0.563	19.613	
geomean				14.448	
median				14.342	

Table A.34. Yield and Spawning Stock biomass per recruit results for witch flounder.

## Yield per Recruit and Spawning Stock Biomass per Recruit  
 ## YPR Version 2.0  
 ## Date of Run: 19 May 2003 10:59  
 ## Input Data File: H:\WITCHASS\YPR\YPR2003\RUN301-F.DAT

Model Title: Witch Flounder (run 301)  
 Start Age = 3  
 End Age = 20 (Does Not Include Plus Group)  
 Fishing Mortality Upper Bound = 1.0000  
 Fishing Mortality Calculation Increment = 0.0001  
 Fishing Mortality Printing Increment = 0.05  
 Natural Mortality = 0.1500  
 Proportion Fishing Mortality Before Spawning = 0.1667  
 Proportion Natural Mortality Before Spawning = 0.1667

Age	Selectivity F	Selectivity M	Stock Weight	Catch Weight	Maturity
3	0.0036	1.0000	0.0787	0.0830	0.0200
4	0.0229	1.0000	0.1459	0.2021	0.0800
5	0.0703	1.0000	0.2319	0.2746	0.3000
6	0.1931	1.0000	0.3328	0.3813	0.6200
7	0.5282	1.0000	0.4442	0.4752	0.8700
8	1.0000	1.0000	0.5615	0.5548	0.9700
9	1.0000	1.0000	0.6816	0.6393	1.0000
10	1.0000	1.0000	0.8006	0.7656	1.0000
11	1.0000	1.0000	0.9175	0.9175	1.0000
12	1.0000	1.0000	1.0399	1.0399	1.0000
13	1.0000	1.0000	1.1348	1.1348	1.0000
14	1.0000	1.0000	1.2335	1.2335	1.0000
15	1.0000	1.0000	1.3259	1.3259	1.0000
16	1.0000	1.0000	1.4097	1.4097	1.0000
17	1.0000	1.0000	1.4875	1.4875	1.0000
18	1.0000	1.0000	1.5575	1.5575	1.0000
19	1.0000	1.0000	1.6215	1.6215	1.0000
20	1.0000	1.0000	1.6787	1.6787	1.0000

Reference Point	F	YPR	SSBR	Mean Age	Mean GT	Exp Spawn
F Zero	0.00000	0.00000	3.22009	7.88231	12.35089	3.51035
F-01	0.19560	0.21504	1.42574	6.17333	9.86110	1.89110
F-Max	0.54470	0.23913	0.70920	5.25697	7.88807	1.10782
F at 40 %MSP	0.23030	0.22321	1.28817	6.01053	9.54415	1.75334

FMORT	CTHN	CTHW	STKN	STKW	SPNSTKN	SPNSTKW	MSP	MNAGE	MNGT	EXSP
0.00000	0.00000	0.00000	6.69668	3.73482	3.97773	3.22009	100.00000	7.88231	12.35089	3.51035
0.05000	0.12719	0.10688	6.09150	3.01110	3.36959	2.49680	77.53824	7.27308	11.60967	2.88137
0.10000	0.21103	0.16547	5.65531	2.51453	2.93327	2.00314	62.20754	6.79993	10.93332	2.43786
0.15000	0.26898	0.19799	5.33144	2.16433	2.61075	1.65669	51.44853	6.43444	10.33526	2.11483
0.20000	0.31092	0.21626	5.08406	1.91048	2.36545	1.40670	43.68521	6.15113	9.81886	1.87226
0.25000	0.34258	0.22661	4.89003	1.72147	2.17388	1.22138	37.93009	5.92942	9.38004	1.68494
0.30000	0.36738	0.23250	4.73412	1.57712	2.02062	1.08043	33.55283	5.75361	9.01047	1.53659
0.35000	0.38740	0.23583	4.60609	1.46422	1.89534	0.97064	30.14315	5.61208	8.70022	1.41647
0.40000	0.40401	0.23766	4.49893	1.37397	1.79097	0.88322	27.42858	5.49635	8.43945	1.31728
0.45000	0.41806	0.23861	4.40769	1.30039	1.70256	0.81225	25.22442	5.40025	8.21931	1.23399
0.50000	0.43018	0.23903	4.32886	1.23933	1.62656	0.75359	23.40289	5.31927	8.03229	1.16300
0.55000	0.44078	0.23913	4.25986	1.18785	1.56039	0.70436	21.87379	5.25012	7.87222	1.10172
0.60000	0.45016	0.23902	4.19878	1.14384	1.50214	0.66244	20.57223	5.19034	7.73411	1.04823
0.65000	0.45855	0.23880	4.14416	1.10574	1.45036	0.62633	19.45062	5.13808	7.61399	1.00106
0.70000	0.46613	0.23850	4.09490	1.07240	1.40393	0.59486	18.47345	5.09193	7.50869	0.95912
0.75000	0.47302	0.23815	4.05013	1.04293	1.36197	0.56718	17.61382	5.05081	7.41569	0.92152
0.80000	0.47934	0.23778	4.00915	1.01665	1.32381	0.54262	16.85101	5.01388	7.33296	0.88760
0.85000	0.48516	0.23740	3.97141	0.99303	1.28889	0.52065	16.16884	4.98047	7.25889	0.85680
0.90000	0.49055	0.23701	3.93647	0.97165	1.25675	0.50087	15.55453	4.95004	7.19216	0.82868
0.95000	0.49558	0.23662	3.90396	0.95218	1.22704	0.48294	14.99784	4.92216	7.13170	0.80287
1.00000	0.50028	0.23623	3.87358	0.93434	1.19945	0.46661	14.49050	4.89647	7.07662	0.77908



Table A.35. Summary of yield and spawning stock biomass per recruit results, corresponding biological reference points and differences between current and former analyses.

	Results			Age 3		
	F40%	Y/R	SSB/R	Mean Rec	Bmsy	MSY
RUN 0 BRP ages 3-11+	0.1643	0.2405	1.6023	12.42	19,901	2,987
RUN 1 BRP with ages 3-20	0.2033	0.2506	1.3692	12.42	17,006	3,113
RUN 2 with new pr	0.2666	0.2712	1.3694	19.6	26,840	5,316
RUN 3 with new wts	0.1918	0.2151	1.3321	19.6	26,108	4,217
RUN 4 with new maturity	0.1920	0.2473	1.3249	19.6	25,968	4,847
RUN 5 with new pr and wts	0.2478	0.2263	1.3322	19.6	26,111	4,435
RUN 6 with new wts and maturity	0.1807	0.2121	1.2883	19.6	25,251	4,158
RUN 7 with new pr and maturity	0.2485	0.2675	1.3246	19.6	25,963	5,244
RUN 8 with new pr, wts and maturity	0.2303	0.2232	1.2882	19.6	25,248	4,375

Differences between estimates from the current (RUN 8) and former (RUN 1) yield and spawning stock biomass per recruit analyses.

	F40%	Y/R	SSB/R	Bmsy (000's)
Total Effect = RUN 8 - RUN 1	0.07	-0.0173	-0.3142	8.242
P-R effect = RUN 2 - RUN 1	0.06	0.0206	0.0002	
Wt effect = RUN 3 - RUN 1	-0.01	-0.0355	-0.0372	
Mat effect = RUN 4 - RUN 1	-0.01	-0.0033	-0.0443	
2-way interaction				
PR and wt interaction effect	0.04	-0.0244	-0.0371	
Wt and mat interaction effect	-0.02	-0.0385	-0.0809	
PR and mat interaction effect	0.05	0.0169	-0.0446	
3-way interaction				
Total effect - all of the above effects	-0.04	0.0469	-0.0702	
SSB/R effect				-1.006
Recruit effect				9.830
interaction				-0.582

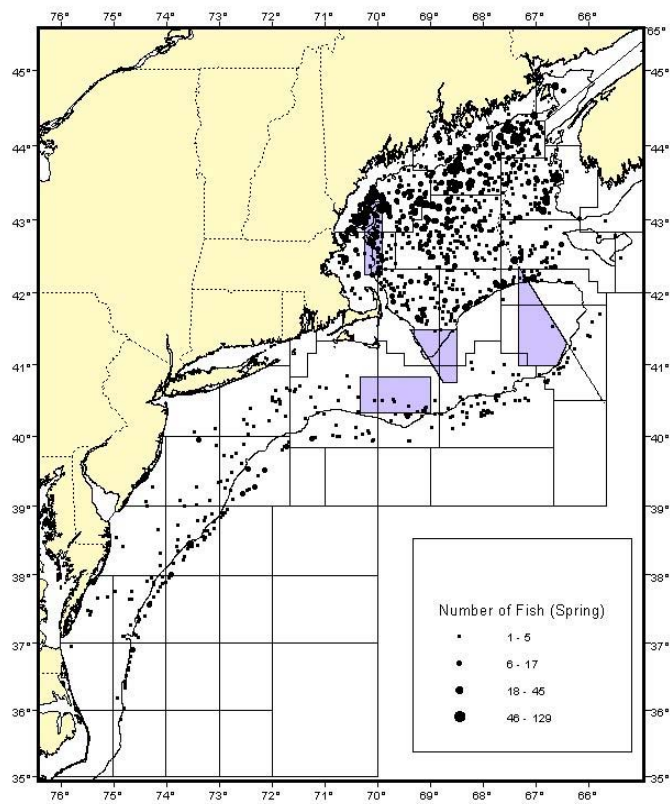
Table A.36. Summary of short-term projection results for witch flounder. Projected median estimates of landings (mt), discards (mt), and spawning stock biomass (mt) are provided: 1) status quo fishing mortality ( $F_{2003} = F_{2002} = 0.41$ ); 2) fishing mortality at  $F_{msy} = F_{40\%} = 0.23$ ; 3) fishing mortality at 75% of  $F_{MSY}$ ; and 4) status quo landings ( $landings_{2003} = landings_{2002}$ ).

Projection input:

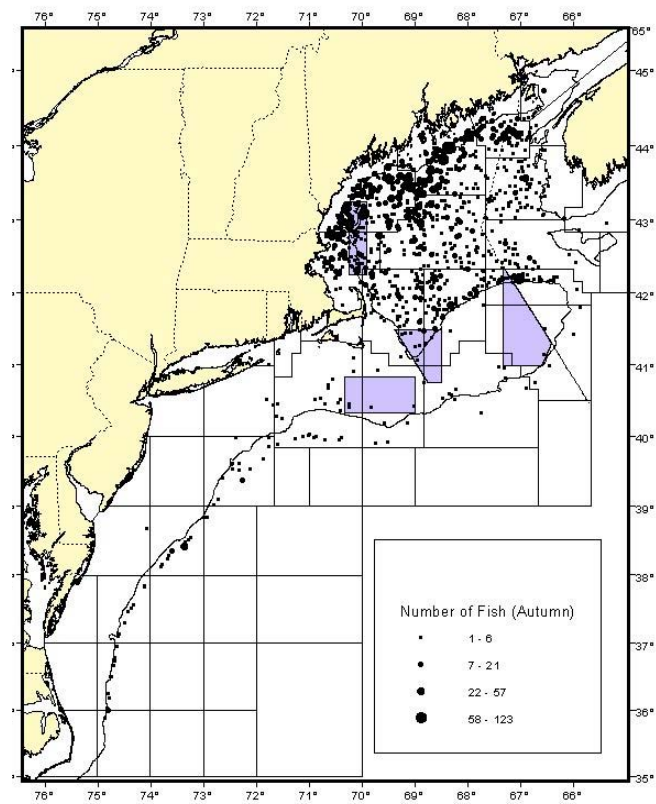
Age	Selectivity F	Selectivity M	Stock Weight	Land Weight	Maturity
3	0.0036	1.0000	0.0443	0.0000	0.0700
4	0.0229	1.0000	0.1214	0.3220	0.1600
5	0.0703	1.0000	0.2267	0.3380	0.3500
6	0.1931	1.0000	0.3206	0.3960	0.5900
7	0.5282	1.0000	0.4202	0.4780	0.7900
8	1.0000	1.0000	0.5151	0.5550	0.9100
9	1.0000	1.0000	0.5995	0.6400	0.9700
10	1.0000	1.0000	0.7281	0.7660	0.9900
11+	1.0000	1.0000	0.8888	0.8889	1.0000

Projection results (weight reported in '000 mt)

Scenario	Year	F	Median Landings	Median Discards	Median SSB
F status quo	2003	0.41	6.254	0.251	26.677
F status quo	2004	0.41	8.652	0.191	32.121
F status quo	2005	0.41	10.474	0.132	33.733
F status quo	2003	0.41	6.254	0.251	26.677
$F_{MSY}$	2004	0.23	5.174	0.109	32.705
$F_{MSY}$	2005	0.23	6.992	0.076	37.600
F status quo	2003	0.41	6.254	0.251	26.677
75% $F_{MSY}$	2004	0.17	3.908	0.081	32.902
75% $F_{MSY}$	2005	0.17	5.480	0.057	39.080
$Landings_{2003} = Landings_{2002}$	2003	0.199	3.186	0.121	27.241
$F_{MSY}$	2004	0.23	5.781	0.111	35.389
$F_{MSY}$	2005	0.23	7.519	0.077	40.160
$Landings_{2003} = Landings_{2002}$	2003	0.199	3.186	0.121	27.241
75% $F_{MSY}$	2004	0.17	4.366	0.083	35.613
75% $F_{MSY}$	2005	0.17	5.899	0.058	41.753

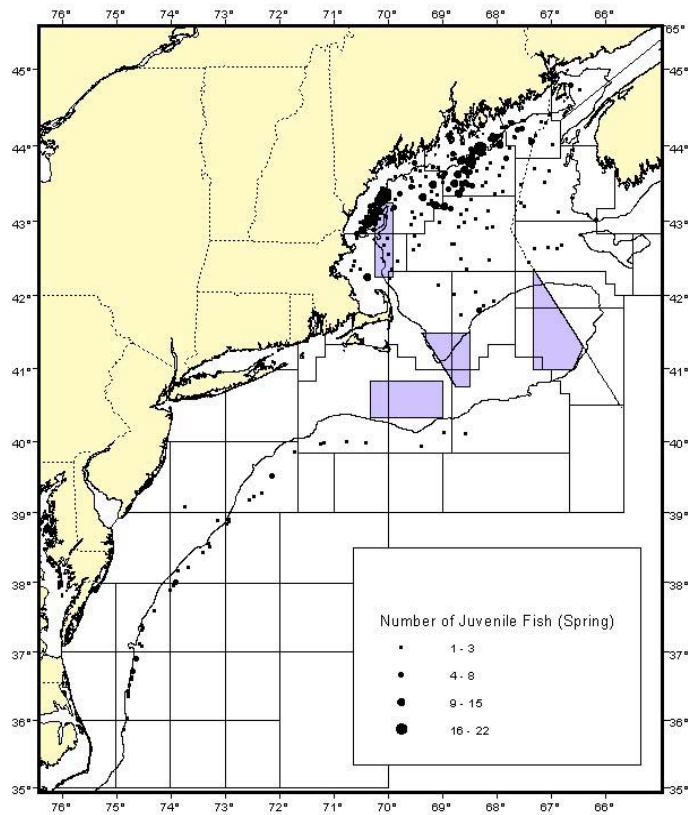


Witch Flounder - Spring 1983 - 2002

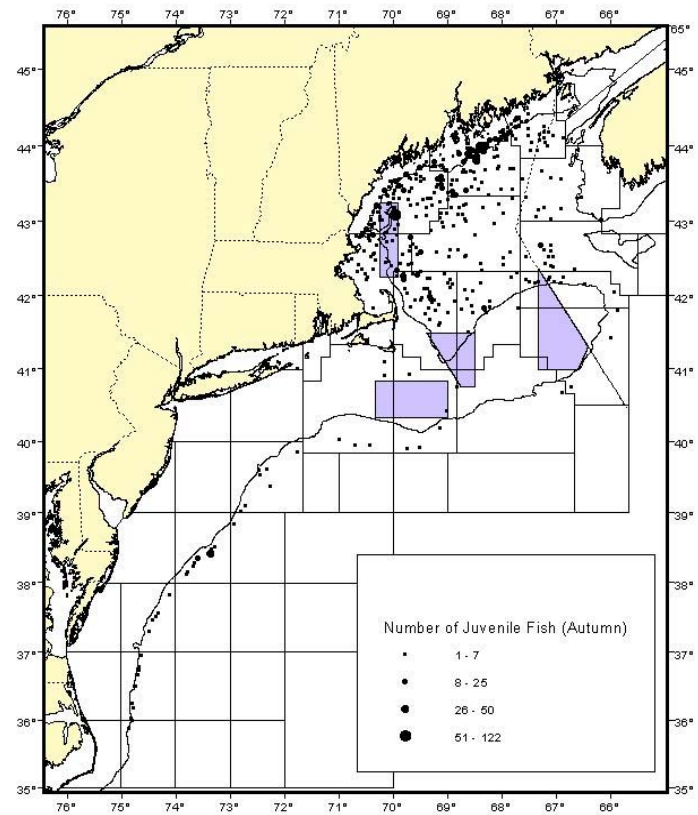


Witch Flounder - Autumn 1983 - 2002

Figure A.1 Number of witch flounder per tow in the NEFSC spring and autumn bottom trawl surveys, 1983-2002; year-around area closures are indicated by shaded polygons.



Witch Flounder - Spring 1983 - 2002 Juveniles < 25 cm



Witch Flounder - Autumn 1983 - 2002 Juveniles < 25 cm

Figure A.2. Number of juvenile (< 25 cm) witch flounder per tow in the NEFSC spring and autumn surveys, 1983-2002; year-around area closures are indicated by shaded polygons.

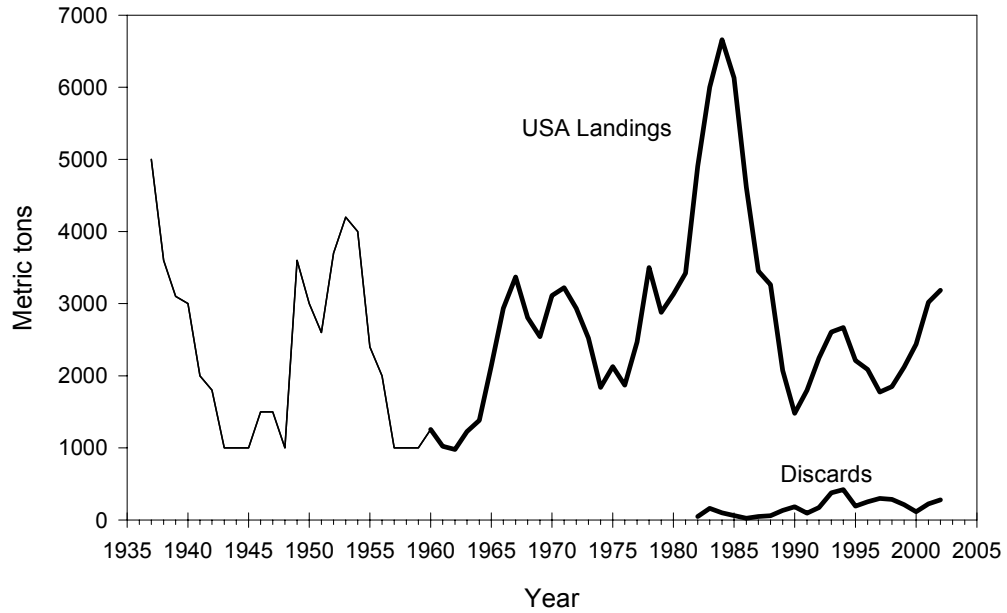


Figure A.3. Historical USA witch flounder landings (mt), excluding USA landings from the Grand Banks in the mid-1980's. Thin line represents provisional landings data taken from Lange and Lux (1978); discards are from the shrimp and large-mesh otter trawl fishery.

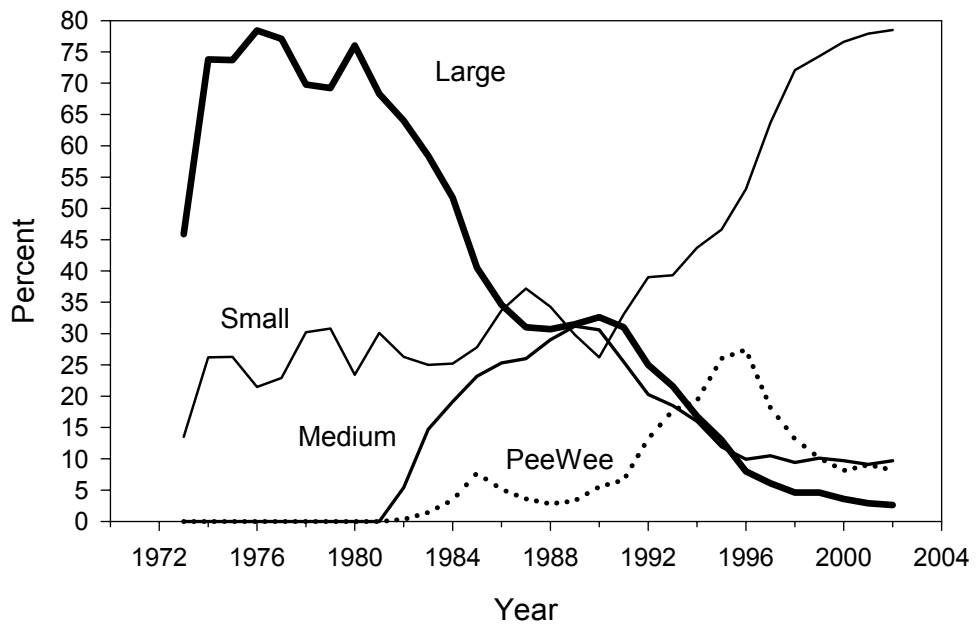


Figure A.4. Commercial landings of witch flounder by market category, 1973 – 2002.

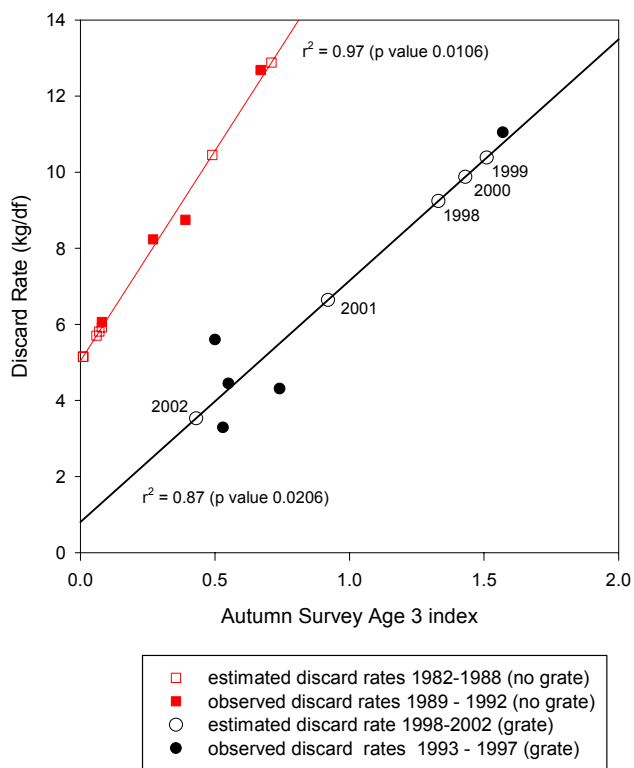


Figure A.5. Observed with flounder discard rates (kg per day fished, closed symbols) from the Fisheries Observer Program, and estimated discard rates (kg/df, open symbols) in northern shrimp fishery estimated from linear regressions (solid line) of observed discard rates and NEFSC autumn survey age 3 index.

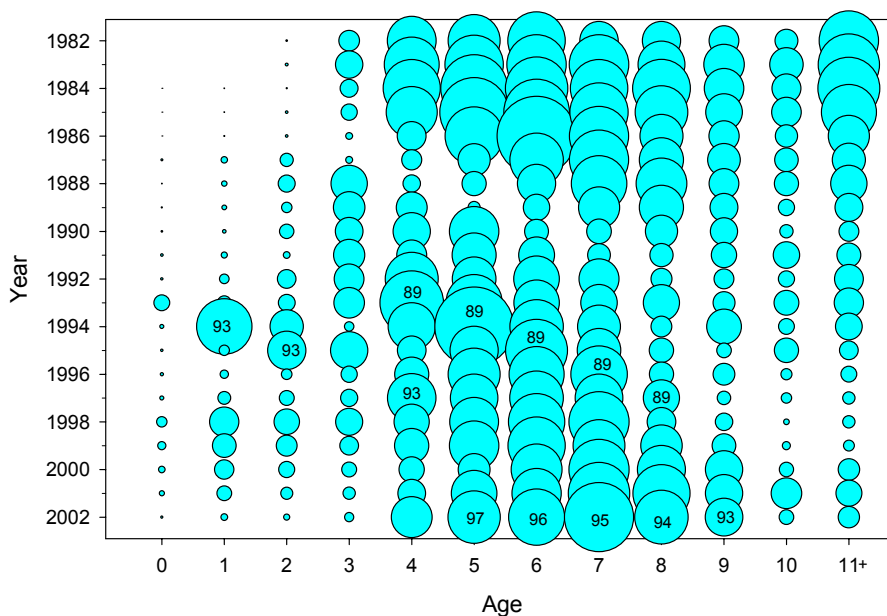


Figure A.6. Witch flounder catch at age (in numbers), 1982 – 2002; selected cohorts are labeled.

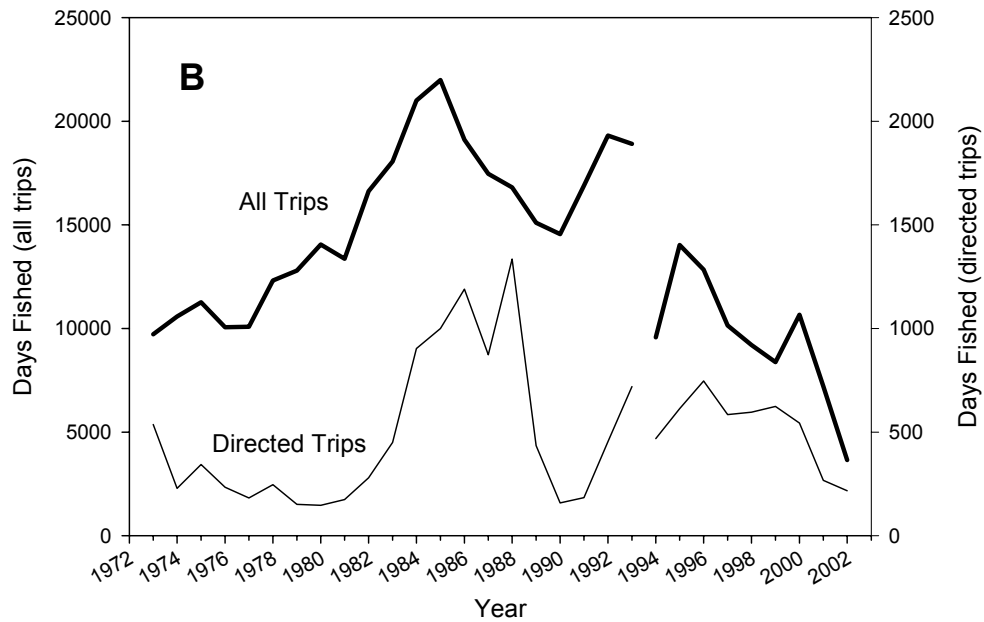
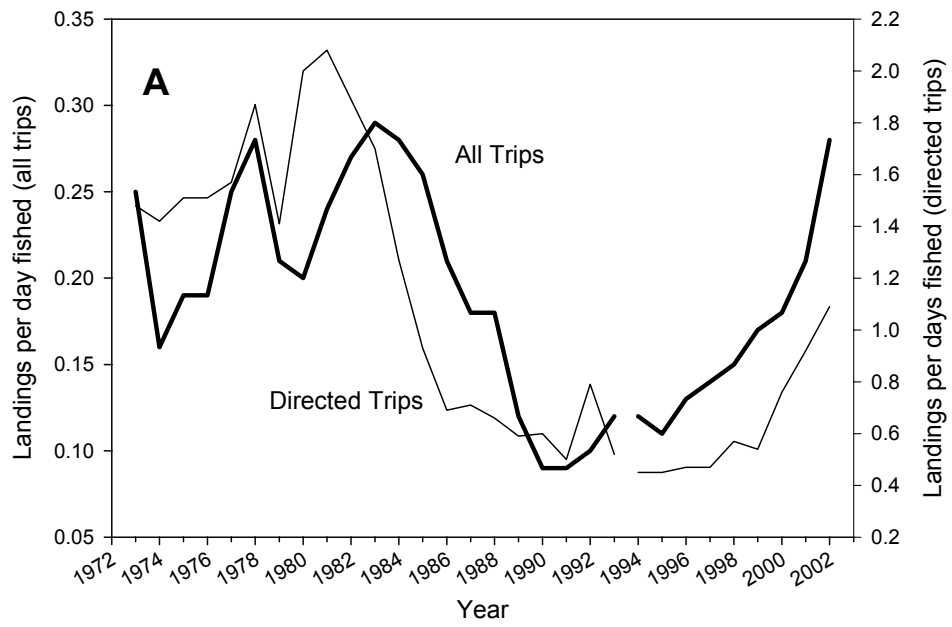
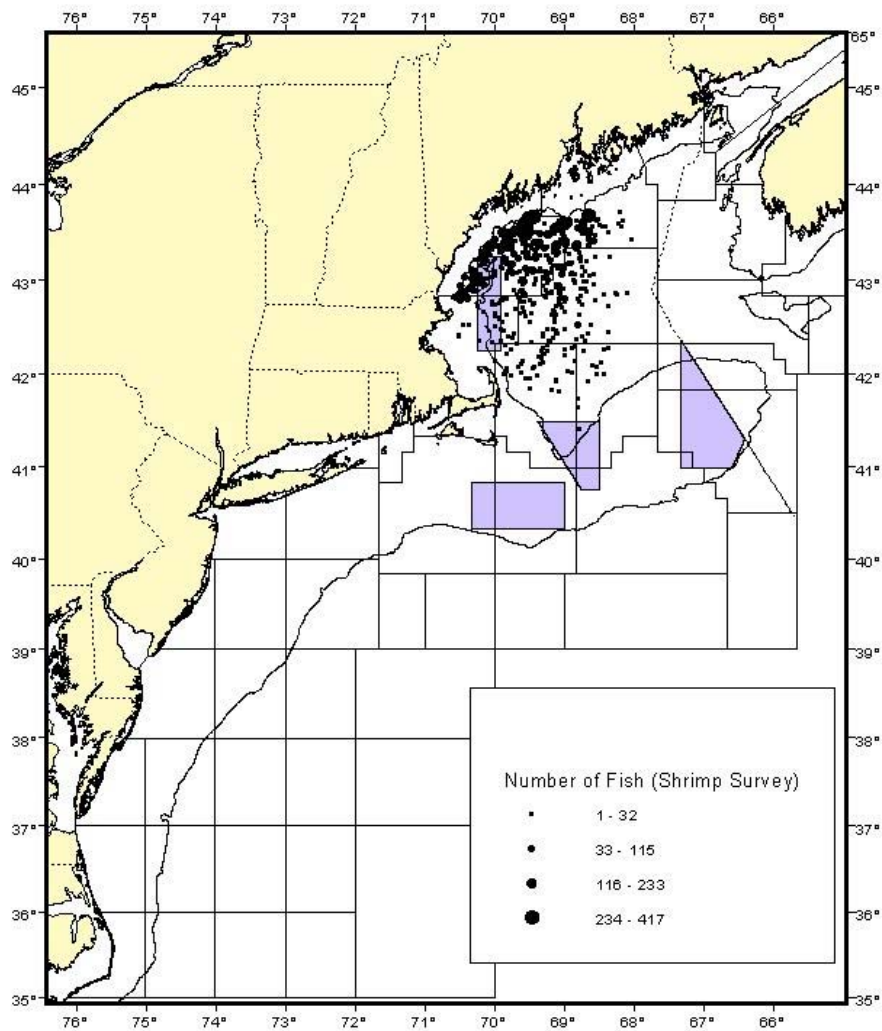


Figure A.7. Trends in USA landings per day fished (A) and effort (B) of witch flounder, 1973 -2002.



Witch Flounder - ASMFC Summer Shrimp Survey 1985 - 2002

Figure A.8. Number of witch flounder per tow in the ASMFC northern shrimp survey, 1985-2002; year-around area closures are indicated by shaded polygons.



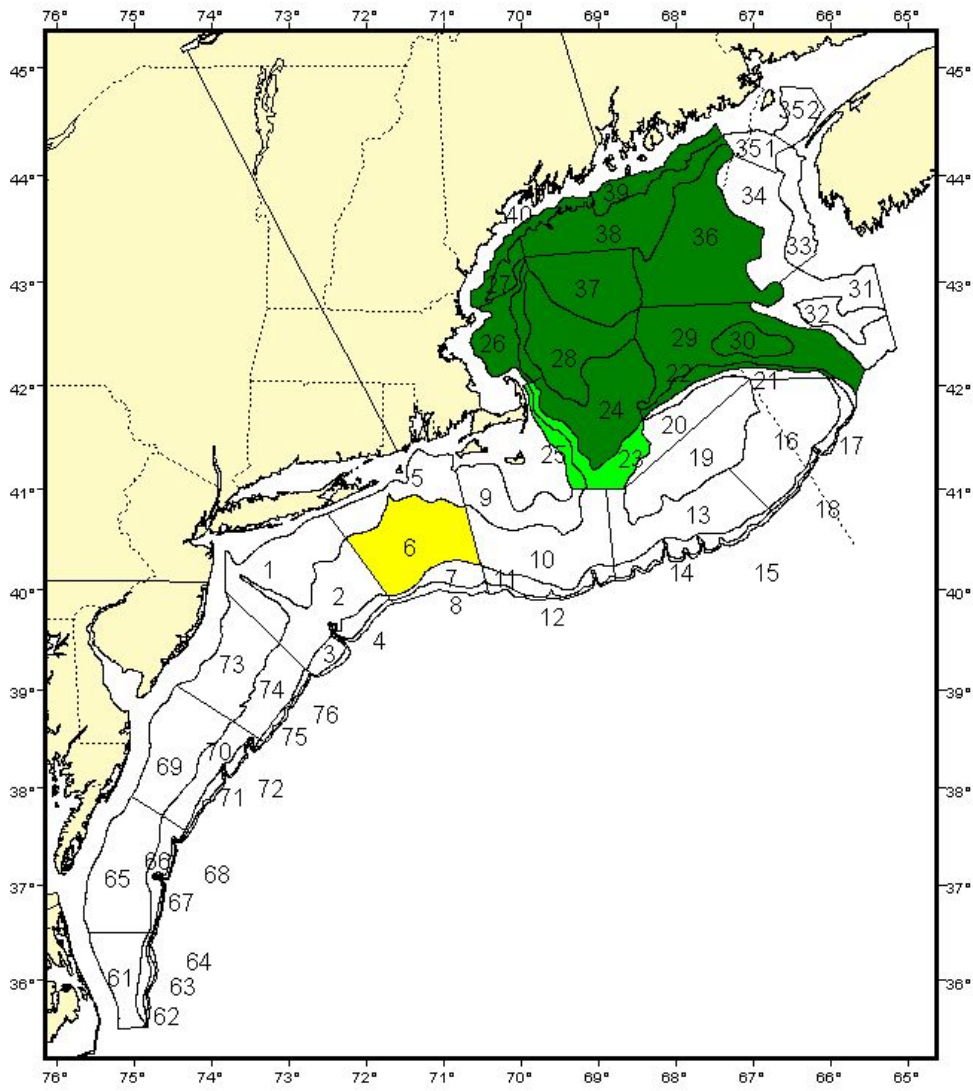


Figure A.9. NEFSC bottom trawl survey sampling strata.

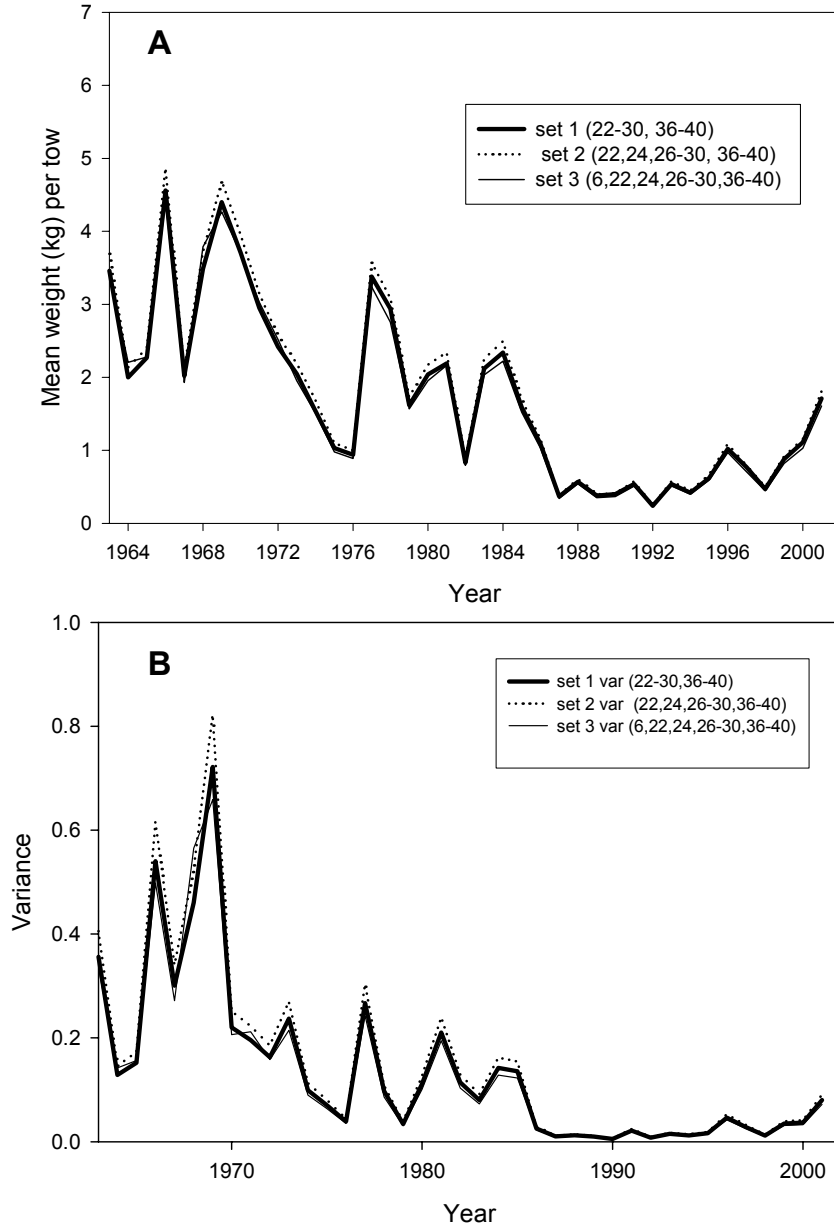


Figure A.10. Stratified mean catch (kg) per tow (A) and variance (B) of witch flounder in the NEFSC autumn bottom trawl surveys for three strata sets in the Georges Bank-Gulf of Maine region, 1963 – 2001.

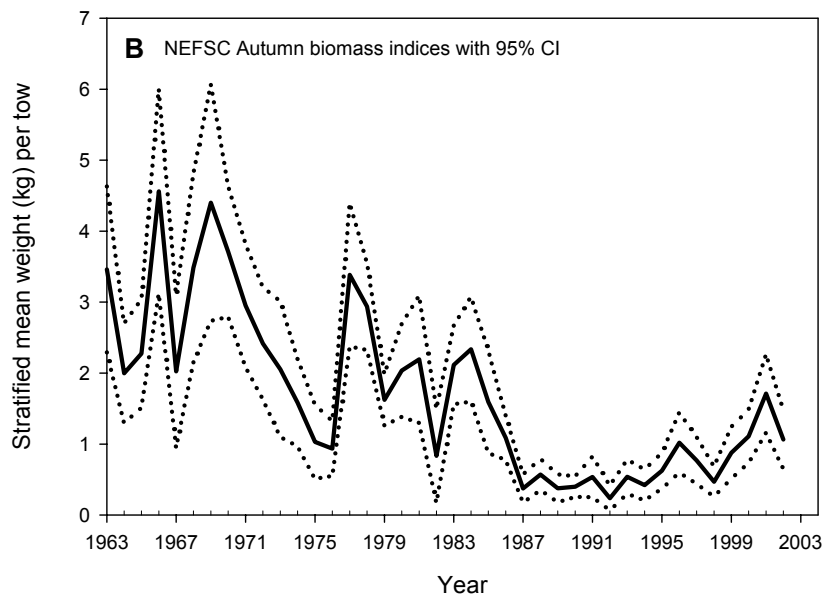
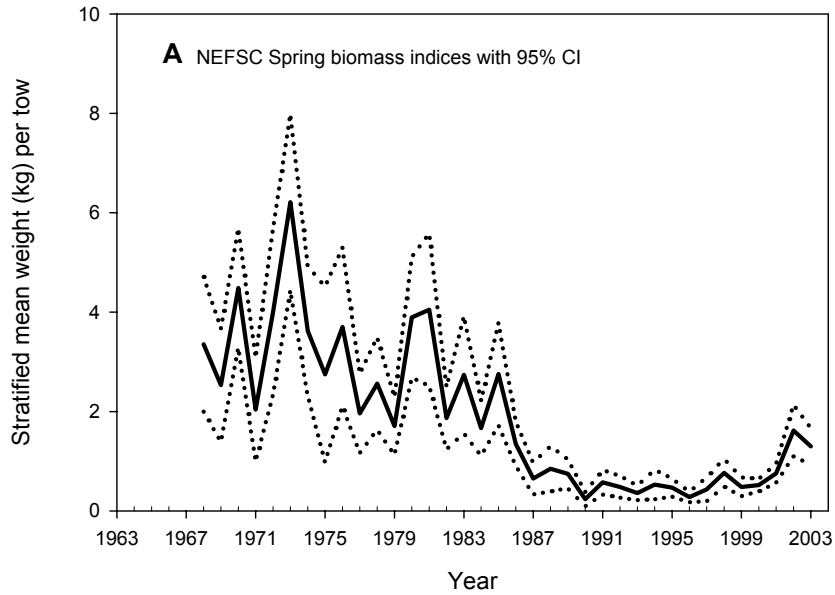


Figure A.11. Stratified mean weight (kg) per tow, with 95% confidence limits, of witch flounder in the NEFSC spring (A) and autumn (B) bottom trawl surveys, 1963 – 2003.

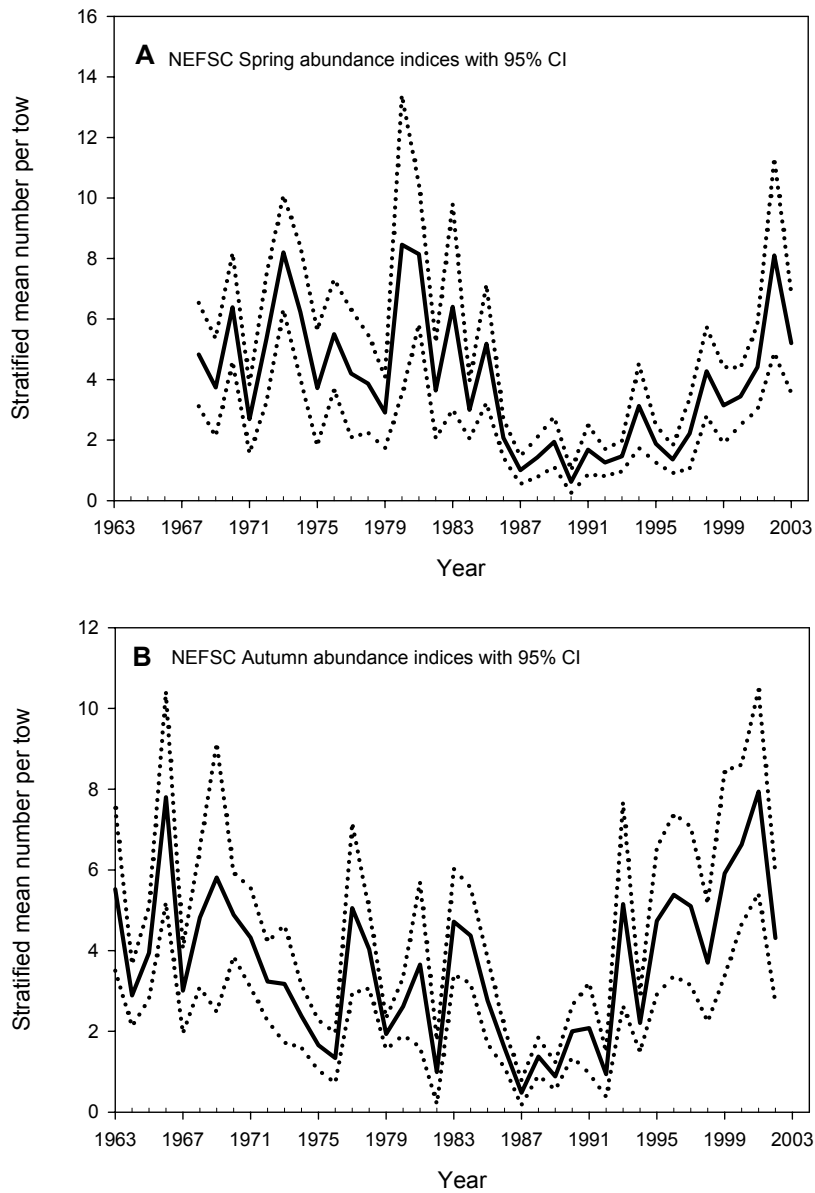


Figure A.12. Stratified mean number per tow, with 95% confidence limits, of witch flounder in the NEFSC spring (A) and autumn (B) bottom trawl surveys, 1963 – 2003.

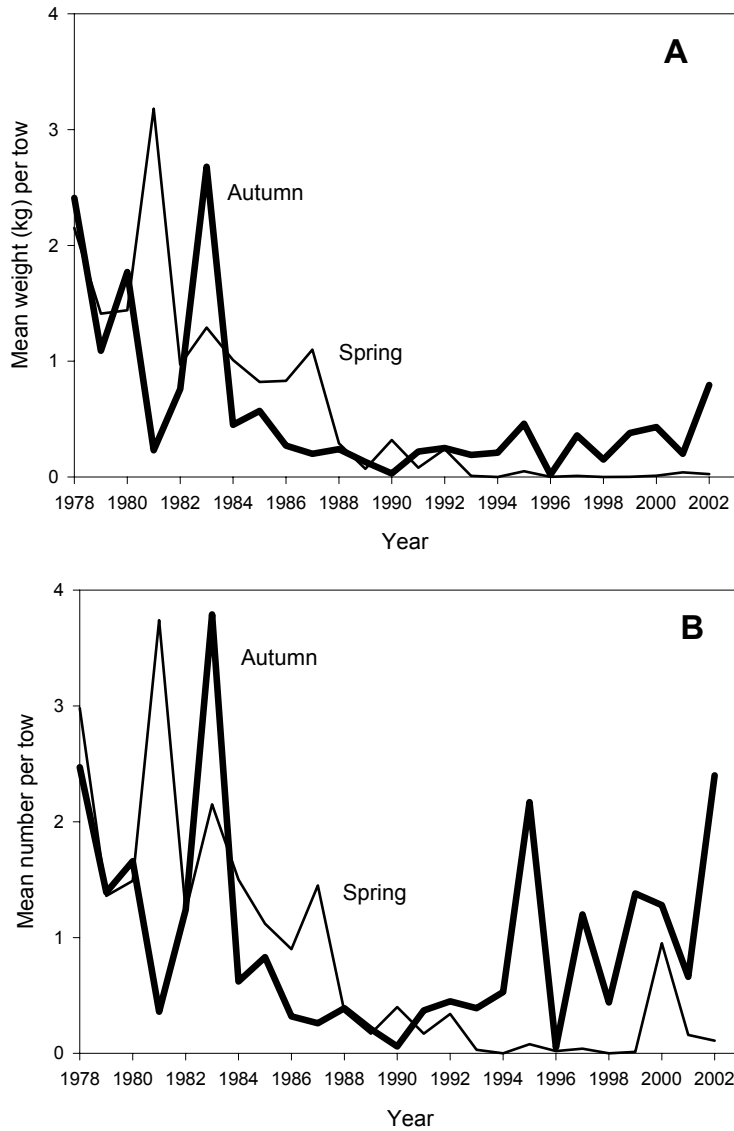


Figure A.13. Stratified mean weight (kg) per tow (A) and mean number per tow (B) of witch flounder in the Massachusetts Division of Marine Fisheries spring and autumn bottom trawl surveys in Cape Cod Bay - Mass. Bay region, 1978 – 2002.

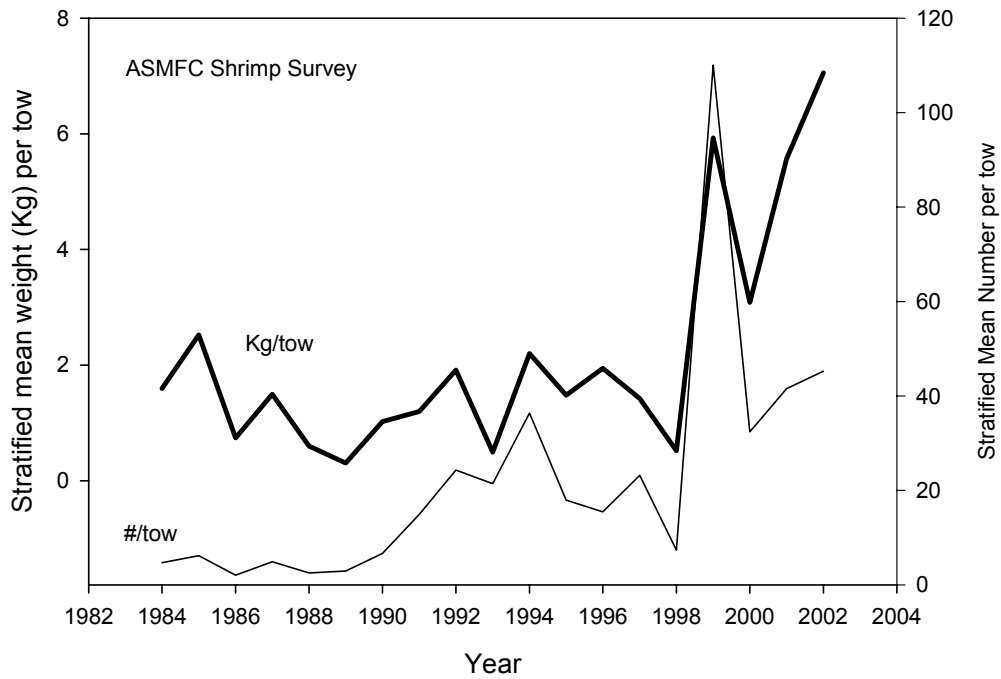


Figure A.14. Stratified mean catch per tow, in weight (kg) and numbers, of witch flounder in the Atlantic States Marine Fisheries Commission summer northern shrimp survey, 1984 – 2002.

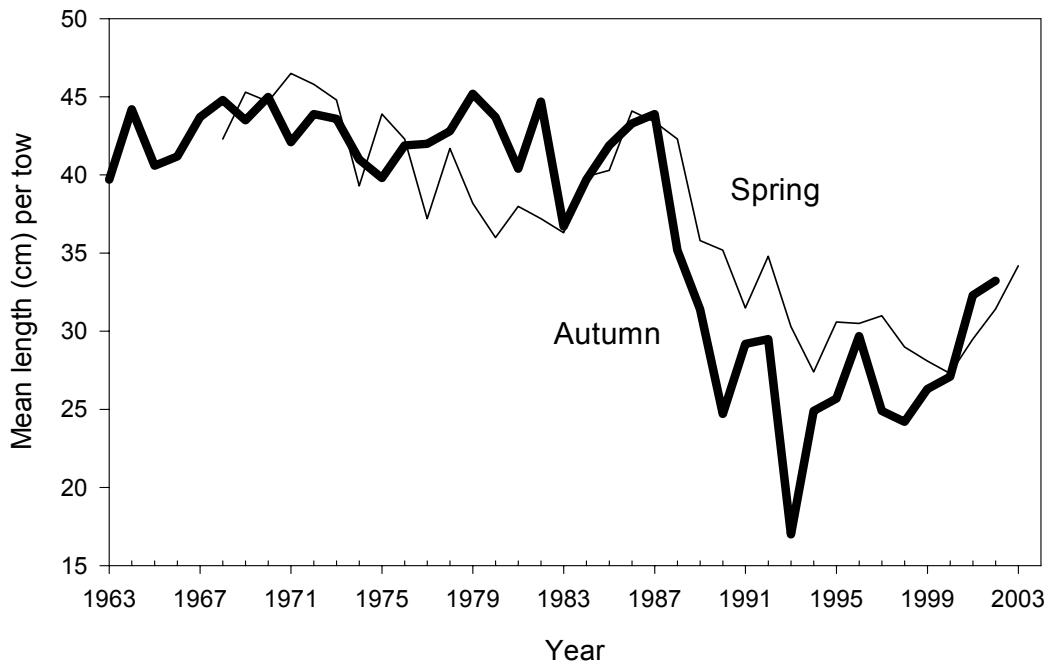


Figure A.15. Stratified mean length (cm) per tow of witch flounder in NEFSC spring and autumn bottom trawl surveys in the Georges Bank- Gulf of Maine region, 1963 – 2003.

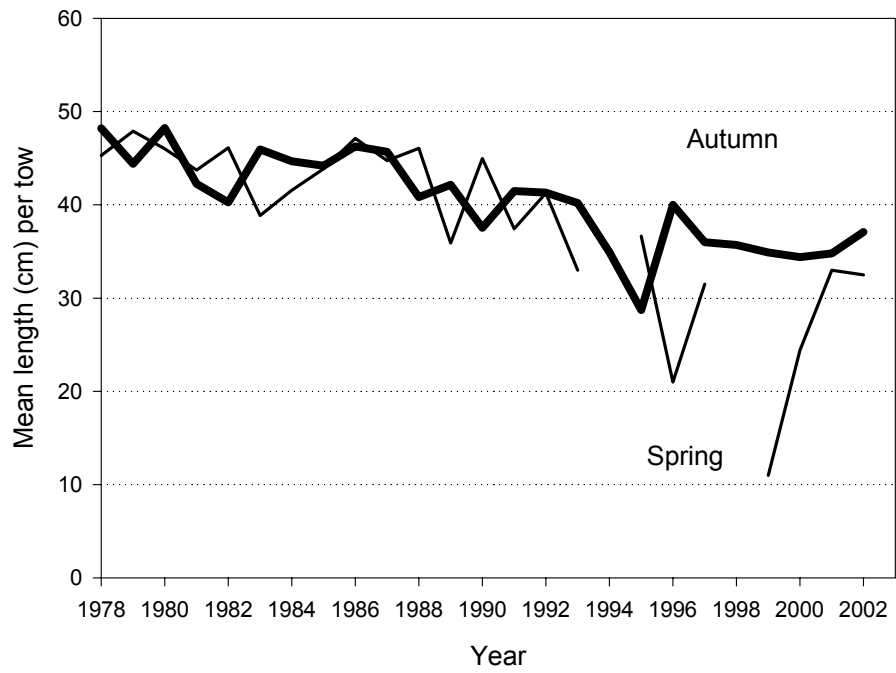


Figure A.16. Stratified mean length (cm) per tow of witch flounder in Massachusetts Division of Marine Fisheries spring and autumn bottom trawl surveys in the Cape Cod Bay – Mass. Bay region, 1978 – 2002.

### Spring Survey: Stratified mean number per tow at age

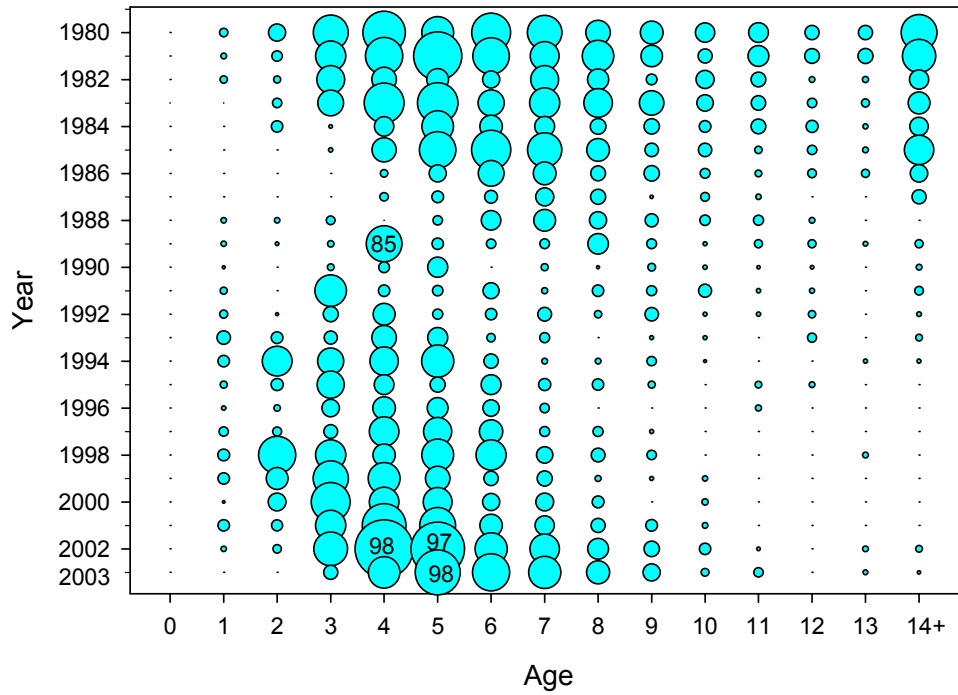


Figure A.17. Stratified mean number of witch flounder per tow at age from NEFSC spring bottom trawl surveys, 1980-2002, preliminary 2003; selected cohorts are labeled.

### Autumn Survey: Stratified mean number per tow at age

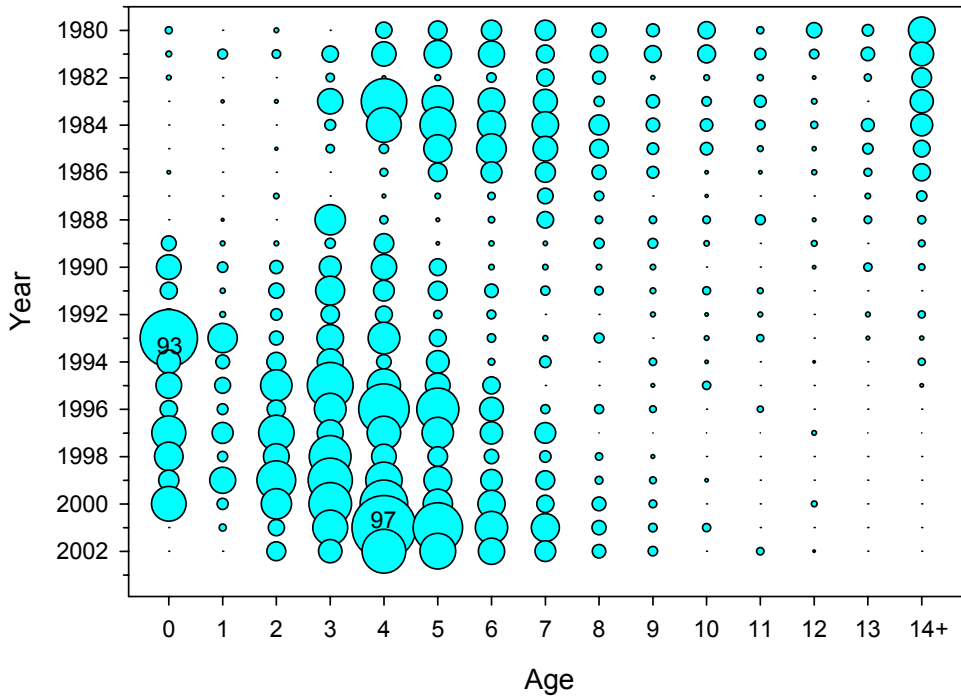


Figure A.18. Stratified mean number of witch flounder per tow at age from NEFSC autumn bottom trawl surveys, 1980-2002; selected cohorts are labeled.



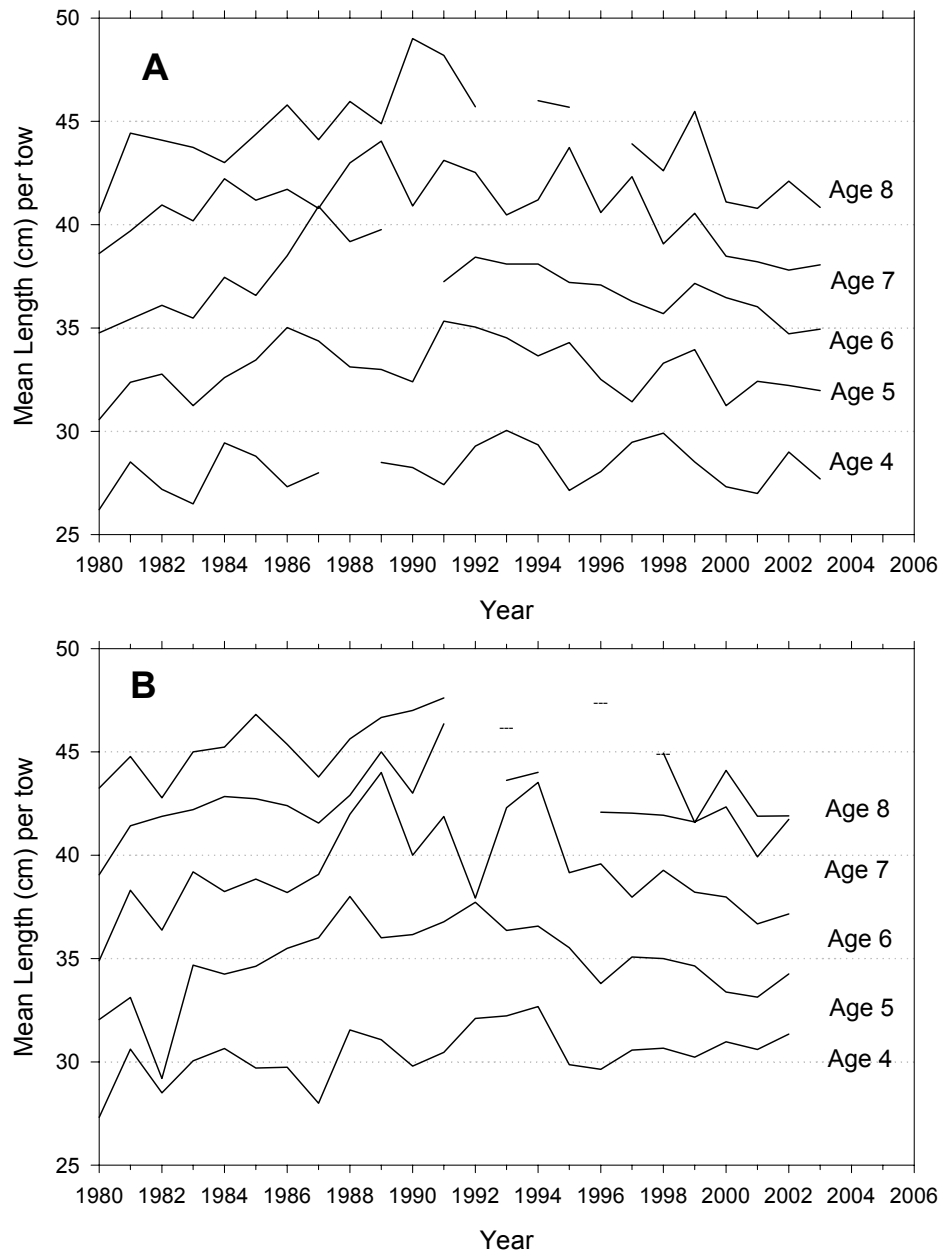


Figure A.19. Mean length (cm) at age of witch flounder for age groups 4 – 8 in spring (A) and autumn (B) NEFSC bottom trawl surveys, 1980 – 2002, preliminary 2003.

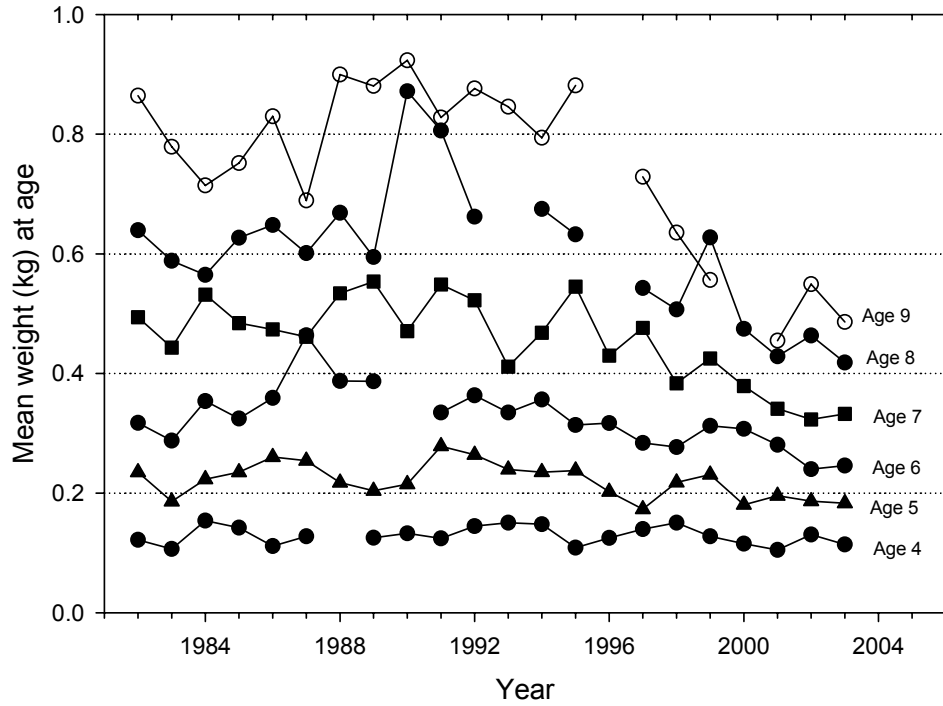


Figure A.20. Mean weight at age of witch flounder in the NEFSC spring bottom trawl survey, 1980 – 2002, preliminary 2003.

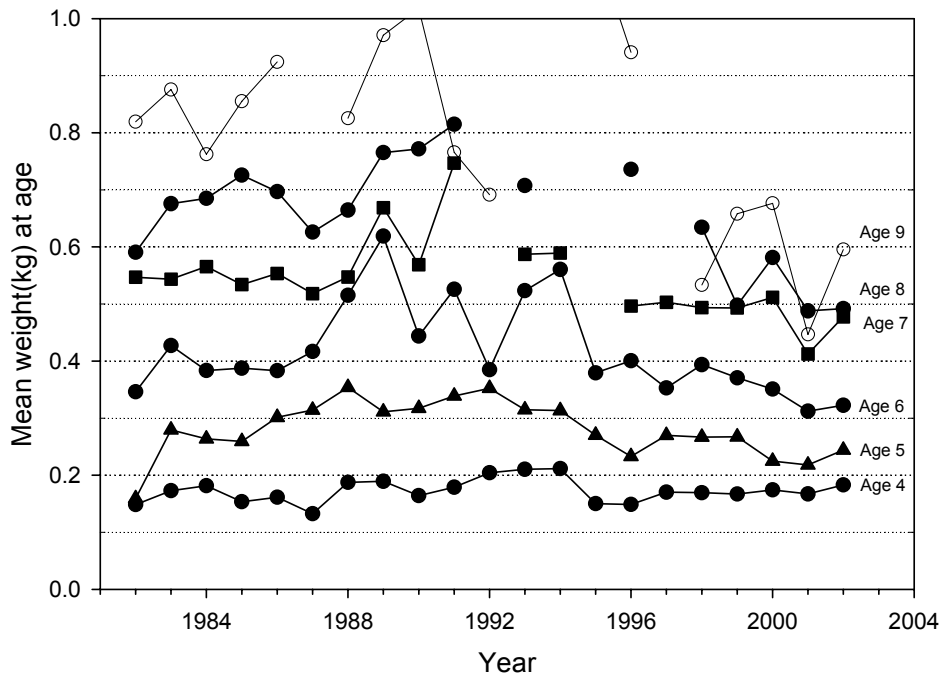


Figure A.21. Mean weight at age of witch flounder in the NEFSC autumn bottom trawl survey, 1980 – 2002.

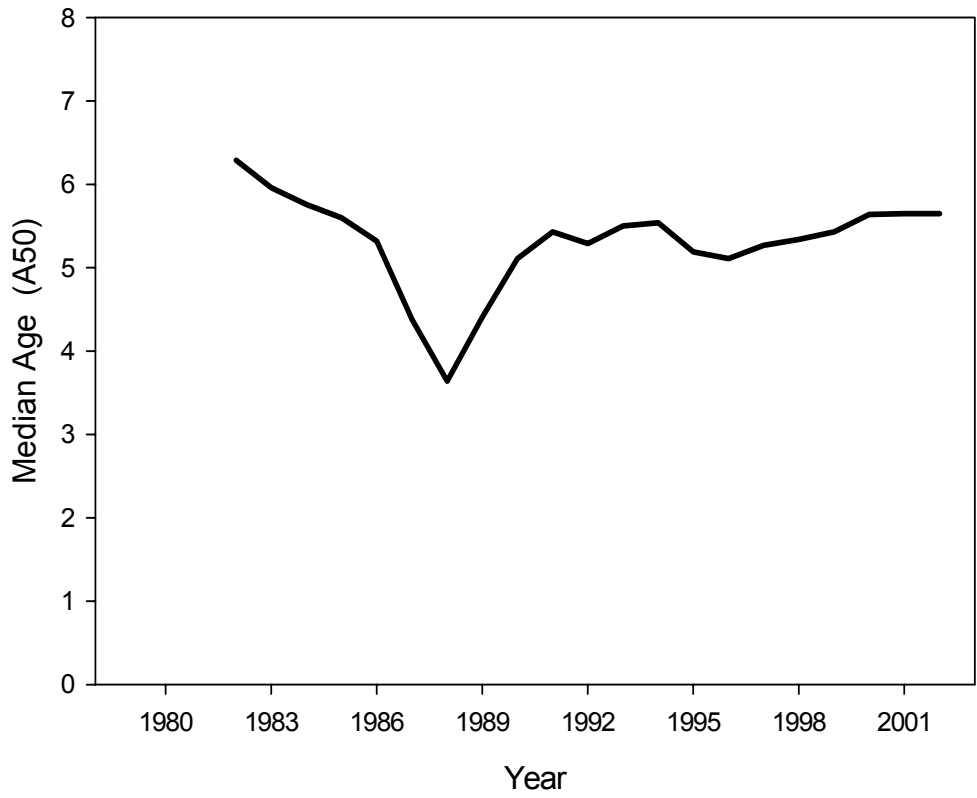


Figure A.22. Annual estimates of median age (A50) of witch flounder derived from a five-year moving time block of maturity observations collected during NEFSC spring surveys, 1980-2003.

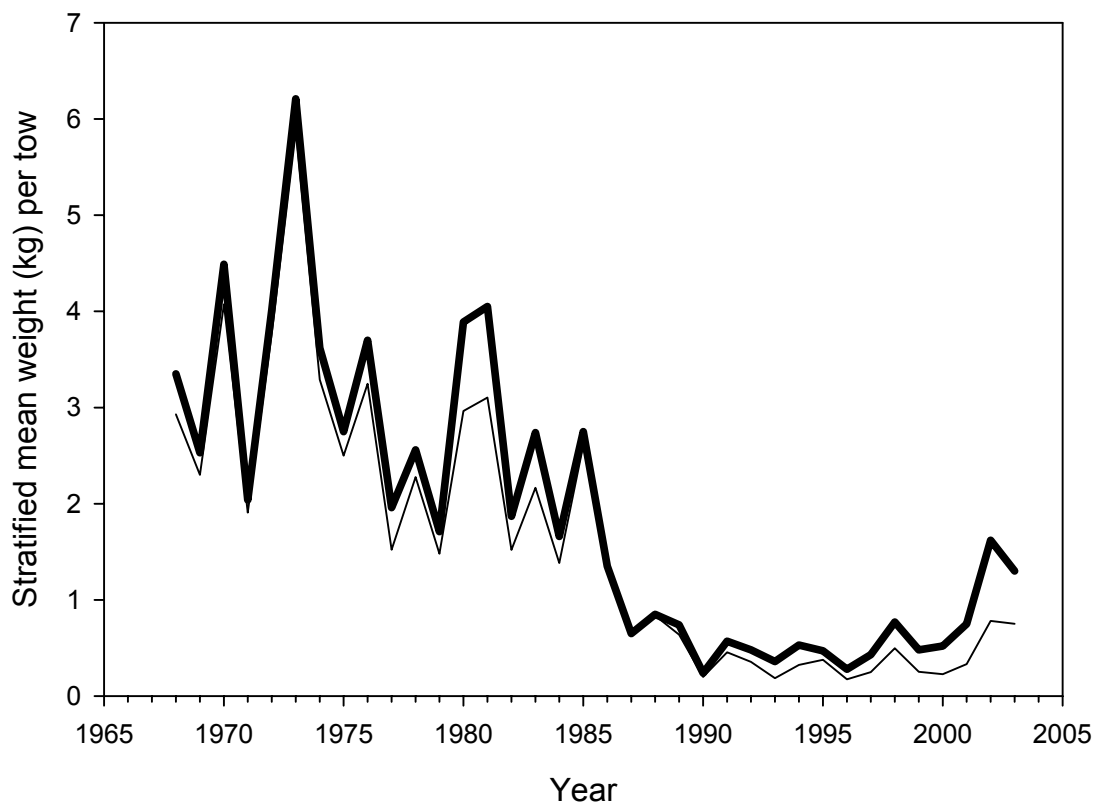


Figure A.23. Stratified mean weight (kg) per tow (thick line) and spawning biomass (kg) per tow (thin line) of witch flounder from the NEFSC spring bottom trawl surveys, 1968 □2002, preliminary 2003.

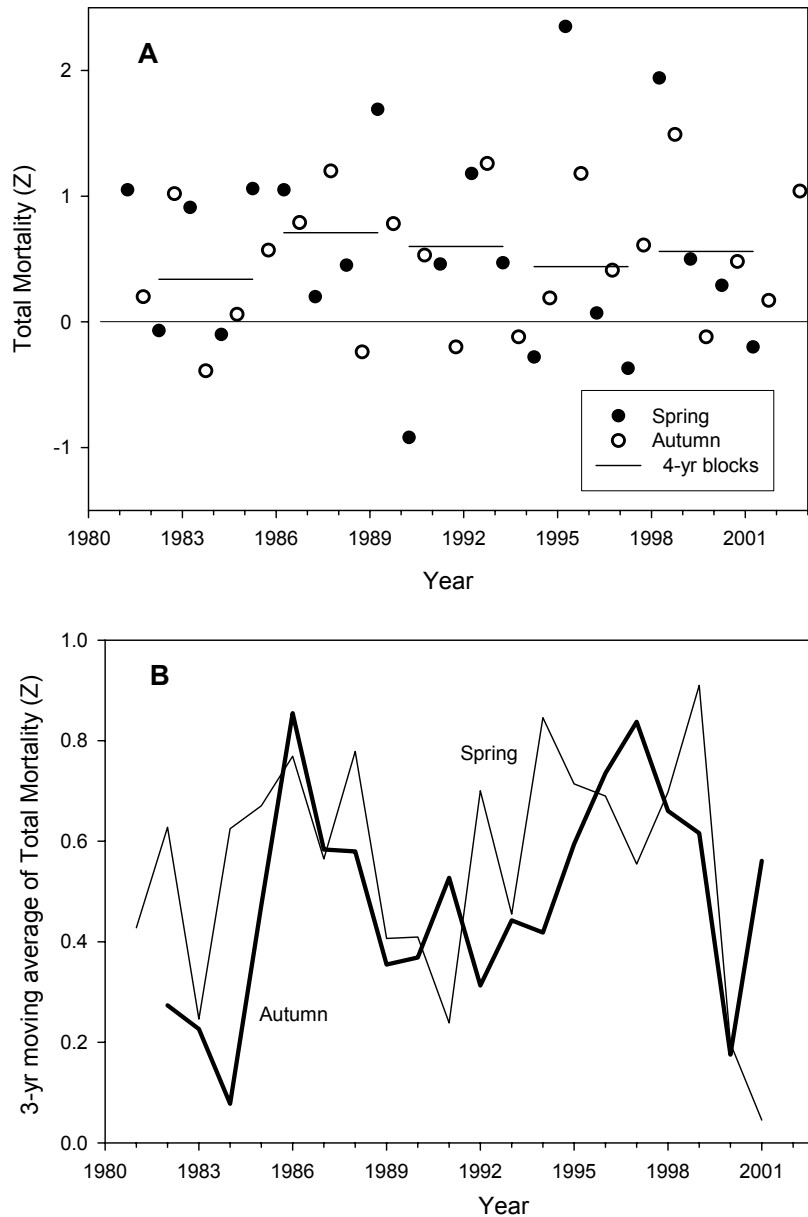


Figure A.24. Estimates of instantaneous total mortality ( $Z$ ) derived from the NEFSC spring and autumn survey catch per tow at age (log ratio  $7+ / 8+$ ) (A) and 3-yr moving average (B).

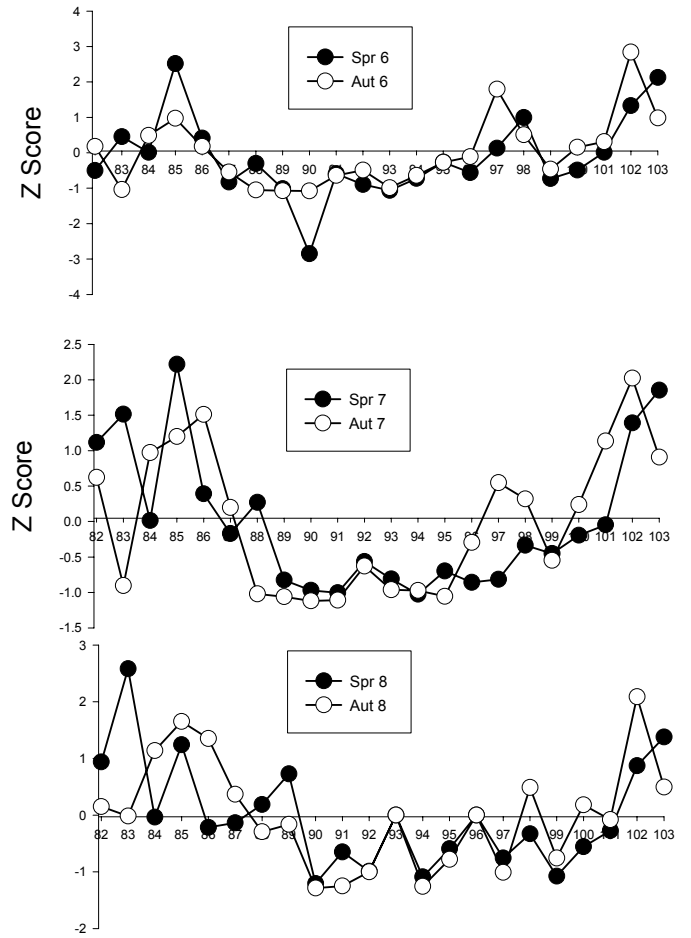
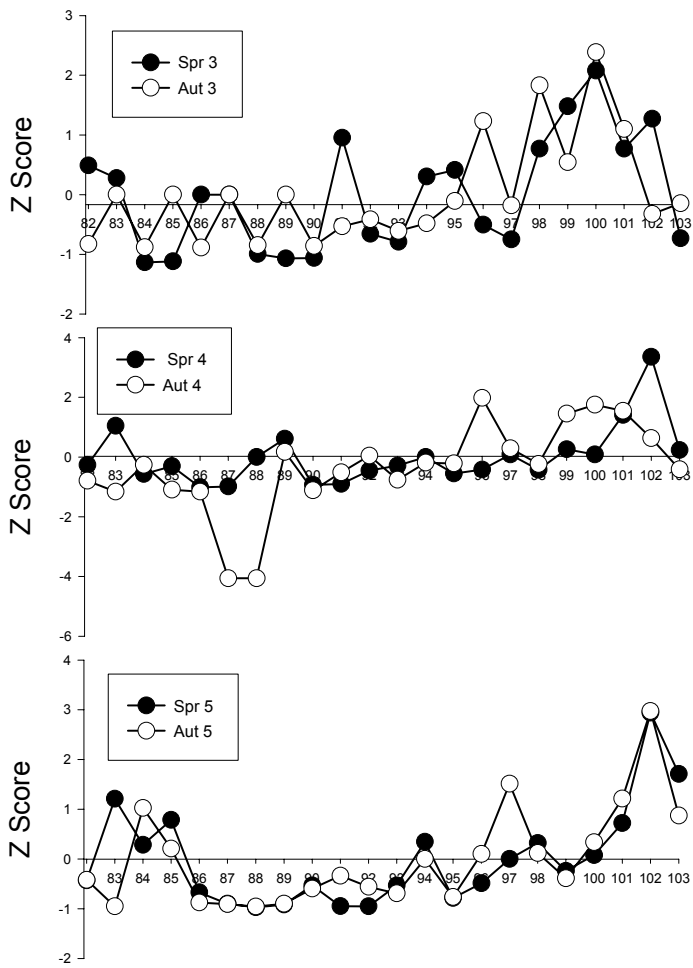


Figure A.25. Scaled (Z score) NEFSC spring and autumn survey indices for ages 3 to 11+, 1982-2003.

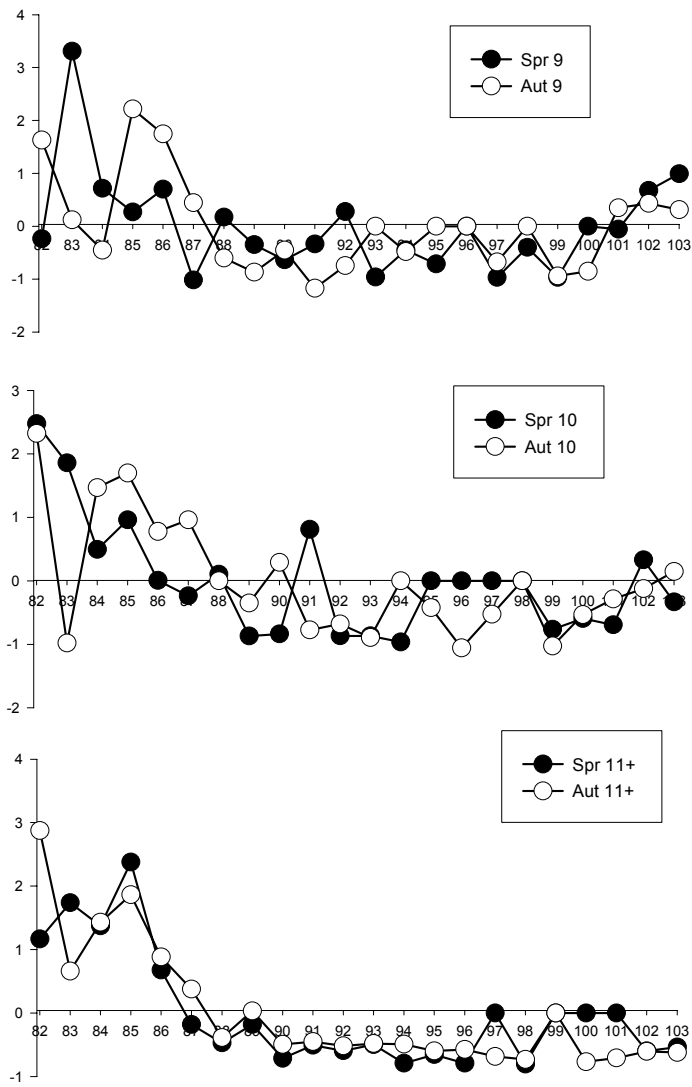


Figure A.25 continued.

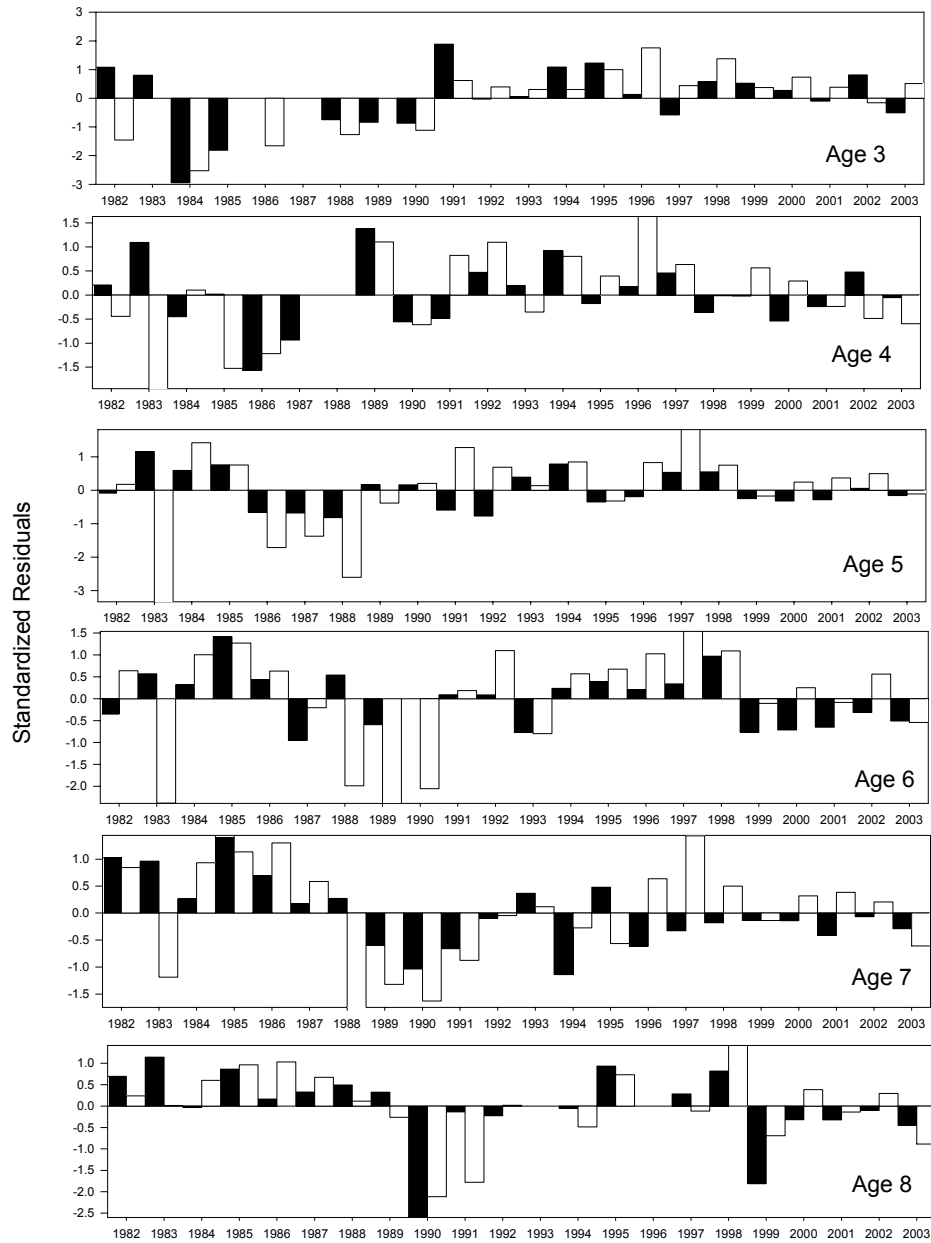


Figure A.26. Standardized residuals for survey indices (spring solid bar and autumn open bar) at age.



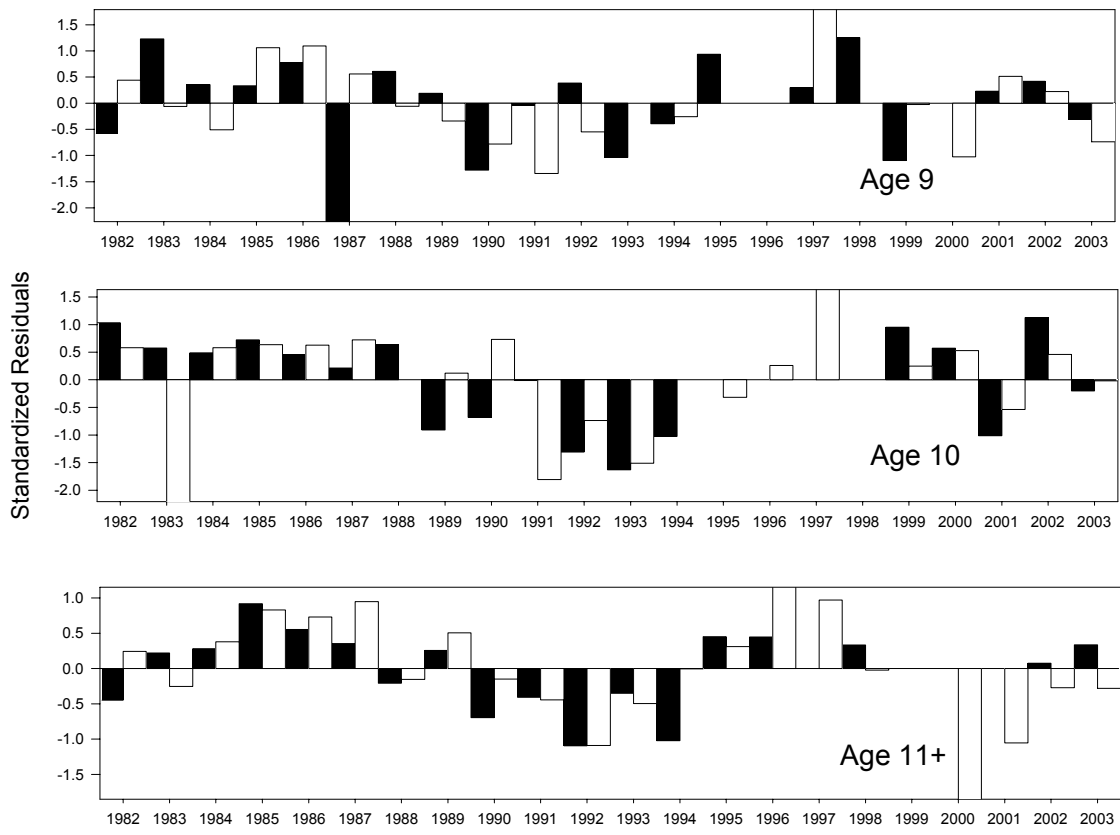


Figure A.26. continued.

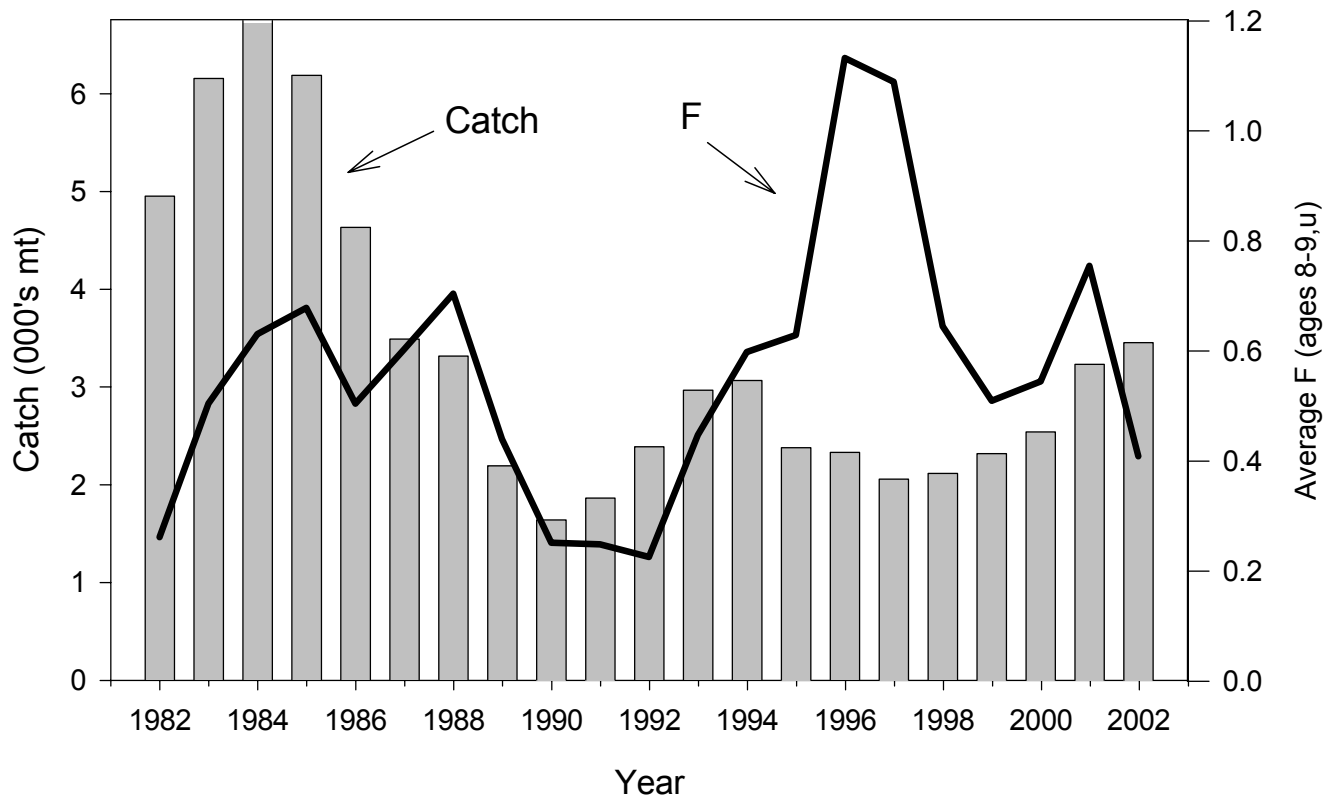


Figure A.27. Trends in total catch and fishing mortality for witch flounder, 1982-2002.

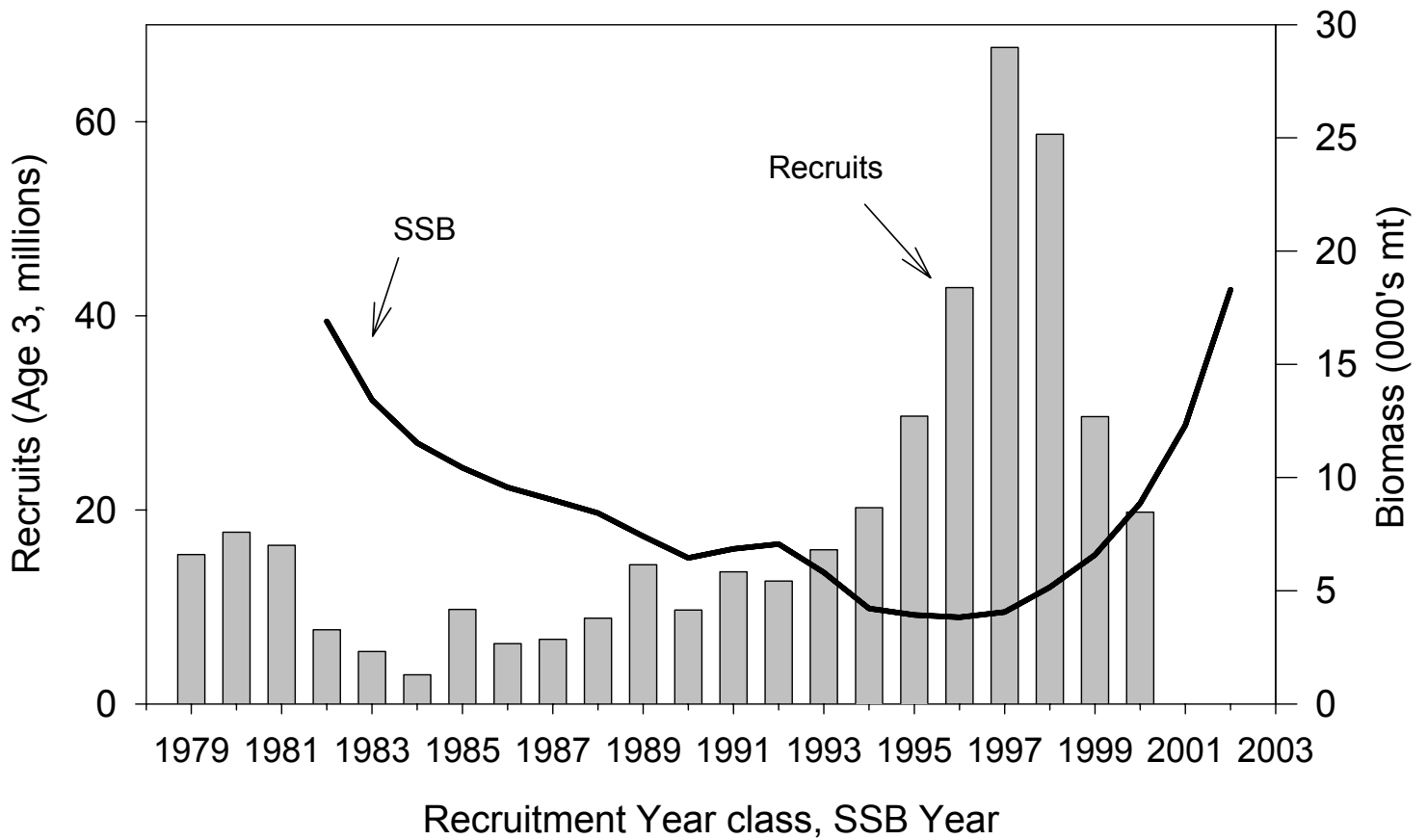


Figure A.28. Trends in spawning stock biomass and recruitment (Age 3) for witch flounder, 1982-2002.

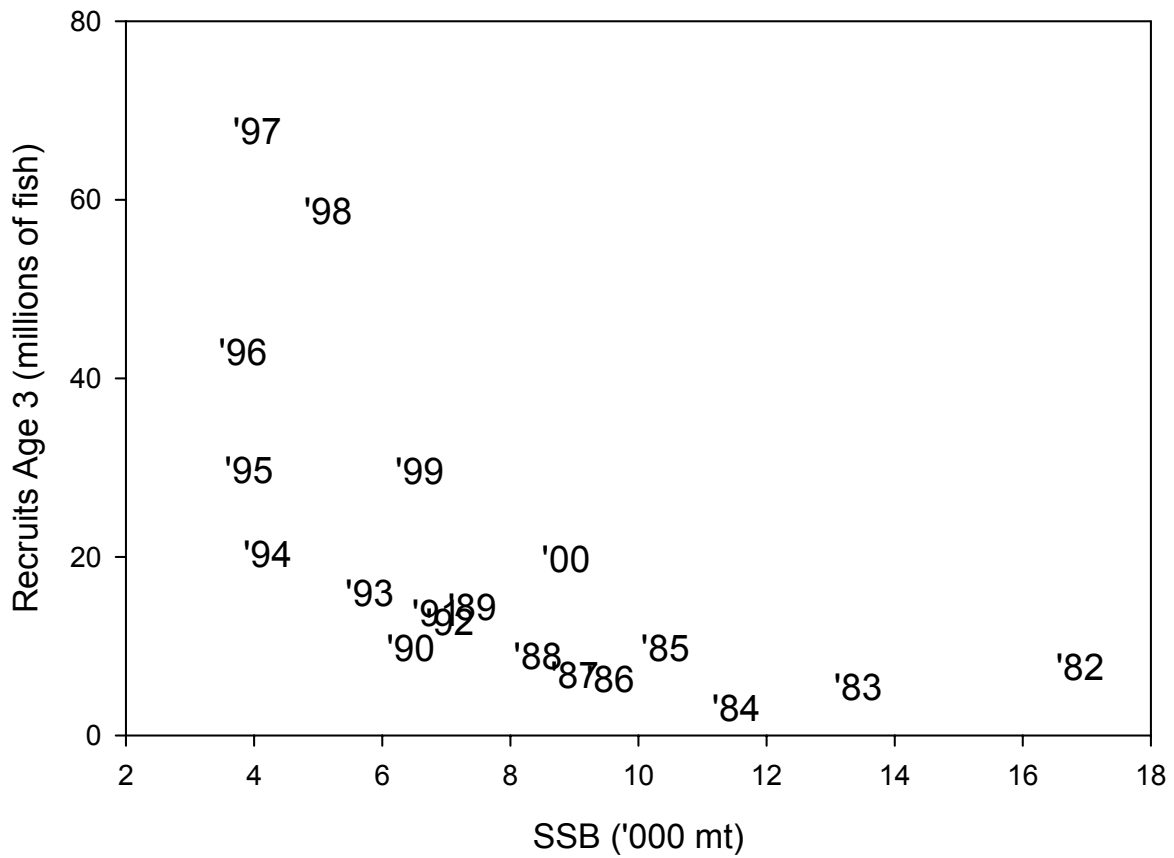


Figure A.29. Spawning stock biomass and recruits (Age 3) for witch flounder, 1982 – 2002 year classes.

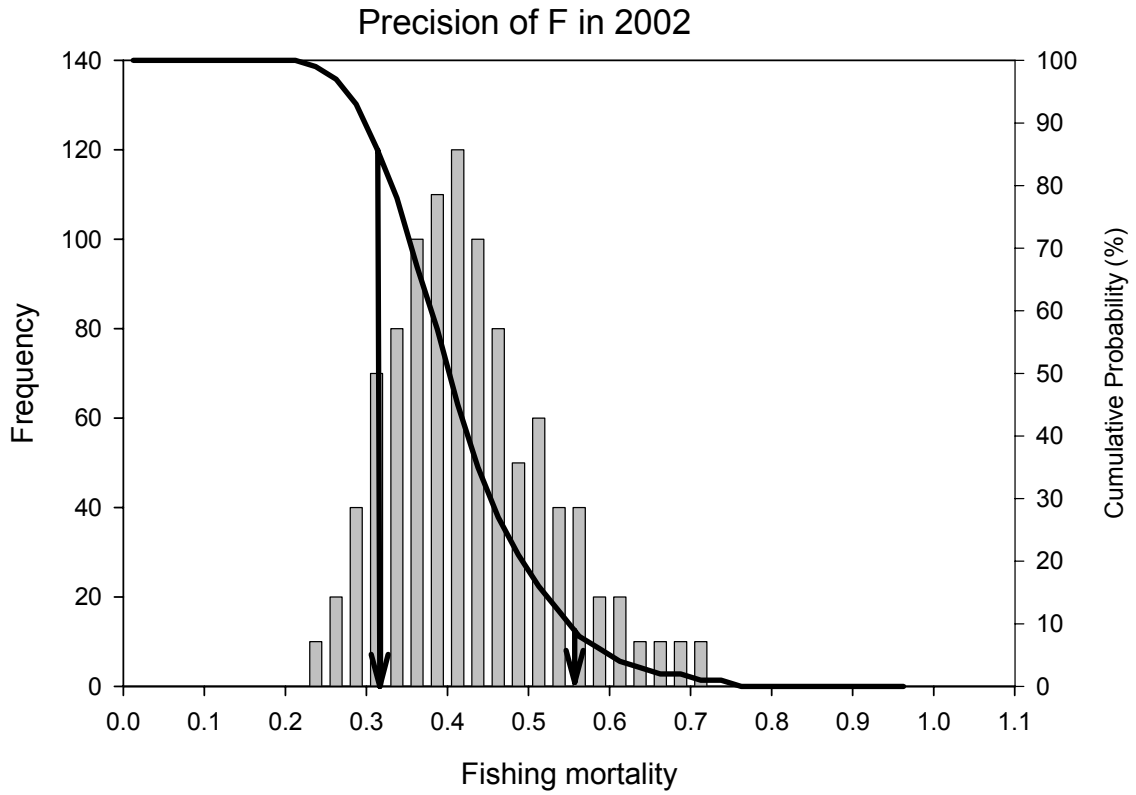


Figure A.30. Precision estimates of fishing mortality (F8-9) in 2002 for witch flounder. Vertical bars display both the range of the bootstrap estimates and the probability of individual values in the range. The arrows indicate the 80% confidence intervals.

### Precision of SSB in 2002

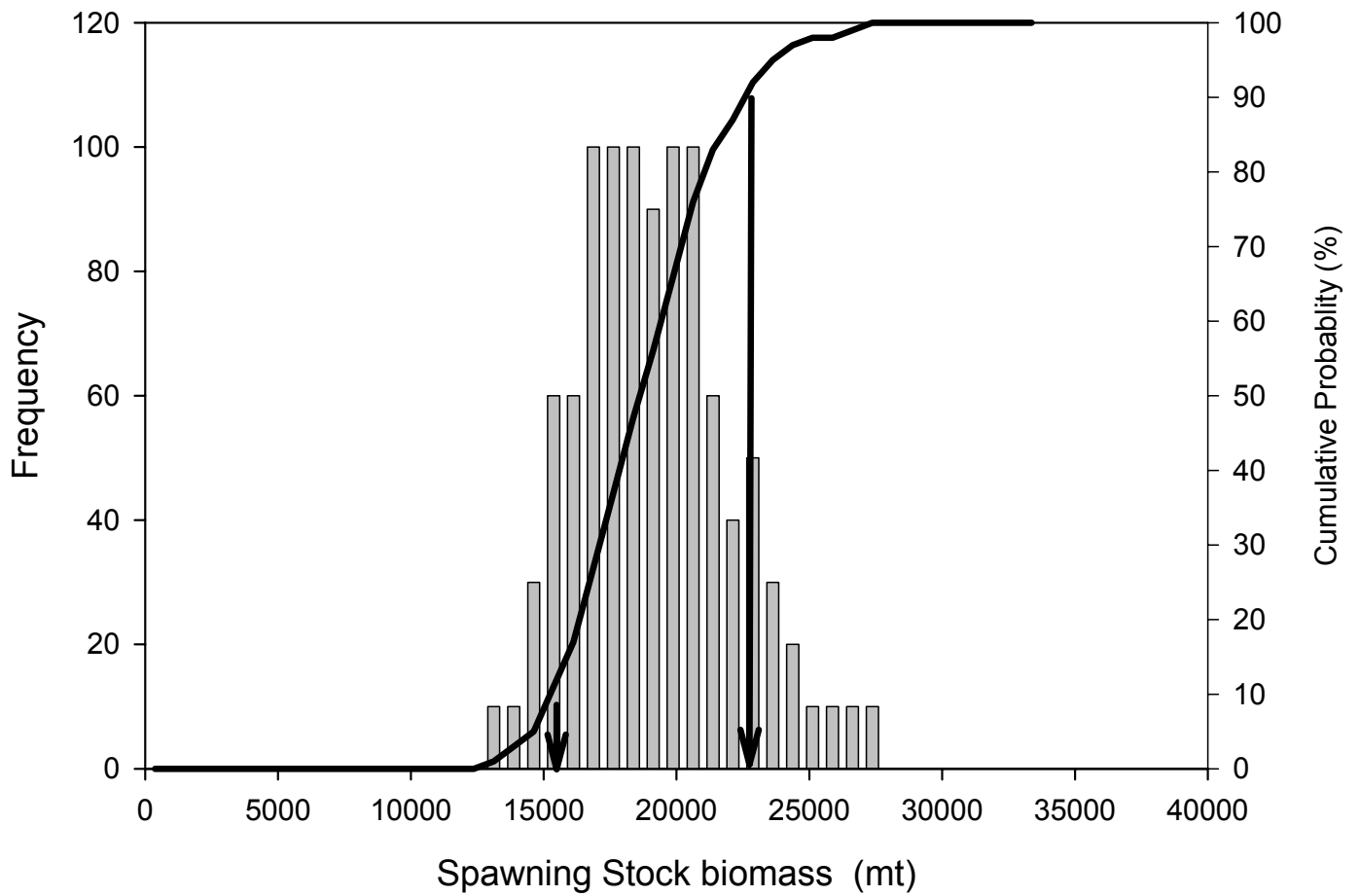


Figure A.31. Precision estimates of spawning stock biomass (mt) in 2002 for witch flounder. Vertical bars display both the range of the bootstrap estimates and the probability of individual values in the range. The arrows indicate the 80% confidence intervals.

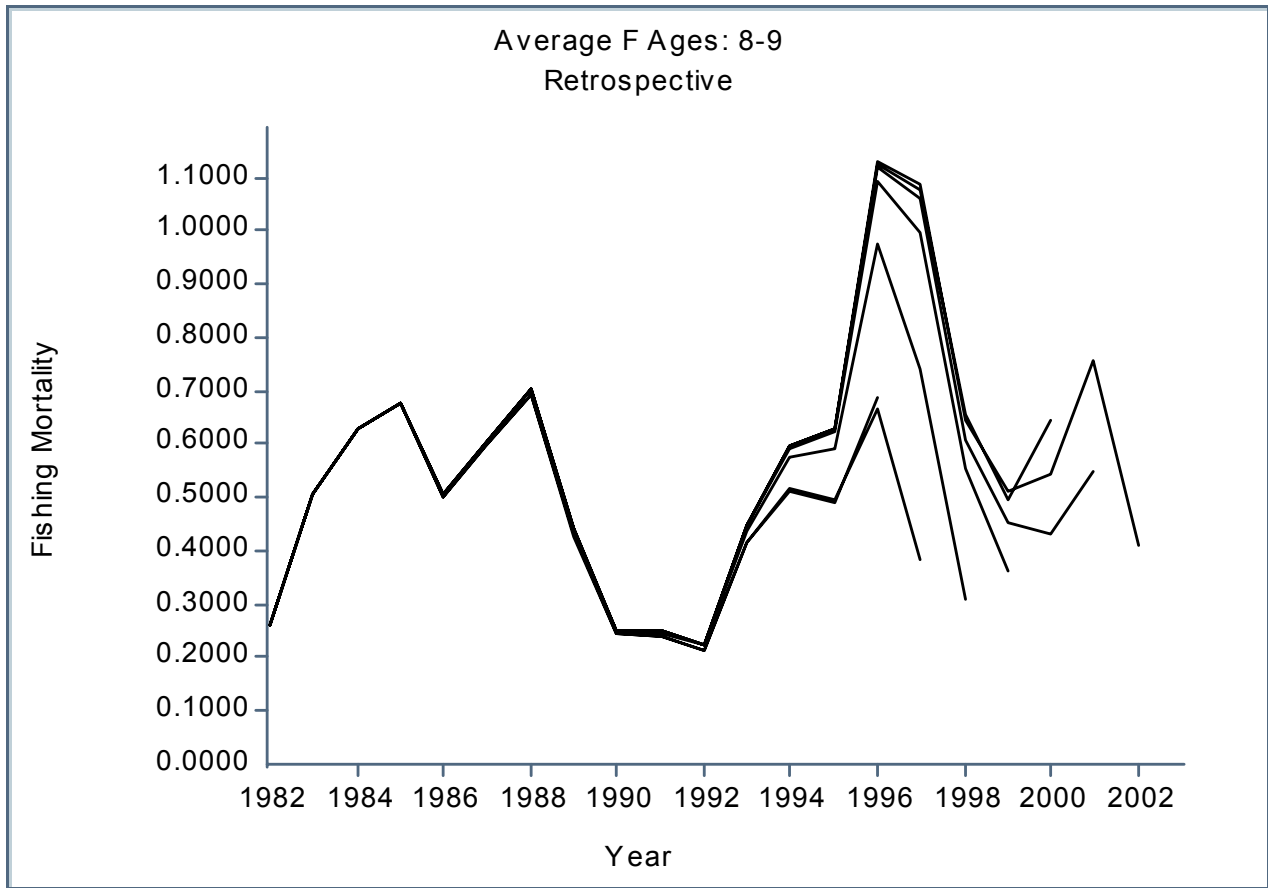


Figure A.32a. Retrospective analysis results for fishing mortality, (F8-9).

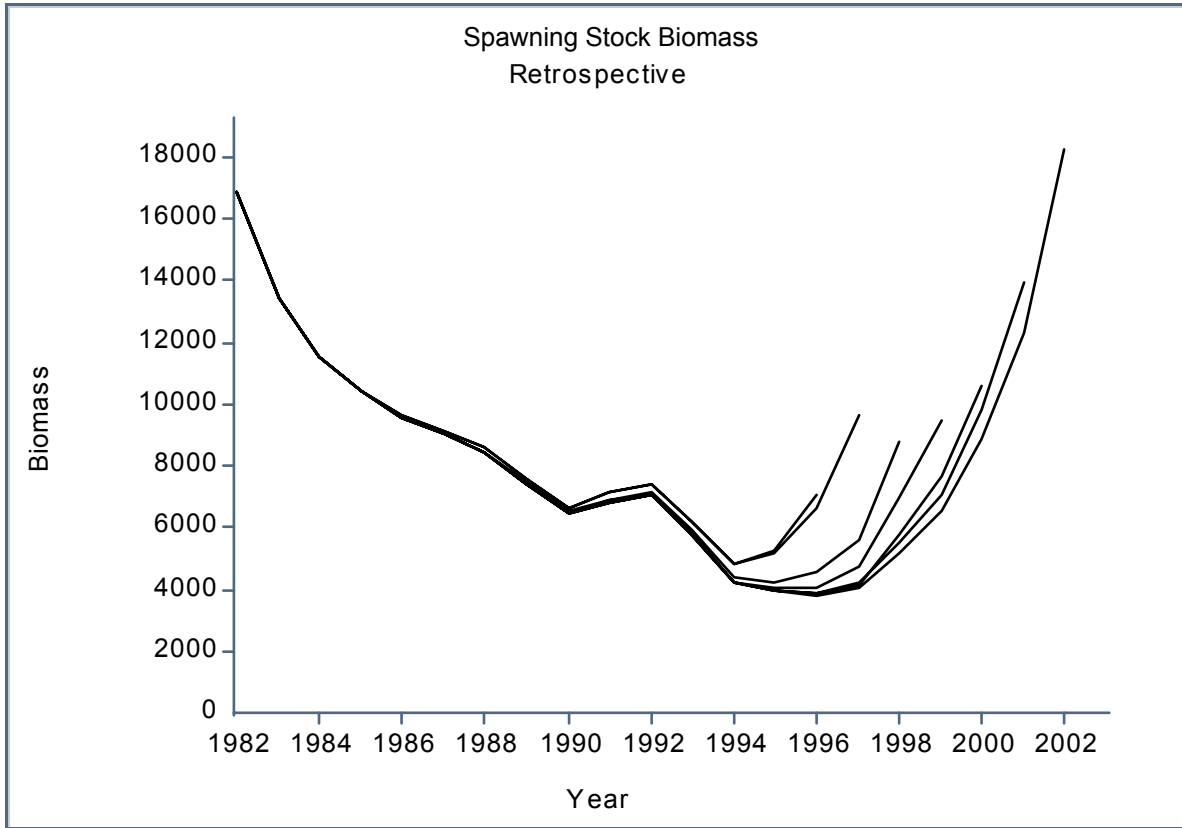


Figure A.32b. Retrospective analysis results for spawning stock biomass.



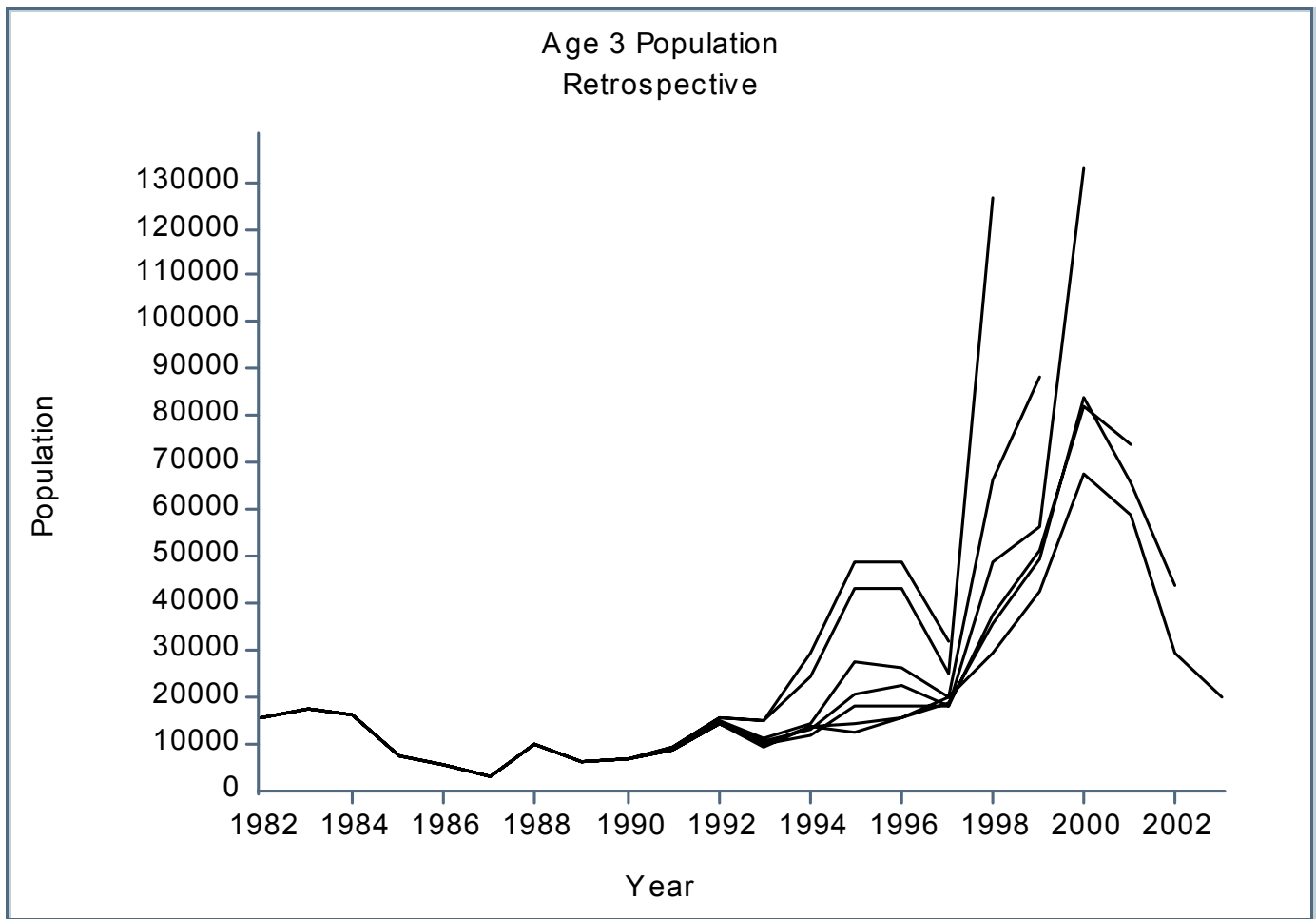


Figure A.32c. Retrospective analysis results for age 3 recruitment.

Witch Flounder Fishery Selectivity by Time Period  
Model 3: Catch Scenario 2: M=0.15

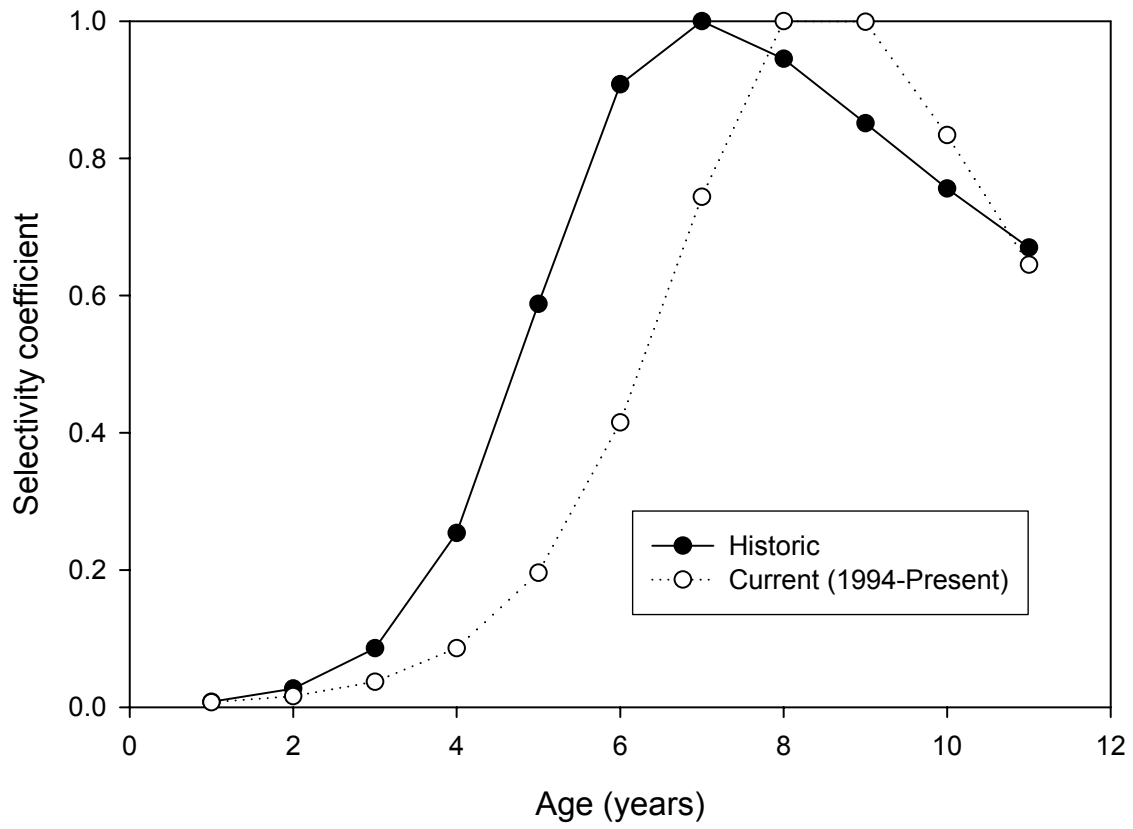


Figure A.33. Selectivity at age.

Witch Flounder Catch Biomass (mt), 1937-2002  
Catch Scenario 2: M=0.15

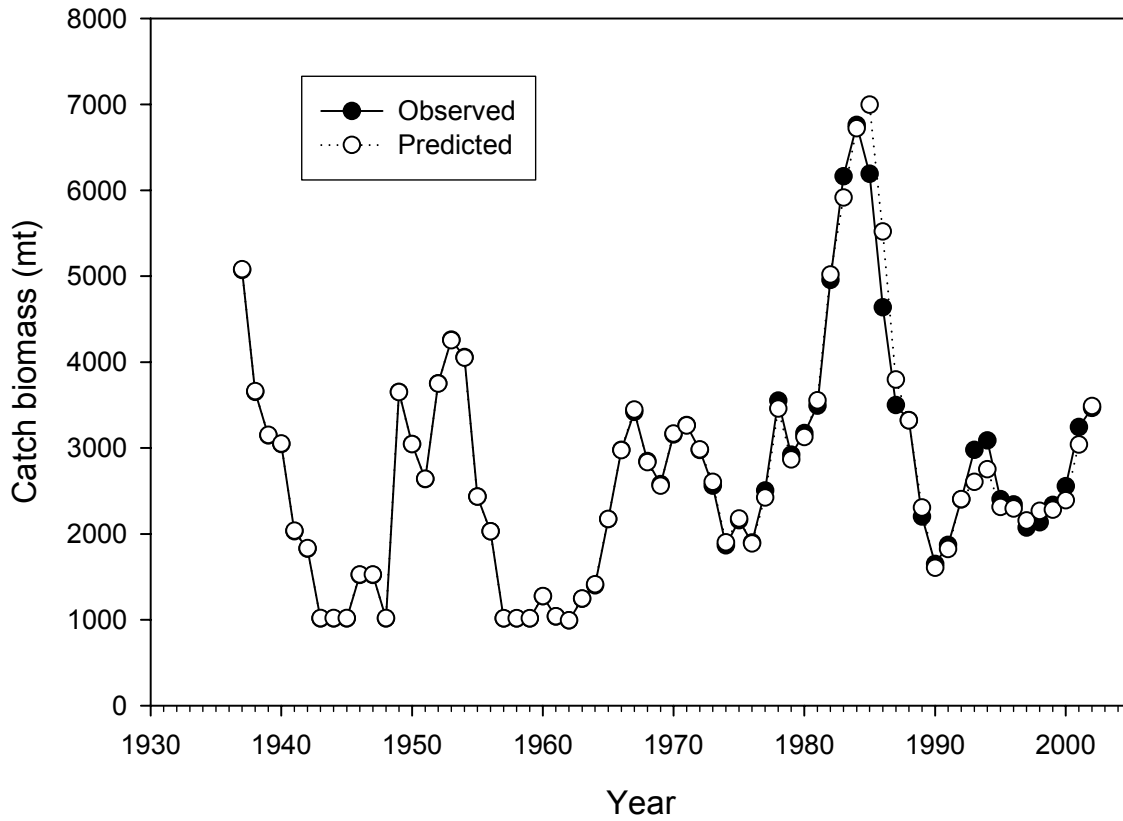


Figure A.34. Trends in catch biomass (mt), 1937 – 2002.

Witch Flounder Survey Selectivity  
Model 3: Catch Scenario 2: M=0.15

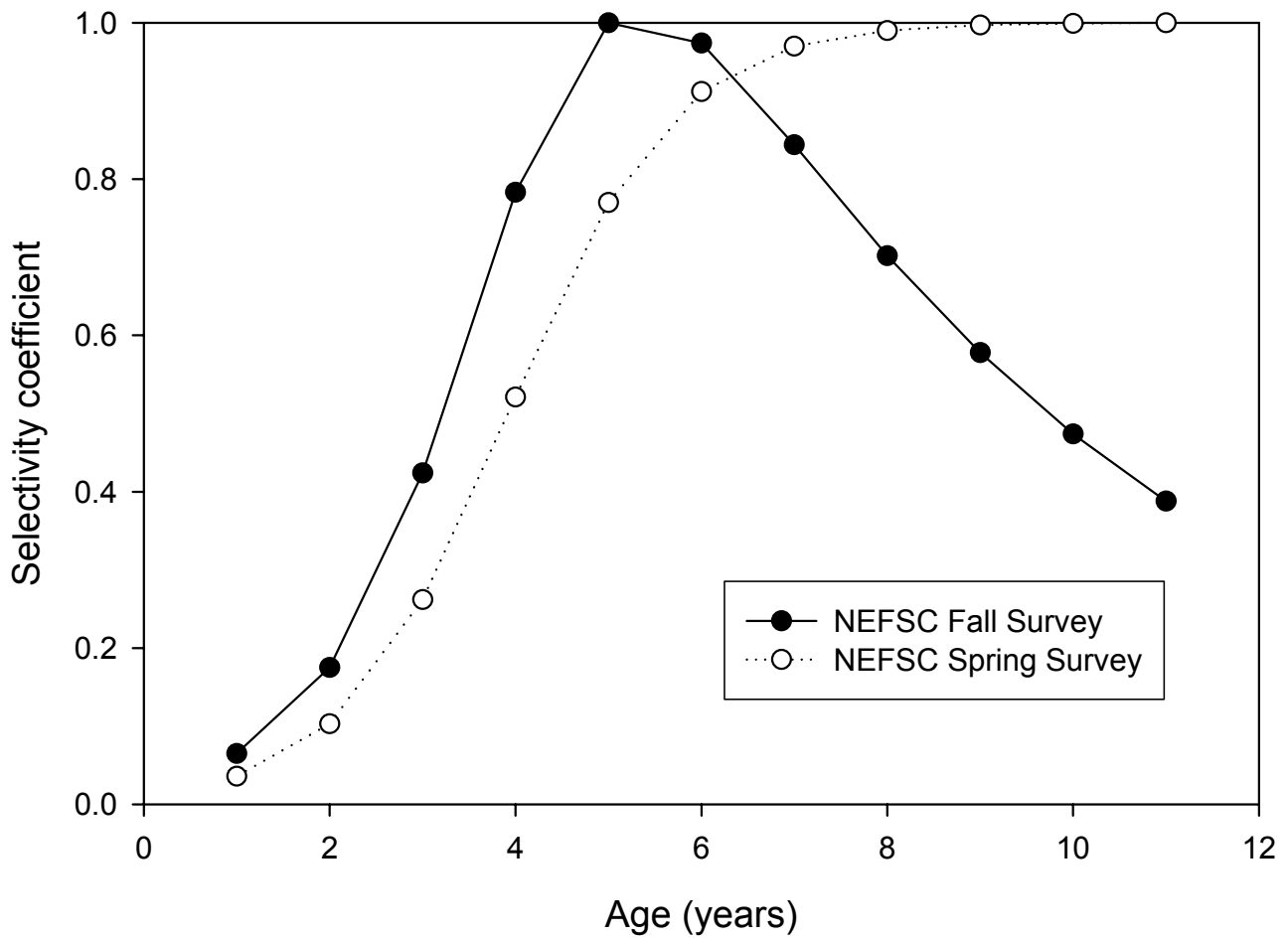


Figure A.35. Survey selectivity at age.

Witch Flounder Fall Survey Biomass Index, 1963-2002  
Model 3: Catch Scenario 2: M=0.15

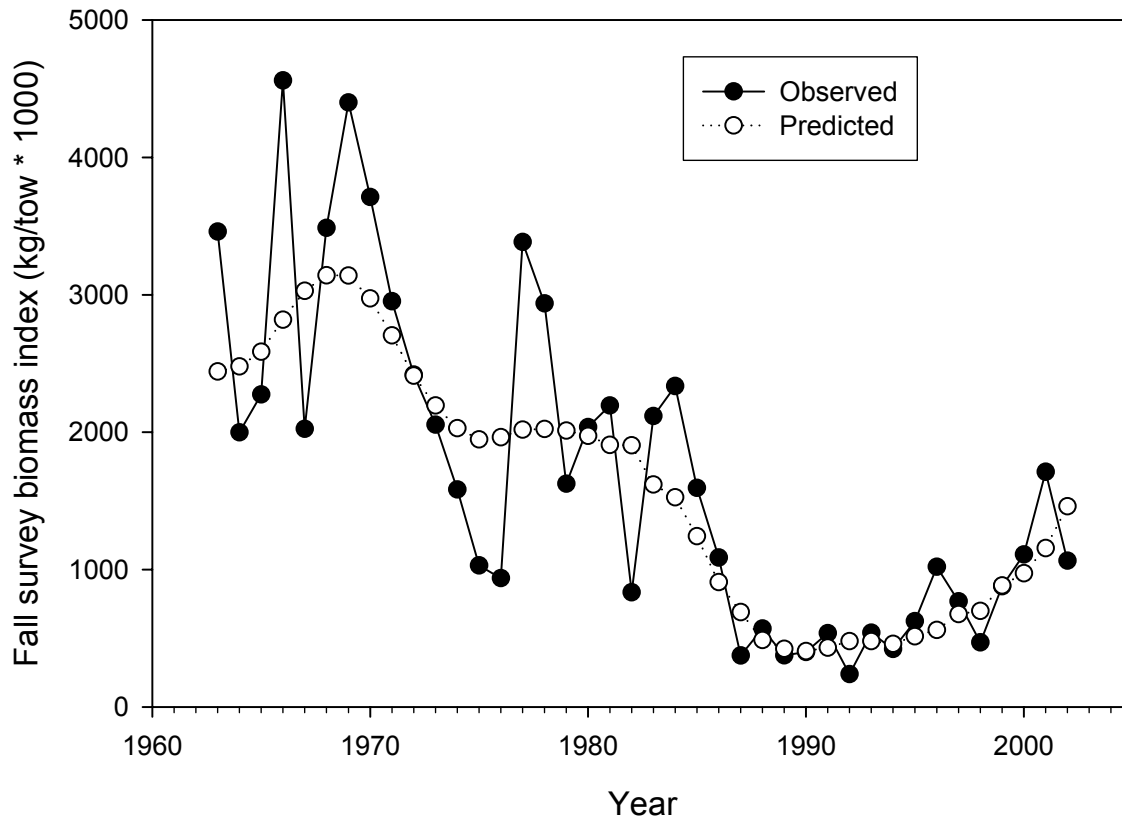


Figure A.36. Trends in NEFSC autumn survey biomass.

Witch Flounder Spring Survey Biomass Index, 1968-2002  
Model 3: Catch Scenario 2: M=0.15

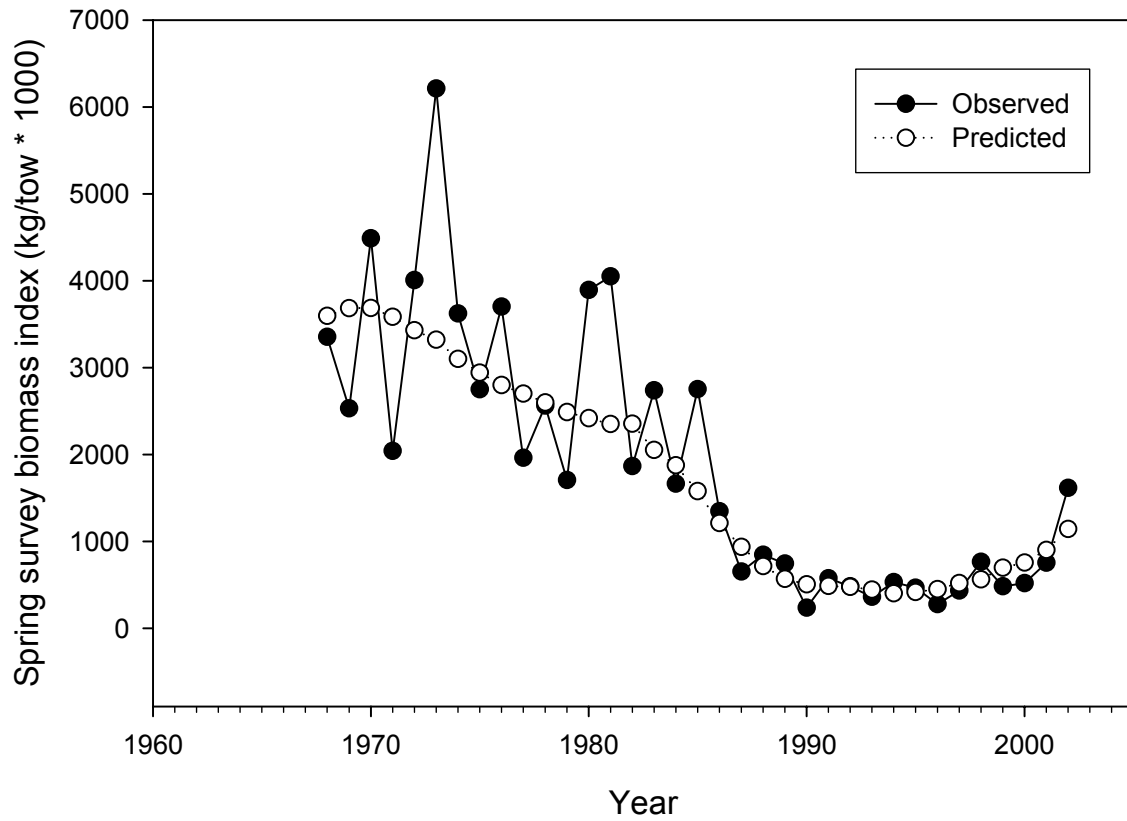


Figure A.37. Trends in NEFSC spring survey biomass.

Comparison of ADAPT virtual population analysis (VPA) and statistical catch-at-age analysis (SCAA) estimates of witch flounder spawning biomass, 1982-2002

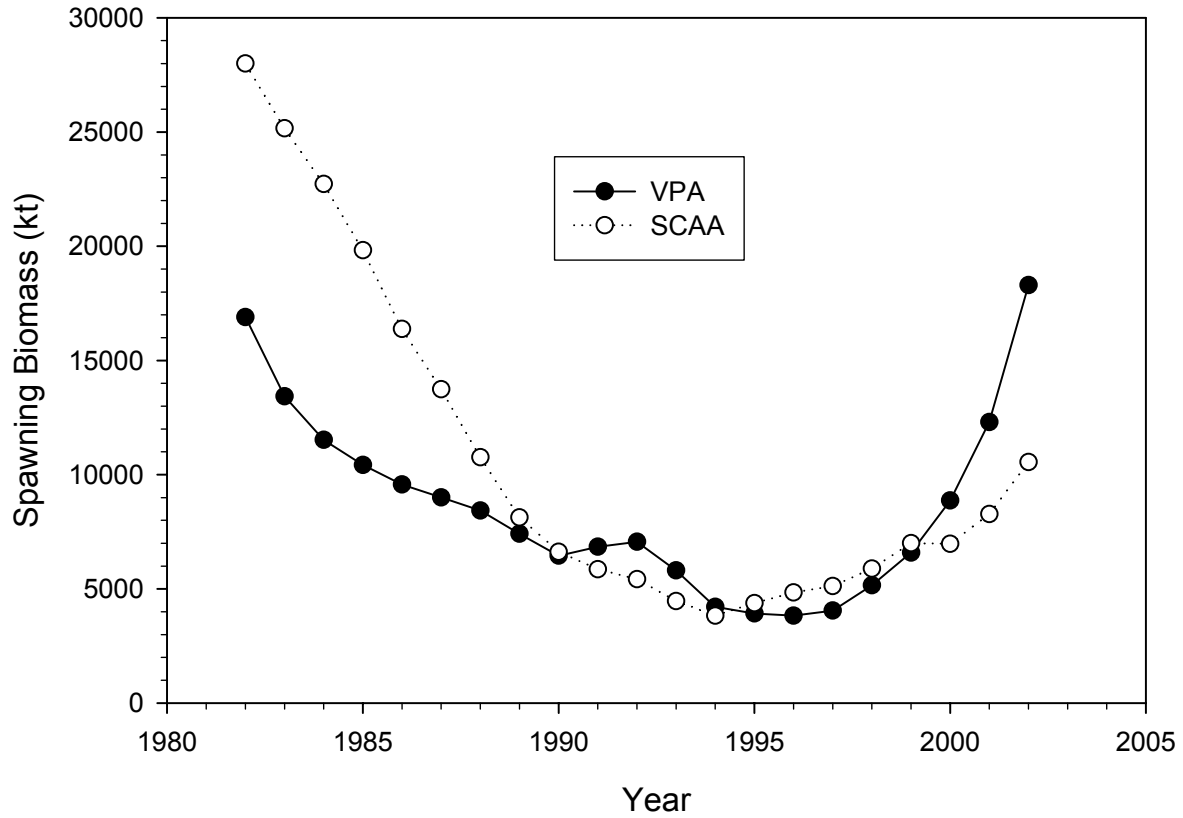


Figure A.38. Comparison of VPA and SCAA estimates of spawning stock biomass.

Comparison of ADAPT virtual population analysis (VPA) and statistical catch-at-age analysis (SCAA) estimates of witch flounder fishing mortality, 1982-2002

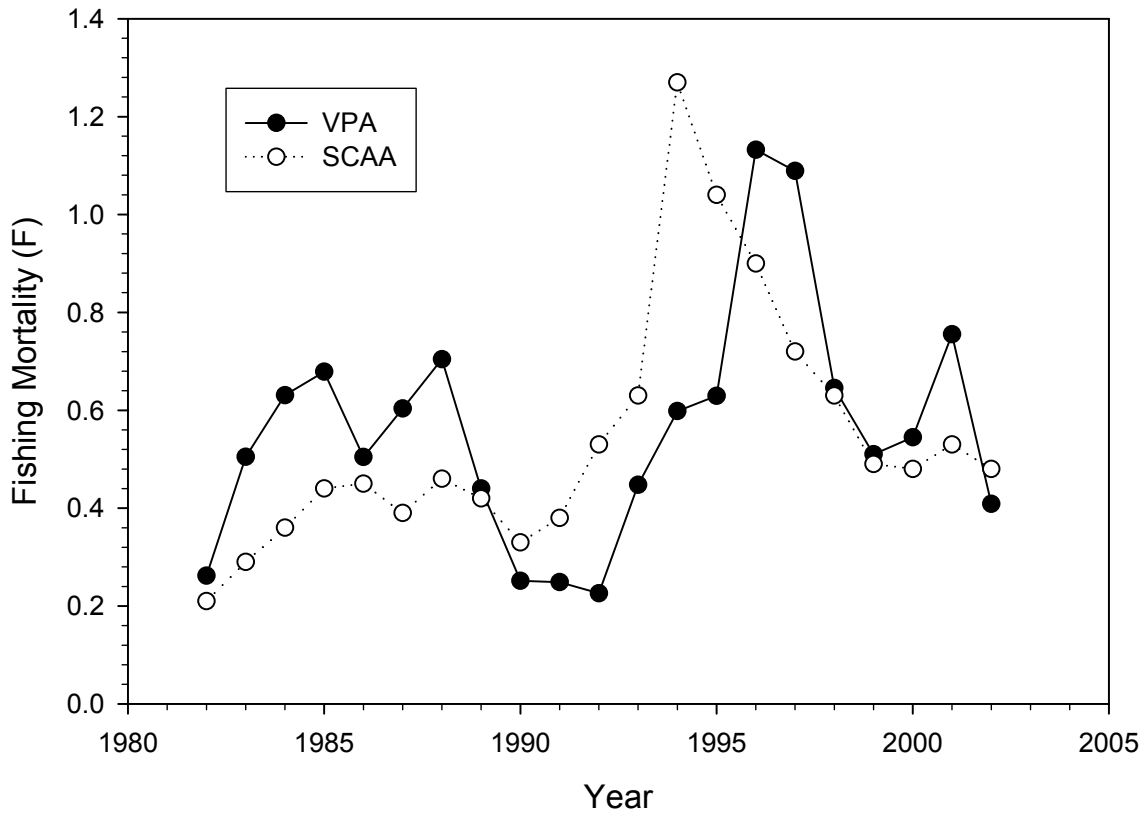


Figure A.39. Comparison of VPA and SCAA estimates of fishing mortality.



Comparison of ADAPT virtual population analysis (VPA) and statistical catch-at-age analysis (SCAA) estimates of witch flounder recruitment, 1982-2002

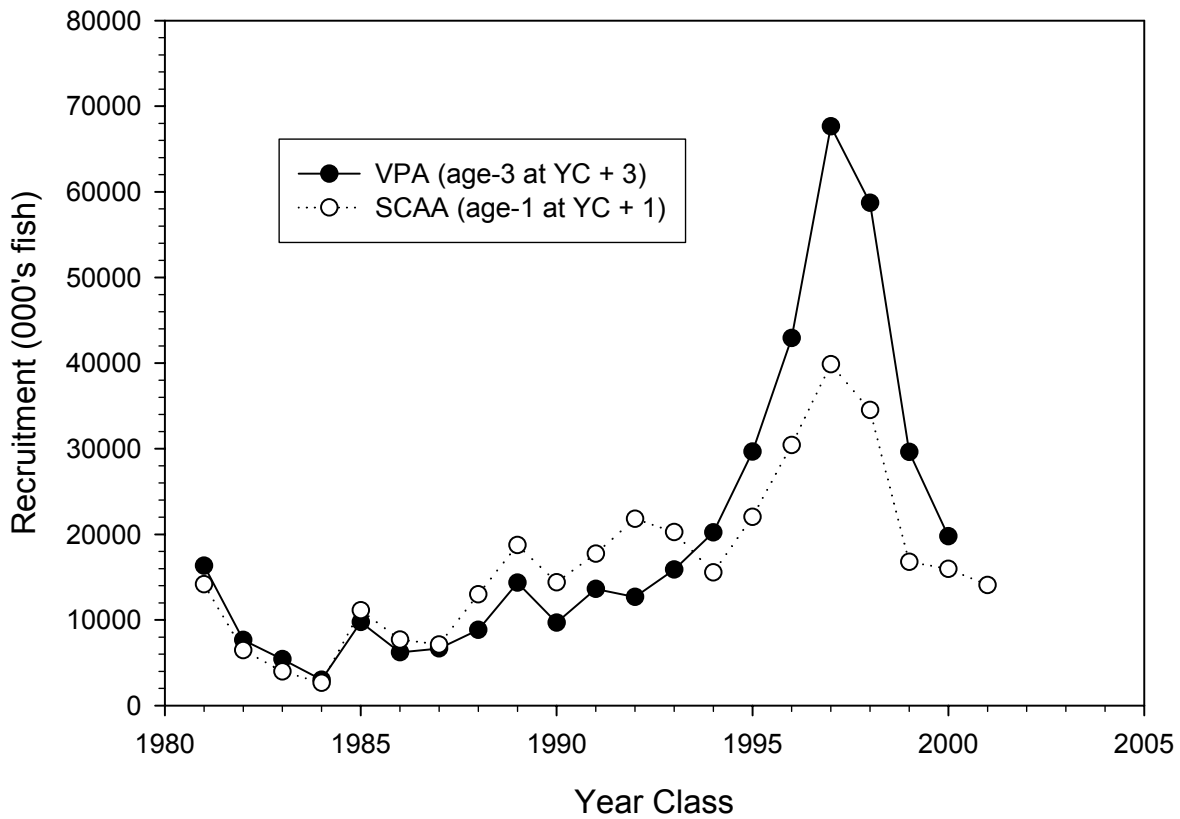


Figure A.40. Comparison of VPA and SCAA estimates of recruitment.

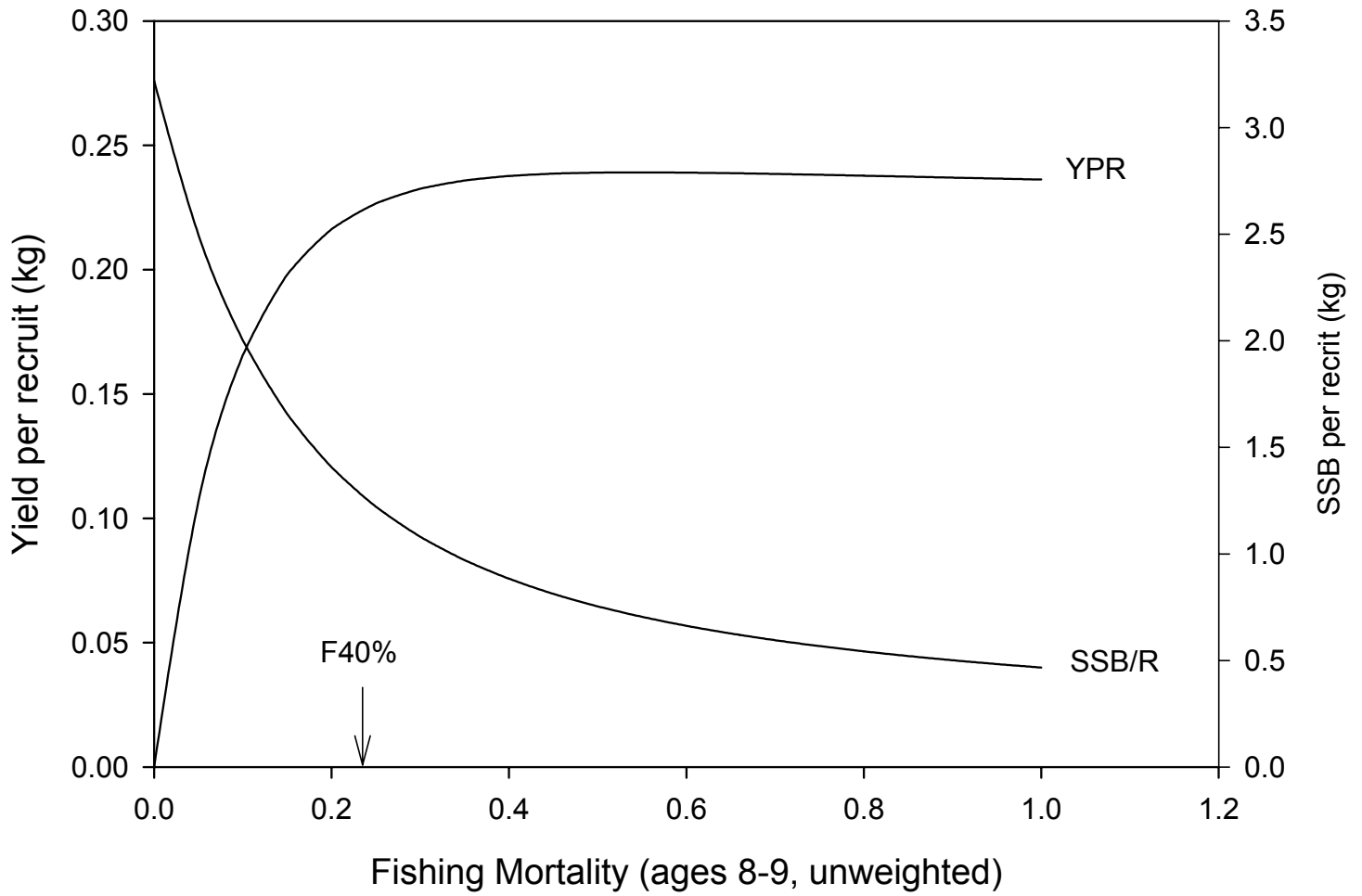


Figure A.41. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) estimates for witch flounder.

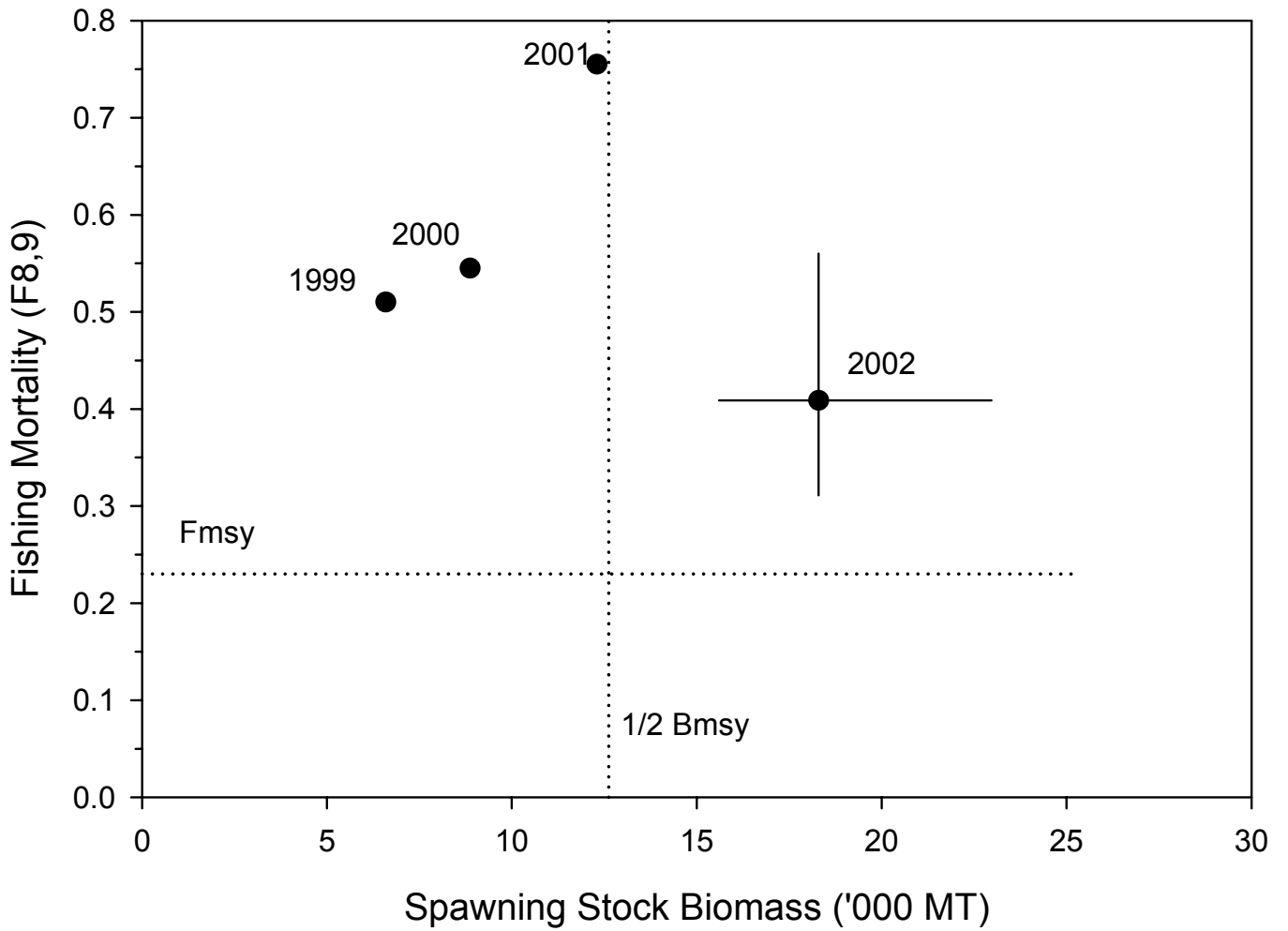


Figure A.42. Spawning stock biomass and fishing mortality (F 8-9) for witch flounder, 1999-2001, and 2002 with 80% confidence interval.

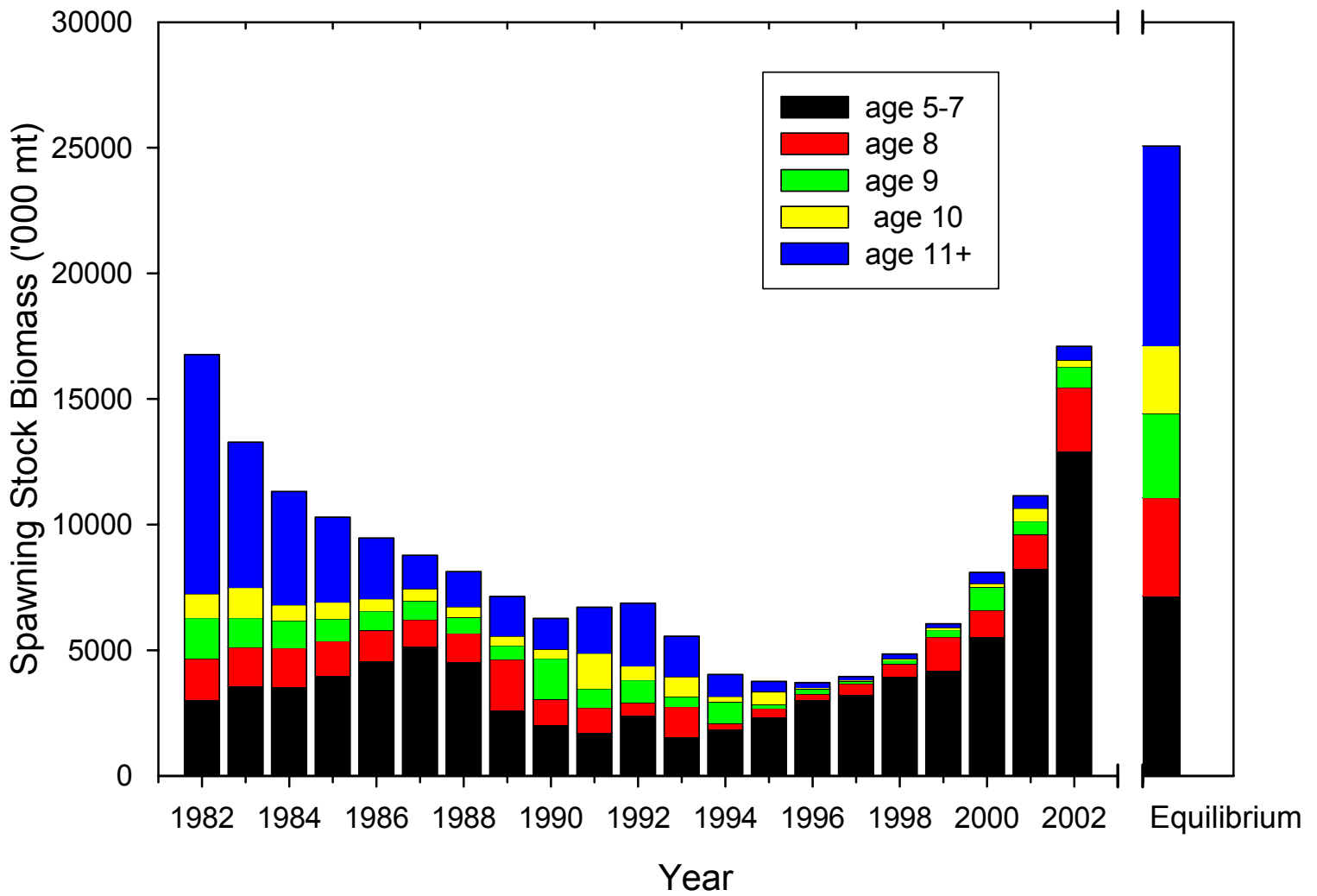


Figure A.43. Age distribution of witch flounder spawning stock biomass, 1982 – 2002 and the expected age distribution of witch flounder at equilibrium.

## B. Spiny Dogfish (*Squalus acanthias*)

### 1.0 Introduction

The Atlantic States Marine Fisheries Commission (ASMFC) Spiny Dogfish Stock Assessment Subcommittee and the Stock Assessment Review Committee (SARC) Southern Demersal Working Group meet jointly during May 12-14, 2003 at the NEFSC in Woods Hole, MA to develop the spiny dogfish stock assessment for 2003. The following scientists and managers participated in the meeting:

Jim Armstrong	Mid-Atlantic Fishery Management Council
Laurel Col	NMFS NEFSC
Eric Dolan	NMFS NERO
Megan Gamble	ASMFC
Joe Grist	North Carolina Division of Marine Fisheries
Ralph Mayo	NMFS NEFSC
Steve Murawski	NMFS NEFSC
Loretta O'Brien	NMFS NEFSC
Chris Powell	Rhode Island Division of Fish and Wildlife
Paul Rago	NMFS NEFSC
Jim Ruhle	Mid-Atlantic Fishery Management Council
Roger Rulifson	East Carolina University
Alexi Sharov	Maryland Department of Natural Resources
Katherine Sosebee	NMFS NEFSC
Mark Terceiro (chair)	NMFS NEFSC

### 2.0 Terms of Reference

The Terms of Reference for the assessment were as follows:

- 1) Characterize the commercial and recreational catch (landings and discards) for the entire stock (includes Canadian catch) and identify methods for improving the accuracy of discard and discard mortality estimates.
- 2) Estimate current and historic fishing mortality, spawning stock biomass, and total stock biomass and characterize the uncertainty of those estimates.
- 3) Update or re-estimate biological reference points (including rebuilding targets) as appropriate.
- 4) Estimate yield based on stock status and target mortality rate ( $F = 0.08$ ) for fishing year 2004 (May, 2004 through April, 2005).
- 5) Provide short term projections (2-3 years) of stock status under a variety of TAC/F strategies

- 6) Evaluate existing and alternative rebuilding schedules based on current/projected stock status.
- 7) Provide estimates of juvenile recruitment and pupping rates. Characterize the uncertainty of these estimates.
- 8) Characterize the level of discards, bycatch rates, discard mortality rates, and length and sex data for spiny dogfish (per trip, per net, etc.) in directed and bycatch fisheries and how changes in regulations and fishing practices may have affected these rates.

### **3.0 Overview**

Spiny dogfish (*Squalus acanthias*) are distributed in Northwest Atlantic waters between Labrador and Florida, are considered to be a unit stock in NAFO Subareas 2-6, but are most abundant from Nova Scotia to Cape Hatteras. Seasonal migrations occur northward in the spring and summer and southward in the fall and winter and preferred temperatures range from 7.2° to 12.8°C (Jensen 1965). In the winter and spring, spiny dogfish are located primarily in Mid-Atlantic waters but also extend onto southern Georges Bank on the shelf break. In the summer, they are located further north in Canadian waters and move inshore (into bays and estuaries). By autumn, dogfish have migrated north with high concentrations in Southern New England, on Georges Bank, and in the Gulf of Maine. They remain in northern waters throughout the autumn until water temperatures begin to cool and then return to the Mid-Atlantic.

Dogfish tend to school by size and, for large mature individuals, by sex. Dogfish are major predators on some commercially important species, mainly herring, Atlantic mackerel, and squid, and to a much lesser extent, haddock and cod. Maximum reported ages for males and females in the Northwest Atlantic were estimated by Nammack (1982) to be 35 and 40 years, respectively, whereas ages as old as 70 years have been determined for spiny dogfish off British Columbia (McFarlane and Beamish 1987). In this paper, a maximum age of 50 years was assumed. Sexual maturity occurs at a length of about 60 cm for males and 75 cm for females (Jensen 1965). Reproduction occurs offshore in the winter (Bigelow and Schroeder 1953), and female dogfish bear live offspring. The gestation period ranges from 18 to 22 months with 2 to 15 pups (average of 6) produced. Females attain a greater size than males, reaching maximum lengths and weights up to 125 cm and 10 kg, respectively.

## **4.0 Fishery-Dependent Information**

### **4.1 Commercial Landings**

Commercial landings data and biological information were obtained from the NEFSC commercial fisheries database. The sex of commercial landings was not recorded routinely until 1982. The commercial landings sampling program is described in Burns et al. (1983). Historical records dating back to 1931 indicate levels of US commercial landings of dogfish

in Subareas 5 and 6 of less than 100 mt in most years prior to 1960 (NEFC 1990). Total landings of spiny dogfish in NAFO Subareas 2-6 by all fisheries climbed rapidly from the late 1960s to a peak of about 25,000 metric tons (mt) in 1974 (Table 4.1). Substantial harvests of dogfish by foreign trawling fleets began in 1966 in Subareas 5 and 6 and continued through 1977. Since 1978, landings by foreign fleets have been curtailed, and landings by US and Canadian vessels have increased markedly. A sharp intensification of the US commercial fishery began in 1990; estimated landings in 1996, in excess of 28,000 mt, were about five times greater than the 1980-1989 average. Landings between 1997 and 1999 averaged about 20,000 mt. Landings in 2001 and 2002 dropped dramatically with the large landings reductions imposed by federal and ASMFC management plans.

#### 4.1.1 US landings

US commercial landings of dogfish from NAFO Subareas 2-6 were around 500 mt in the early 1960s (Table 4.1), dropped to levels as low as 70 mt during 1963-1975 while averaging about 90 mt, and remained below 1,000 mt until the late 1970s. Landings increased to about 4,800 mt in 1979 and remained fairly steady for the next ten years at an annual average of about 4,500 mt. Landings increased sharply to 14,900 mt in 1990, dropped slightly in 1991, but continued a rapid expansion from 18,987 mt in 1992 to over 28,000 mt in 1996.

Landings in 1996 were the highest recorded since 1962, exceeding previous peak years during the early 1970's when the fishing fleet was dominated by foreign vessels (Figure 1). Landings declined in 1997 and 1998 to around 20,000 mt. In 1999, the last full year unaffected by regulations, the landings declined to 14,860 mt. US landings dropped to about 2,200 mt in 2001 and 2002 in response to quota restrictions.

#### 4.1.2 Foreign landings

A substantial foreign harvest of dogfish occurred mainly during 1966-1977 in Subareas 5 and 6. Landings, the bulk of which were taken by the former USSR, averaged 13,000 mt per year and reached a peak of about 24,000 mt in 1972 and 1974 (Table 4.1). In addition to the former USSR, other countries which reported significant amounts of landings include Poland, the former German Democratic Republic, Japan, and Canada. Since 1978, landings have averaged only about 900 mt annually and, except for those taken by Japan and Poland, have come primarily from Subareas 4 and 3. Canadian landings, insignificant until 1979 when 1,300 mt were landed, have been sporadic, but again totaled about 1,300 mt in 1990. Canadian landings increased about nine-fold between 1996 and 2001 with landings of 3,755 mt in 2001. Landings in 2002 have not been finalized but should range between 3,000 and 3,400 mt (Steve Campana, DFO personal comm.).

#### 4.1.3 Gear types

The primary gear used by US fishermen to catch spiny dogfish has been otter trawls and sink gill nets (Table 4. 2, Figure 4.2). The latter accounted for over 50% of the total US landings during the 1960s, while the former was the predominant gear through the 1970s and into the early 1980s. During the peak period of exploitation in the 1990s sink gill nets were the dominant gear. Landings in otter trawls ranged around 3,000 – 5,000 mt during this period. Both otter trawl and gill net landings decreased markedly in 2001, coincident with the rise in landings by hook gear. Landings of dogfish in drift gillnets peaked in 1998 with over 1,300 mt landed but have since declined to near zero. Spiny dogfish taken by the distant water

fleets were caught almost entirely by otter trawl. Recent Canadian landings have been mainly by gill nets and longlines.

#### 4.1.4 Temporal and spatial distribution

The temporal and spatial pattern of dogfish landings are closely tied to the north-south migration patterns of the stock. Peak landings from May through October coincide with residency of dogfish along the southern flank of Georges Bank, the Gulf of Maine and the near shore waters around Massachusetts. As the population migrates to the south in late fall and early winter, landings increase in the southern states, especially North Carolina. US dogfish landings have been reported in all months of the year, but most landings traditionally occur from June through September (Table 4.3). During the peak years of the domestic fishery, substantial quantities were also taken during autumn and winter months.

Landings by statistical area were not updated for this assessment. As reported in SARC 19 (NEFSC 1994) most landings during the 1980's originated from statistical area 514 (Massachusetts Bay). Following the intensification of the fishery in 1990, statistical areas 537 (Southern New England) and 621 (off Delmarva and southern New Jersey) produced substantial quantities. In 1992 and 1993, large landings were reported from statistical areas 631 and 635 (North Carolina).

In most years since 1979, the bulk of the landings occurred in Massachusetts (Table 4.4). Other states with significant landings include New Jersey, Maryland, and Virginia. Landings in North Carolina peaked in 1996 at 6,200 mt, about half of the Massachusetts landings, but dropped sharply to about 1,300 mt between 1997 and 2000. North Carolina landings in 2001-2002 were negligible. In 2001 and 2002, virtually all of the landings were taken north of Rhode Island.

## **4.2 Recreational Landings**

Estimates of recreational catch of dogfish were obtained from the NMFS Marine Recreational Fishery Statistics Survey MRFSS (see Van Voorhees et al. 1992 for methodology). Recreational catch data have been collected consistently since 1979 but sex is not recorded. Methodological differences between the current survey and intermittent surveys before 1979 preclude the use of the earlier data. The MRFSS consists of two complementary surveys of anglers via on-site interviews and households via telephone. The angler-intercept survey provides catch data and biological samples, while the telephone survey provides a measure of overall effort. Surveys are stratified by state, type of fishing (mode), and sequential two-month periods (waves). For the purposes of this paper, annual catches pooled over all waves and modes and grouped by subregion (ME to CT, NY to VA, and NC to FL) were examined.

The MRFSS estimates are partitioned into three categories of numbers caught and landed: A, B1, and B2. Type A catches represent landed fish enumerated by the interviewer, while type B1 are landed catches reported by the angler. Type B2 catches are those fish caught and returned to the water. Inasmuch as dogfish are generally caught with live bait and are often mishandled by anglers, 100% discard mortality was assumed. The MRFSS provides



estimates of landings in terms of numbers of fish. Biological information on dogfish is generally scanty, resulting in wide annual fluctuations in mean weights. To compute total catch in mt, an average weight of 2.5 kg per fish was assumed for all years.

Total recreational catches increased from an average of about 350 mt per year in 1979-1980 to about 1,700 mt in 1989-1991 (Table 4.1). Since 1991 recreational landings have decreased continuously from nearly 1,500 mt to less than 400 mt in 1996. Landings by number (Figure 4.3) suggest a similar, but less pronounced decline. During the 1990s, recreational landings represented a small fraction of the total fishing mortality on spiny dogfish. Even if all of the Type B2 catch died after release, recreational catches have comprised only about 8% of the total landings during this period. In 2001 and 2002 estimated B2 catches increased sharply. Total recreational catches represent about 25% of the landings in those years. As most of the recreational landings are discarded, with discarding unlikely to be size or sex selective, recreational landings were added to the total discard estimates in this assessment. This treatment of the data will be discussed more fully in Section 7.

### **4.3 Size and Sex Composition of Commercial Landings**

The seasonal distribution of biological sampling of the landings generally coincided with the seasonal pattern of landings (Table 4.5). Most samples were taken in June through November with much lower effort from January to May. In addition to the samples listed in Table 4.5, port samples obtained by MADMF in 2000 (15) and 2002(8) (provided by Brian Kelly, MADMF), were incorporated into the analyses. These samples provided a substantial increase to the total number of measured fish in these years. The biological characteristics of the landings are driven primarily by the marketplace, particularly the acceptance of small dogfish. The major increase of small males in the 1996 landings probably reflects their acceptance by export markets as well as the availability of processing equipment for smaller dogfish. The estimated size and sex composition of the landings are based on pooled samples over the entire year.

From 1982 to 1995, over 95% of the sampled landings of spiny dogfish were females greater than 84 cm. Males comprised a small fraction of the landings and were rarely observed above 90 cm in length. In 1996 landings of male dogfish increased dramatically, both in numbers and total weight (Table 4.6). The increased fraction of male dogfish in the landings continued through 1999 but dropped markedly from 2000 through 2002. Presumably, the drop in total quota resulted in a return to the remaining large females in the population.

Shifts in length frequencies toward smaller sizes reflect the marked increase in landings since 1989. The average size of landed females appears to have decreased by more than 15 cm since 1988 (Figure 4.4, top). The average size of males dropped about 5 cm between 1994 and 2000 (Figure 4.4 bottom). Reductions in average weight of females (Figure 4.5) are dramatic with a decline of average individual weight greater than 2 kg per fish since 1992. Again, the decline for males in 1996 is evident (Figure 4.5) but the drop is about 25% for males in contrast to the 50% decrease for females. Decreases in average size are consistent with increased fishing mortality, but could also be due to changes in the mix of otter trawl

and sink gill net catches. Corroboration of these trends in the research surveys (later section) suggest that these trends are the result of increased fishing mortality.

Mean sizes in the commercial fishery have declined to the extent that the increase in total landings of 14,731 mt in 1990 to 27,241 mt in 1996 (an increase of 85%) was accompanied by a 311% increase in numbers landed. Percentage of males in the landed jumped dramatically in 1996 to 17% by weight and 25% by numbers. Commercial landings by weight in 1999 (17,327 mt) were about equal to those in 1992 (17,687 mt) but the decrease in average weight resulted in the removal of almost twice as many dogfish (9.3 million fish versus 4.6 million fish). The relative increase in number killed as a function of average size can be evaluated by considering mean lengths of the landed fish (Figure 4.6 top). For example, a decline of average size from 95 cm to 70 cm in females would imply a 3-fold increase in the total numbers removed. A drop from 95 to 85 cm average size would result in a 50% increase. Switching to male dogfish would result in even more severe increases in numbers killed since the weight at length for males is less than for females of the same length (Figure 4.6). As an illustration, a switch from 85 cm females to 80 cm males would imply 50% more deaths of males for the same landings weight. The effects of selectivity will be characterized more fully in Section 7.3.2 when fishing mortality rates are considered.

#### 4.4 Discards

##### Methods

Owing to their ubiquitous distribution, dogfish are caught in a wide variety of fisheries. Owing to their low price per pound and need for special handling procedures onboard, dogfish are often discarded if more valuable species are present. Hence, high rates of dogfish bycatch and discards are expected. Previous assessments of spiny dogfish in the Northeast US have emphasized the need to estimate discard rates in other fisheries. In NEFSC (1994) preliminary analysis suggested that total discards were about the same order of magnitude at the commercial fishery. SARC 19 accepted provisional estimates of discard mortality of 0.75 in gillnets and 0.5 in otter trawls but noted the considerable uncertainty in these estimates. To our knowledge, no scientific studies of post-capture survival rates have been conducted for spiny dogfish. Ongoing tagging studies by Roger Rulifson (East Carolina State University, pers. comm.) may provide indirect evidence of these important parameters.

The primary database for discard estimates in the Northeast began in 1989 with the advent of a large-scale fisheries observer program for commercial vessels (Murawski et al. 1995, Anderson 1992). Species catch, effort, and associated biological and fishery data are collected for each trip. Previous estimates of dogfish discards used a ratio estimator to expand the sample discard rates to the total population. A primary component of this expansion was the reliance on the skipper's characterization of "primary species sought". Total estimates of dogfish discards were expanded by multiplying the discard/ton ratio by the total tonnage of landings of the target species. Previous estimates of dogfish discards were hampered by low sample sizes in major gear/area/target species cells.

The ratio-estimator concept was expanded in this study in several important ways. First, the target species were defined by first identifying 21 species groups or associations (Table 4.7).

These associations were determined via consultations with stock assessment scientists within NEFSC. Similarly, fisheries were grouped in to general gear types (Table 4.8) wherein minor differences among gears were ignored. The objective of the grouping by species and gear types was to increase the number of samples available for estimation of the discard ratios from the fishery observer program and to allow for estimation of variance estimates. Likely differences among areas were aliased by the choice of species groups. For example, the principal groundfish category encompasses most of the Gulf of Maine (GOM) and Georges Bank (GB) areas, whereas the fluke-four spot flounder species group aliases the Mid-Atlantic flatfish fishery. The flatfish group (witch, yellowtail, plaice, winter, windowpane, southern, hogchoker), in general, aliases the GOM, GB and Southern New England (SNE) areas. Second, the primary species group was identified post hoc by the actual landings pattern within the observed trip. The primary species was identified as the most abundant species group (by weight) within the set of 21 possible species groups. Third, we tested the relationship between the discard rate and the primary species group landed. One of the key assumptions of ratio estimators is that the predictor variable (i.e., primary species group) should be positively correlated with the dependent variable (i.e., dogfish discards). Finally, we estimated the variance of the discard estimates using the approximate variance approach of Cochran (1963, see also Fogarty and Gabriel, 2003, unpublished report).

To test whether the species grouping method sufficiently characterized the total landings of the observed trip, the relationship between total landings and primary species was plotted for all gears and species groups (Figure 4.7), trawl gear (Figure 4.8) and gill nets (Figure 4.9). In all instances the post hoc identification of primary species group appears to characterize the overall landings from the trip. For trips with over 1,000 pounds of total landings, the primary species group generally comprised more than 75% of the total landings. In contrast, the second most abundant species group had a much weaker association with the total landings (bottom panels of Figures 4.7-4.9).

Given an acceptable predictive ability to define the primary species group, the second critical requirement is that the dogfish discard level should be proportional to the landings of the primary species group. This assumption is tested by plotting observed dogfish discards versus the observed primary species group landings for all gears, years, and species groups (Figure 4.10), all years and species groups in observed trawl gear trips (Figure 4.11 top), and all years and species groups in observed gill net gear trips (Figure 4.11 bottom). The associations between discards and landings were positive, as expected, but the magnitude of the variation suggested that some species groups might have weaker associations. Examination of individual species groups plots (not shown in this report) suggested that certain species groups were only weakly related to dogfish discards. For example, no further consideration was given to discards in the large pelagic, mollusk, other sharks, other fish categories (Table 4.7).

The ratio of dogfish discards to primary species landed is multiplied by the total landings of the species group within the gear group. In order for this estimator to be reliable, it is important to consider the relationship between the observed landings and the total landings reported in the dealer records. The ratio of these two quantities can be considered the

sampling ratio. The inverse of this quantity is the expansion factor that will be applied to the total observed dogfish discards. For example, a sampling rate of 0.001 would imply an expansion factor of 1000 and a concomitant increase in the sampling variability. Plots of the sampling rates for the primary species groups versus year suggest an overall sampling rate of about 0.01 since 1990 (Figure 4.12). For trawl gear (Figure 4.13) the sampling rate is about 0.05, but for gill nets, the sampling rate seems to be clustered around 0.03 to 0.05 (Figure 4.14). The lower panels of Figures 4.12-4.14 show the degree of association between the total landing of the species groups from the dealer records (x axis) and the total landings observed during sea-sampling trips. Again, the relationship appears stronger for the gill net gear than for trawls, but both groups' relationships seem acceptable.

Collectively, the results presented in Figures 4.7 to 4.14 were considered sufficient to proceed with the computation of discard rates based on landings within the trawl and gill net gear groups, and the following species groups: Atlantic herring, crustaceans, dogfish, flatfish, fluke- four spot, mackerel, menhaden, monkfish, principal groundfish, scup-sea bass, skates, small-mesh groundfish, and squid-butterfish. A completely parallel set of analyses were conducted using a trip-based ratio estimator. These analyses gave similar results to the catch-based ratio estimator but appeared to be more variable. The subcommittee considered both sets of information and recommended the use of the catch-based estimator. Of particular concern was the lack of consideration of trip duration, and variations in vessel power. More detailed analyses, perhaps using GLM or Generalized Additive Models (GAM) could be used to more precisely identify the association between effort and discards.

Means and variances of the discard estimates were computed using standard formula for ratio estimators per Cochran (1963). For completeness, these estimators are summarized below.

$D_{G,S,T}$  = Observed discards of dogfish in gear G for target species S and trip T

$L_{G,S,T}$  = Landings of target species S in gear G and trip T

$L_{G,S}$  = Landings of species S in gear G

$$D_{TOT} = \sum_G \sum_S \left( \frac{\sum_T D_{G,S,T}}{\sum_T L_{G,S,T}} \right) L_{G,S}$$

The approximate variance is estimated by assuming that the dealer records of landings are measured with negligible reporting error and that most of the error obtains from the variance of the discard ratio R.

Let

$$\hat{R}_{G,S} = \left( \frac{\sum_T D_{G,S,T}}{\sum_T L_{G,S,T}} \right)$$

$$V(D_{G,S}) = V(\hat{R}_{G,S}) L^2_{G,S}$$

Where

$$V(\hat{R}_{G,S}) = \frac{(\hat{\sigma}_{D,G,S}^2 + \hat{R}_{G,S}^2 \hat{\sigma}_{L,G,S}^2 - 2\hat{R}_{G,S} \text{cov}(\hat{\sigma}_{L,G,S}, \hat{\sigma}_{D,G,S}))}{\left( \sum_T \bar{L}_{G,S,T} / N \right)^2}$$

It is important to note that the variance of R is obtained by substituting the sample variances and co-variances for the population estimates.

### Results

A composite table of dogfish discard estimates and variances are summarized by primary species groups for trawl, gill net and hook gear groups for 1989 to 2002 in Table 4.9. The discard estimates are based on a fishing year, defined as May 1 to April 30. Hence, the sampling in January-April 1989 sea sampling trips are labeled as the 1988 fishing year. Sampling frequency for hook gear was very low but this gear group was considered important for contemporary fishing practices under the federal and ASMFC management plans. Of the 13,637 trips analyzed, over 80% of the observer trips were on vessels using gillnets. Since 2000, the number of trips on trawling vessel has increased, with the number of trips exceeding 250 in each year. It should be noted that all of the standard MADMF observer trips are recorded in the NMFS observer database. Ancillary sea-sampling trips (~20 trips) conducted by MADMF in 2000 and 2002 on targeted dogfish trips will be summarized and compared with the current estimates in a later report.

Total discard estimates by year ranged from a high of nearly 90,000 mt in 1989 and 1990. The large estimates are driven by a limited number of trips in the trawl fishery. For example, the 55,000 mt estimate in the 1988 fishing year is based on one trawl trip in which mackerel were the primary species. Estimates of dogfish discards in later years consistently had discard rates an order of magnitude less, even though the number of trips per year approached 15 in many years (Table 4.9). Similarly high rates were observed in a few scup-sea bass group trips in 1990 (36,016 mt) and squid-butterfish trips in 1991 (29,532 mt). In both instances, the CV of the estimate exceeded 75%, suggesting that the numbers were highly imprecise. In contrast, the results from 1992 onward suggested much more stable estimates, with relatively few outliers.

To avoid complications of arbitrarily deleting species groups across years, a consistent set of species group was used to generate annual estimates of discard rates by year and gear category (Table 4.10). After 1993 the discard estimates decline steadily, and the variance of the estimates decreases as well (Figure 4.15, top panel). By coincidence, the estimated discards for 1993 fishing year of 24,188 mt agrees well with an alternative estimator summarized in NEFSC (1994) and published in Rago et. al (1998). In general, the coefficients of variation for the annual totals were on the order of 25%. Higher CV values were typically associated with large discard estimates in the trawl fishery. Standard errors of the total discard estimates were generally proportional to the total discard estimate for all species groups for both trawls and gill nets (Figure 4.16). The projected number of dead discards was estimated by multiplying the discards in each gear group by an assumed level of discard mortality (Table 4.11). Discards mortality rates in the gill net, trawl, and hook gear categories were 0.75, 0.5 and 0.25, respectively.

As noted above, an analogous set of computations were conducted using a trip-based ratio estimator (Table 4.12). Although the numbers will not be used in the assessment, the numbers for the sum of the trawl and gill net gear groups agree well with the rates derived from the catch based estimator (Fig. 4.15, 4.17). The number of trips by gear groups is very large (Table 4.13) implying large expansion factors. Together with the indeterminacy of what constitutes a standard “trip”, additional work is necessary before such estimates could be useful for assessments.

## **5.0 FISHERY-INDEPENDENT DATA**

### **5.1 Research Vessel Abundance Indices**

#### 5.1.1 NEFSC surveys

The Northeast Fisheries Science Center (NEFSC) has conducted both spring and autumn trawl surveys of the USA continental shelf annually since 1968. The surveys extend from the Gulf of Maine to Cape Hatteras. Details on the stratified random survey design and biological sampling methodology may be found in Grosslein (1969), Azarovitz (1981) and NEFSC (1995). Sex of spiny dogfish was not entered into the database until 1980.

Indices of relative stock biomass and abundance for spiny dogfish were calculated from NEFSC spring and autumn bottom trawl survey data. Overall indices were determined using only the offshore strata (1-30, 33-40, and 61-76) in order to obtain longer time series (i.e., 1967-1993 for the autumn survey and 1968-1994 for the spring survey). The autumn survey could not be extended back to 1963 because sampling of the Mid-Atlantic strata (61-76) did not begin until 1967.

In both the spring and the autumn surveys, there was considerable variability in the indices (Table 5.1 ,5.2, Figure 5.1). Both sets of indices indicate an overall increase in abundance and biomass from the early 1970s through the early 90s. Since that time, total index biomass has begun to decline, with greatest change occurring with females in the spring survey. The

rate of change in the autumn survey has generally been less than observed for spring. At SARC 18 it was determined that the higher variability in the fall survey is attributable to variable fraction of the population present in Canadian waters during the NEFSC fall survey. The NEFSC winter survey utilizes a flat net without the large rock-hopper rollers present on Yankee 36 trawl used in the spring survey. Average catches in the winter survey are generally 3 to 5 times greater than the other NEFSC surveys (Table 5.3) Overall catches exhibit a slight downward trend but higher average catch rates are typically associated with higher SE of the estimates. An analysis of the relationship between the standard deviation of stratum estimates and its mean (Figure 5.2) illustrates the strong association linear relation between the SD and mean of each stratum. The proportionality suggests that a log transformed catch rate might lead to more stable estimates, although an initial examination of this relationship for the spring survey (Figure 5.3) revealed comparable levels of interannual variation.

### 5.1.2 State surveys

Abundance indices for spiny dogfish from Massachusetts spring and autumn inshore bottom trawl surveys in 1978-2002 reveal two different facets of dogfish abundance. The spring survey usually occurs before the major influx of dogfish to Massachusetts waters. Catches are low but variable. In the fall, catches tend to be an order of magnitude larger, as much of the dogfish stock is concentrated near the Massachusetts coast (Table 5.4, 5.5, Figure 5.4). Wide variations in availability results in highly variable survey indices. High variability in this survey is also a reflection of the seasonal use by dogfish of the area surveyed by the State of Massachusetts.

### 5.1.3 Canadian surveys

Indices of relative abundance for 1970-1993 from the Canadian summer bottom trawl survey conducted in NAFO Divisions 4VWX (Campana, pers. comm.) are depicted graphically in Figure 5.5. Overall dogfish abundance increased along with the rise the US spring survey. In contrast to the US surveys, male dogfish are more abundant than females. Additional work is necessary to understand differences between abundance patterns in US and Canada surveys.

## **5.2 Size and Sex Compositions**

Size frequency distributions of spiny dogfish (sexes combined) from the spring and autumn NEFSC surveys were examined (Figure 5.6 a-d). The spring survey length frequencies have three modes corresponding to new recruits ( $\leq 40$  cm), mature males (70-80 cm), and mature females 95 cm. Large numbers of recruits have appeared periodically in the time series, especially in the early 1970s. The length frequency patterns in the autumn survey catches are much less consistent and there is no apparent tracking of modal lengths over time. Since 1997 both the spring and fall surveys are characterized by a single mode (Figure 5.6d).

Male and female size frequencies distributions are summarized by year for the spring (Figure 5.7 a-c) and fall surveys (Figure 5.8a-c). Male length frequencies are strongly skewed with an accumulation near the asymptotic size limit.

Qualitatively similar size frequency patterns for both sexes combined can be seen in the Massachusetts survey data (Figure 5.9 a-c) autumn survey.

Further insight into the changes in abundance and size composition may be obtained by examining the averaging size frequency compositions over multi-year periods (Figure 5.10). Three stanzas are considered. The first, 1985-88, illustrates the expected female size composition in a stable population. A large number of adults greater than 80 cm are present with a peak near the asymptotic size. Concomitantly, a relatively large number of juveniles less than 35 cm are also present. The second stanza can be considered the state of the resource during the peak of the fishery, 1995-1997. The numbers of adults has declined substantially and pups are much less abundant. Finally, the most recent stanza, 2001-2003, illustrates the cumulative effects of reductions in the spawning stocks and the near absence of pups in the surveys in the last 7 years. The reduction in abundance of the dogfish in the 50-60 cm range provides support for the hypothesis that the absence of recruits beginning in 1997 is real, since dogfish in this size range are expected to be about 4-7 years old. Changes in the total biomass at length (Figure 5.10 lower) illustrate the progressive removal of spawning stock over the three stanzas.

## 6.0 ANALYSIS OF INDEX TRENDS

In this section we further examine the changes in the survey indices and consider changes in swept area biomass for various size groups by sex. We then consider changes in the average size of mature females, the average size of pups, and demonstrate the relationship among maternal size, numbers of pups and average size of pups.

### 6.1 Swept-Area Biomass Estimates

Estimates of minimum stock biomass were determined from the NEFSC spring survey catches. Mean numbers per tow by sex and 1-cm length class were converted to average weights using a length-weight regression (females:  $W = \exp(-15.0251) * L^{3.606935}$ ; males:  $W = \exp(-13.002) * L^{3.097787}$ ). These average weights were then multiplied by the total survey area (64,207 n mi<sup>2</sup>) and divided by the average area swept by a 30-minute trawl haul (0.01 n mi<sup>2</sup>). Three size categories were defined ( $\leq 35$  cm, 36-79 cm, and  $\geq 80$  cm) which approximately correspond to new recruits, males and immature females, and mature females, respectively (Table 6.1).

One of the critical assumptions of the swept area computation is the size of the trawl footprint. The nominal footprint is based on the area swept by the net traveling at an average speed of 3.5 knots for 30 minutes. The effective capture zone is the distance between the wings of the net. Recent information (unpublished net mensuration data, Survey Branch, NEFSC) on variations in vessel speed and the increased contact time during haulback suggest that the effective area swept is greater than the nominal footprint. Additional details on this are provided in section 7. To illustrate the effect of this factor, the swept area biomass estimates are also computed with a nominal footprint of 0.012 n mi<sup>2</sup> (Table 6.2).



Swept area biomass estimates, using the 0.012 n mi<sup>2</sup> footprint were partitioned into size groups <36 cm, 36-79 cm, and ≥80 cm. For females, these size ranges roughly correspond to dogfish less than one year old, immature individuals and mature adults, respectively. For males, the intermediate size range represents both adolescent and mature individuals. Male dogfish >80 cm are mature, but relatively uncommon, as the average asymptotic size is about 80 cm.

Swept-area estimates of stock biomass exhibit annual variation that exceeds biologically realistic changes for such a long-lived species. Therefore, LOWESS smoothed (tension=0.5) estimates of biomass were considered to be better measures of population trends. Overall biomass estimates increased steadily from 1968 through 1992 to about 600 k mt, but have declined to about 400 k mt, about the same level as observed in 1985 (Figure 6.1). The changes in total biomass mask significant changes that have occurred within size and sex groups. Most of the change since 1992 has occurred in the 80+ cm male and female spawners stock where abundance has declined from about 250 k mt to about 50 k mt in 2003 (Figure 6.2, top). The pool of male and female dogfish between 36 and 79 cm has remained relatively stable over the past decade (Figure 6.2, bottom) at about 350 k mt. From 1980 onward, dogfish sex was recorded in the NEFSC database, allowing examination of the trends by sex as well. Figure 6.3 reveals the marked change in female spawner biomass (top) and evidence of reductions in the large males as well (bottom). Biomass changes in the intermediate size range of females are now evident (Figure 6.4, top) as the fishery has continued to accept smaller sized dogfish. No change is apparent in male 36-79 cm dogfish since the early 1990's (Figure 6.4, bottom).

The biomass of dogfish less than 36 cm represents individuals less than one year old at the time of the survey and are considered recruits to the population. Recruitment generally has been stable through most of the time series with a number of strong year classes in the 1980's (Figure 6.5). The numbers of recruits in the last 7 years, however, are the 7 lowest in the 36 year series. Coincident with the change in abundance, the average size of dogfish in this size range has also declined about 3 cm (Figure 6.6). The trend in abundance of recruits is consistent with the reduction in spawning stock, but the magnitude of the change is unexpected. In the following sections we explore possible reasons for the decline in pup abundance and introduce new biological information on dogfish reproduction.

## **6.2 Changes in Mean Size of Mature Females**

In recent years, considerable attention has been paid to the impacts of demographic variation on reproductive output (Murawski et al. 2001). In general evidence for many fish populations suggests lower reproductive output from younger spawners, and these differences are greater than simple reductions in number of eggs produced. To examine the reduction in average size of mature female dogfish, the average length of mature dogfish (80+ cm) was computed for the NEFSC fall (1980-2002), winter (1992-2003), and spring (1980-2003) surveys, the MADMF spring (1980-2002) and fall (1980-2002) surveys, and the NC SeaMap (1997-2003) surveys. The trends in average size of mature females show a remarkable consistency across all surveys (Fig. 6.7). Average size has declined from about

95 cm to 85 cm over this period, with consistent rates of change among surveys . Even the much shorter time series of the NC SeaMap survey shows a size range of mature dogfish consistent with the observations of the 5 other surveys (Figure 6.8). From these data, there is no evidence that a population of large-sized females is present in the Northeast US. The Canadian summer survey typically captures a much smaller sized female than the US surveys (S. Campana, DFO, per comm.). Additional analyses of Canadian data are warranted.

### **6.3 Potential Reasons for Reduced Pup Production 1997-2003**

#### 6.3.1 Fecundity and Pup Size in Relation to Maternal Size

In 1997 the SARC 26 noted the first year of low pup production and commented that it may be related to the reduction in spawning stock. A substantial amount of additional information on the reproductive biology of dogfish has been collected since the last assessment. Here we provide additional information on the factors that may underlie these changes in dogfish abundance.

Spiny dogfish females 65 cm or greater in total length (10 cm below the previously estimated size at first maturity) were examined during the bottom trawl surveys conducted by the NEFSC from 1998-2002. The trawl surveys are conducted in three seasons: winter (February), spring (March-April), and autumn (September-October) (Azarovitz 1982). The spring and autumn surveys cover the region from Cape Hatteras, NC, through the Gulf of Maine. The winter survey covers the region from Cape Hatteras, NC, to Georges Bank. A summary of the sampling by year and survey is provided in Table 6.3.

Each female was examined for the presence of free embryos, fertilized uterine eggs (candled embryos), and ovarian eggs. Immature females were classified as those with small ovaries containing either no eggs or small, non-developing eggs. A female was determined to be mature if large, well-developed eggs were present in the ovaries or if embryos were present in the uterus. If free embryos were present and time permitted, the embryos were counted for fecundity analysis. Candled embryos and ovarian eggs were not used in the fecundity analyses because they were prone to rupture.

The relationships between pup weight and average pup weight with maternal length (Figure 6.9) show a consistent increase with maternal length. All of the data in Figure 6.9 represent near-term free embryos at least 18 months old. A 100-cm female produces a pup that is 5 cm longer and about 50% heavier than an 80 cm female. The number of pups produced also increased with maternal length (Figure 6.10, top) but females with more than 6 pups were uncommon for dogfish less than 95 cm. The number of fertilized eggs and free embryos did not appear to change with gestational month (Figure 6.10 bottom). Such changes might be expected if capture stress or other factors were decreasing the number of fertilized eggs within the females. Larger numbers of near-term free embryos also corresponded to larger average sizes (Figure 6.11). Thus, larger females produce larger clutches of eggs and larger average-sized pups. Collectively, these factors suggest, but do not confirm, that larger females produce a more fit offspring, potentially subject to a smaller spectrum of predators.

A simple test of this hypothesis was conducted by examining the relationship between the predicted pup production from the spring survey and the observed numbers in the survey. Using a 3-yr average size composition of females, the predicted number of pups in year  $t$  was estimated at the sum product of the number at length and the average pups per 1-cm length group. The total pup production from this computation is multiplied by the first year survival rate (Section 8.0) = 0.68. No other statistical adjustments to the data were computed. The relationship between the observed and predicted numbers of pups (Figure 6.12) reveals good agreement in terms of scale. Moreover, the differences between the observed and predicted pup production shows that predicted number of pups are consistently negative from 1997 onward. Thus, the number of pups actually produced are lower than expected even when accounting for the reduced abundance of mature females. Figure 6.13 provides additional support for this hypothesis, showing the decrease in numbers and average size of mature females (top) and the clustering of negative residuals by year (bottom). These results suggest that population projections that rely on a constant first year survival rate (Section 9.0) may be overly optimistic with respect to population recovery.

## 7.0 Fishing Mortality and Biomass Estimation

### 7.1 Beverton-Holt Estimator

Instantaneous total mortality rates ( $Z$ ) for female dogfish were estimated using the length based method of Beverton and Holt (1956)

$$Z = \frac{K(L_{\infty} - \bar{L})}{\bar{L} - L'}$$

where  $K$  and  $L_{\infty}$  are from the von Bertalanffy growth model and  $L$  is the stratified mean length of individuals in the spring survey greater than the critical length  $L'$ .  $L'$  is the 25%-ile of length in the commercial landings. Parameters for female were  $K=0.1128$ ,  $L_{\max}=105$  cm. Fishing mortality rate is obtained at the difference between  $Z$  and natural mortality  $M$ . The Beverton-Holt estimator was evaluated over a range of sizes at entry to the fishery and natural mortality rates ( $M=0.092$ ; 50-yr lifespan,  $M=0.06$ ; 100-yr lifespan) to explore the sensitivity to these assumptions.

Mortality rates averaged about 0.06 during 1980's when landings averaged about 6,000 mt. Landings nearly tripled between 1989 and 1990, increased since then to over 28,000 mt in 1997 and have subsequently decreased (Table 4.1). The increase in fishing mortality rates reflects the increase in landings to levels above 0.4 in the late 1990's. Regardless of the underlying parameter assumptions, the estimates of  $F$  exceed the biological reference points of 0.08 (target) and 0.11 (threshold) (Figures 7.1, 7.2). The Beverton-Holt estimator is expected to lag the true rate of fishing mortality when fishing mortality is increasing. Conversely, since it is dependent on the growth and assumes an equilibrium size structure, it

is subject to transient conditions. Thus, the mortality estimates for the female population in the last 3 years, when fishing mortality rates have declined, are likely to reflect the history of the fishery rather than the contemporary status. During the course of various meetings related to the development of the federal and ASMFC management plans, it was noted that additional analyses would be required to assess contemporary fishing mortality rates. Those analyses are presented below.

## 7.2. Selectivity of Fishery

The changes in average size of dogfish are consistent with the targeted removal of large females. However, the changes in size selectivity over time also have important implications for the total force of fishing mortality on the population. High rates of mortality over a broad range of size groups have greater biological implications than an equivalent fishing mortality rate over a narrow range of size classes. The magnitude of these changes is important for estimation of fishing mortality, for evaluation of reference points and for population projections under various management scenarios. The first step in developing an estimator of  $F$  which incorporates both landings and survey information is to estimate a size specific selectivity function.

The selectivity of the fishery was approximated by assuming that proportion of stock available to the commercial fishery could be expressed as a logistic function of the size frequency distribution of the survey. Let  $p_s(\ell)$  represent the proportion at length  $\ell$  in the survey and let  $p_c(\ell)$  represent the proportion at length  $\ell$  in the commercial landings. The statistical model to relate these quantities can be written as

$$p_c(\ell) = \frac{p_s(\ell) \left( \frac{1}{1 + e^{a+b\ell}} \right)}{\sum_{\ell=50}^{L_{\infty}} p_s(\ell) \left( \frac{1}{1 + e^{a+b\ell}} \right)}$$

where  $a$  and  $b$  represent the parameters to be estimated. In general this model fit the data very well. Details on the application of this model to data from 1990-2002 by sex are provided in Appendix 1.

Additional data on the size selectivity of the dogfish fishery are can be obtained by examining detailed discard size composition data provided by the Massachusetts Division of Marine Fisheries for 2000-2002. The fraction retained by size interval was fit to a logistic function by year (Fig. 4.18). Model results suggest that the median size of retained dogfish in Massachusetts fisheries declined from 77 cm in 2000 to 70 cm in 2001 and further decreased to 65 cm in 2002.

## 7.3 Stochastic Estimation of Fishing Mortality and Biomass

### 7.3.1 Methods

A stochastic estimator of fishing mortality was developed to improve the estimation of contemporary estimates of fishing mortality. The estimator developed below incorporates a greater degree of mechanistic detail and uncertainty in the data. Several different measures of fishing mortality are of interest. First, we are interested in the total rate of mortality on the exploitable stock of male and female dogfish ( $F_1$ ). Second, we are interested in the mortality generated by the removals of discards ( $F_2$ ). This quantity is differentiated from  $F_1$  because it acts non selectively over the entire stock, not just the exploitable stock. The weighted average of  $F_1$  and  $F_2$ , called  $F_{\text{bar}}$ , represents the force of mortality acting on the entire stock. (In VPA speak, this is the biomass-weighted  $F$ ). In terms of evaluating the fishing mortality rate with respect to a biological reference point, we are interested in a metric commensurate with the pup-per-recruit analyses (Section 8.0).

Define

$F_1 = F$  generated by total landings acting on the exploitable biomass of male and female dogfish

$F_2 = F$  generated by total discards plus recreational catch, acting on the total biomass of male and female dogfish.

$F_{\text{bar}} =$  Biomass-weighted average  $F$  derived from  $F_1$  and  $F_2$

$F_3 =$  Fishing mortality rate on female dogfish, estimated as the ratio of female dogfish landings divided by exploitable biomass of female dogfish

$F_4 =$  Fishing mortality rate on male dogfish, estimated as the ratio of male dogfish landings divided by exploitable biomass of male dogfish

Using the catch equation, it is possible to define the various  $F$  metrics as follows

#### Variable Definitions

$L =$  Total landings(mt) of USA plus Canadian commercial landings

$L_f =$  Landings(mt) of female dogfish in USA plus Canadian commercial landings

$L_m =$  Landings(mt) of male dogfish in USA plus Canadian commercial landings

$B(\ell) =$  Total biomass(mt) of male plus female dogfish at length  $\ell$ .

$B_f(\ell) =$  Total biomass(mt) of female dogfish at length  $\ell$ .

$B_m(\ell) =$  Total biomass(mt) of male dogfish at length  $\ell$ .

$B(\ell) = B_f(\ell) + B_m(\ell)$

$B_{\text{expl}}(\ell) =$  Exploitable biomass(mt) of male plus female dogfish at length  $\ell$ .

$B_{\text{fxpl},f}(\ell) =$  Exploitable biomass(mt) of female dogfish at length  $\ell$ .

$B_{\text{expl,m}}(\ell)$  = Exploitable biomass(mt) of male dogfish at length  $\ell$ .

$B_{\text{expl}}(\ell) = B_{\text{expl,f}}(\ell) + B_{\text{expl,m}}(\ell)$

$D$  = Total discards (mt)

$N(\ell)$  = Number of dogfish in population at length  $\ell$ .

$I(\ell)$  = Index number of dogfish in population at length  $\ell$ .

$p(\ell)$  = proportion of dogfish in population of length class  $\ell$

$\text{sel}_f(\ell)$  = Selectivity fraction for females of length  $\ell$ .

$\text{sel}_m(\ell)$  = Selectivity fraction for males of length  $\ell$ .

$W_f(\ell)$  = Average weight (kg) of females of length  $\ell$ .

$W_m(\ell)$  = Average weight (kg) of males of length  $\ell$ .

$A$  = Total domain of offshore survey strata ( $\text{nm}^2$ )

$a$  = Area swept by standard trawl tow ( $\text{nm}^2$ ).

$\bar{X}_{t}$  = Average number of dogfish caught per tow in NMFS spring survey in year  $t$ .

$S_t^2$  = Estimated variance of mean catch per tow in NMFS spring survey in year  $t$ .

$$L_f + L_m = \sum_{l=l_{\min}}^{l_{\max}} F_1 (\text{sel}_f(l) B_f(l) + \text{sel}_m(l) B_m(l))$$

$$D = \sum_{l=l_{\min}}^{l_{\max}} F_2 B(l)$$

$$L_m + L_f + D = \sum_{l=l_{\min}}^{l_{\max}} F_{\text{bar}} B(l)$$

$$L_f = \sum_{l=l_{\min}}^{l_{\max}} F_3 \text{sel}_f(l) B_f(l)$$

$$L_m = \sum_{l=l_{\min}}^{l_{\max}} F_4 \text{sel}_m(l) B_m(l)$$

The estimates of  $F$  can be obtained by rearranging Eq. 1 to 5, simply dividing the left hand side by the non- $F$  terms on the right hand side equation.

The biomass variables can be written as the product of survey numbers at length and average weight at length and a scaling factor equal to the ratio of the total survey area divided by the footprint of the average tow.

$$B(l) = B_f(l) + B_m(l)$$

where,

$$B_f(l) = N_f(l)W(l) = I_f(l)\left(\frac{A}{a}\right)W_f(l)$$

$$B_m(l) = N_m(l)W(l) = I_m(l)\left(\frac{A}{a}\right)W_m(l)$$

The index number at length by sex can be further generalized to express it as the average number per tow,  $\bar{X}_{\text{bar}}$ , times the fraction of the population at length  $p(l)$ . The proportion at length is derived from the survey.

$$I_f(l) = \bar{X}_f p(l)$$

$$I_m(l) = \bar{X}_m p(l)$$

All of the quantities in Eq. 1 to 5 are measured with error but, for this assessment, it is assumed that the errors in the estimates of landings by sex and length class are negligible. Much greater variation is likely for survey abundance measures and total discards. To capture the effects of these sources of variation, stochastic versions of Eq. 1 to 5 were computed by convolving distributions of survey abundance, discards and trawl footprints.

Substantial variation in survey based estimates of dogfish abundance occurs across years. For some years, the variation exceeds what would be expected in terms of possible biological changes. To accommodate such variation, we use a simple 3 yr moving average smooth of the overall abundance estimates. The composite averages by sex are estimated as

$$\bar{\bar{X}}_{f,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{X}_{f,j}}{3}$$

$$\bar{\bar{X}}_{m,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{X}_{m,j}}{3}$$

The associated variances are estimated as

$$\bar{S}_{f,t}^2 = \frac{\sum_{j=t-1}^{j=t+1} \bar{S}_{f,j}^2}{3}$$

$$\bar{S}_{m,t}^2 = \frac{\sum_{j=t-1}^{j=t+1} \bar{S}_{m,j}^2}{3}$$

Sampling theory suggests that the survey mean should be asymptotically normal. We exploit this feature to simplify the estimation of the stochastic distribution of the Fs.

A summary of the 3-yr moving average and its composite variation is provided in Table 7.1.

The survey footprint is also measured with error. One source of error is the magnitude of variation in the length of the tow. The effective time on the bottom can exceed the nominal tow duration owing to delays in lifting the net off the bottom during haulback. As the net is moving forward with the combined forward velocity of the vessel plus the forward speed of the cable, the effective area swept will exceed the nominal target. To account for this variation in footprint size, preliminary data collected aboard the R/V Albatross IV in 2002 were used to estimate the possible variation in tow lengths (See Table 7.2).

Variation in discards was estimated using the method described in Section 4.4.

#### Evaluation Method

Let  $\Phi$  = Normal cumulative distribution function. The inverse of  $\Phi$ , denoted as  $\Phi^{-1}$  allows the evaluation of a set of values over a specified range, say  $\alpha_{\min}$  and  $\alpha_{\max}$ , over equal probability intervals.

$$X'_{t,\alpha} = \Phi^{-1}(\alpha | \bar{X}, \bar{S}_t^2)$$

The step size between successive values of  $\alpha$  was set as 1/500 (0.975-0.025), where  $\alpha_{\min}$  = 0.025 and  $\alpha_{\max}$  = 0.975. An equivalent approach was used for evaluation of the footprint parameter  $a$  where  $a \sim N(\mu_a, \sigma_a^2)$  and the discard estimate  $D \sim N(\mu_D, \sigma_D^2)$ . For both of these parameters the sample mean and variance estimates were used to estimate the normal distribution parameters.

The sampling distribution of each of the Fs described above was evaluated by integrating over each of the normal distributions for X, a, and D. As each parameter was evaluated over 500 equal probability intervals, there is reasonable assurance that the sampling distributions of the Fs will be appropriately estimated. The computer program for evaluating the distributions of F is provided in Appendix 2.



### 7.3.2 Results

#### Biomass Estimates

Stochastic estimates of exploitable biomass, total biomass and spawning stock biomass are summarized in Table 7.3 (minimum footprint assumption) and Table 7.4 (maximum footprint assumption) for 1990 to 2002. Trends in total biomass and SSB biomass are comparable to results presented in Tables 6.1-6.2. Incorporation of the uncertainty in the survey mean numbers per tow and footprint variation (within the two alternatives, i.e., min versus max footprint) suggests relatively precise estimates. The exploitable biomass quantities vary as a function of the selectivity functions derived in Section 7.2. These quantities are more erratic as they reflect the joint action of a temporally varying selectivity pattern and changes in underlying total biomass. The derived sampling distributions of the various biomass estimates are depicted graphically in Figures 7.3 to 7.6. As the selectivity of the fishery shifted toward smaller individuals the distributions of total and exploitable biomass exhibited a greater degree of overlap (Figures 7.3 and 7.5). The decline in SSB between 1990 and 2002 is evident in Figures 7.4 and 7.6, and notably, the reduced variation is also evident. By 2002, the stochastic SSB estimates were coincident with the exploitable biomass estimates. This suggests that the fishery is selecting individuals over the entire range of sizes within the exploitable stock.

#### Fishing Mortality Estimates

Stochastic estimates of F attributable to removals, the total exploitable biomass, discards, and exploitable biomass by sex are summarized in Table 7.5 (minimum footprint assumption) and Table 7.6 (maximum footprint assumption) for 1990 to 2002. The fishing mortality on the total biomass peaked in 1996 at 0.09 and has decreased since then to about 0.03 (Table 7.5). Under the assumption of the maximum footprint, the fishing mortality on total biomass is on the order of 0.07 (Table 7.6). Discard mortality, as it acts over the entire population, has generally been low, ranging under 0.03 over the last 10 years (Table 7.5). For the maximum footprint assumption, the discard F has generally been less than 0.06 (Table 7.6).

From the standpoint of the stock assessment, the most relevant quantity is the fishing mortality rate on the exploitable female biomass. As noted above, this quantity is now equivalent to the total spawning stock. The fishing mortality rate on the exploitable stock is denoted as  $F_3$  in Tables 7.5 and 7.6. Under the assumption of the minimum footprint, the F on the exploitable female biomass is 0.094. Note that the fishing mortality biological reference points are 0.08 for the target and 0.11 for the threshold. Note also that the target F for rebuilding of the stock is intended to be 0.03. The implications of these rates of fishing mortality for population recovery are treated more fully in Section 9.

The derived empirical distributions of F estimates on the exploitable biomass by sex and the discard mortality rate are shown in Figures 7.7 (min footprint) and 7.8 (max footprint). Despite the wide variation in the range of discard estimates, the overall rate remains relatively low except in the early 1990s. The distribution of F on females has been greatly reduced by the management measures in the US but these have been offset by concomitant increases in landings in Canada.

### Comparison with Beverton-Holt Estimates

An overall comparison of the stochastic mean estimates of F on the exploitable female population and the Beverton-Holt estimates is provided in Figure 7.9. The range of stochastic Fs derived under the alternative footprint values generally envelope the quantities derived from the BH estimates. The lack of agreement is greatest in the last 3 years, consistent with the hypothesis that the BH estimator would be more strongly influenced by the transient population condition. It is also interesting to note the substantial degree of agreement among the estimates during the period when the fishery was growing rapidly through the mid 1990s.

### **8.0. Life History Model**

The life history model used to estimate biological F reference points for spiny dogfish are summarized in Rago et al. (1998) and in SARC 26. No additional work on this particular aspect of the assessment has been conducted.

The application of the Ricker stock-recruitment relationship to spiny dogfish was reviewed jointly by the New England and Mid-Atlantic Fishery Management Councils' Statistical and Scientific Committees in 1999. On the basis of these meetings, an estimate of the SSB necessary to produce the maximum recruitment, denoted as  $SSB_{max}$ , was set at 200,000 mt. It should be noted that the estimate of 200,000 mt “roughly” corresponds to a swept area biomass estimate based on a nominal trawl footprint of  $0.01 \text{ nm}^2$ . The modifier “roughly” is used because the estimate was taken from a graph of the Ricker function plot. The stock and recruitment data for spiny dogfish are summarized in Table 8.1. The actual point estimate corresponding to the peak value of the Ricker function for the 1968-1996 data is 215,024 mt. The data used in this relationship were two year averages of recruitment, and SSB.

It is important to note that the estimate of  $SSB_{max}$  scales directly with the NEFSC spring research trawl survey. The abundance index, in kg/tow, for female dogfish greater than 80 cm is converted to total biomass by multiplying the average by the ratio of the total survey area ( $\sim 64,207 \text{ nm}^2$ ) and the footprint of the trawl. Evidence presented in section 6.3 suggests that the actual footprint exceeds the nominal footprint of  $0.01 \text{ nm}^2$  by about 10 to 20%. More specifically, since SARC 26, updated information on vessel speed and contact time suggested that the average footprint corresponded to a contact time of 33 minutes (rather than 30) and a vessel speed of 3.8 knots (rather than 3.5). These changes increase the nominal footprint to  $0.012206 \text{ nm}^2$  or about 20% greater than the nominal footprint. Increasing the footprint reduces the swept area biomass estimate, leading to an alternative estimate of the  $SSB_{max}$  of 167,000 (i.e.,  $200,000 \text{ mt} * (0.01/0.12) = 166,667 \text{ mt}$ ).

The important conclusion from this example is that the trawl footprint simply scales the abundance index for both recruitment and SSB. The underlying relationship between recruits and SSB is unaffected, such that estimates can be derived from analyses of the survey data alone (recruits expressed in numbers per tow, SSB expressed in kg/tow). The results of alternative model formulations are summarized in Table 8.2. The estimate of  $SSB_{max}$  of 214,024 mt corresponds to an average weight per tow of 33.2 kg. If unsmoothed data, rather

than a 2 point moving average, are used, the estimate of  $SSB_{max}$  becomes 35.9 kg, but its variance increases significantly.

Inclusion of the data from 1997 to 2003 illustrates another important property of the  $SSB_{max}$  estimate. Recruitments since 1997 represent the seven lowest values in the 1968-2003 time series. Incorporation of these values into the Ricker model estimate has no effect on the  $R_{max}$  estimate, but the estimate of  $SSB_{max}$  increases by 37% to 294,000 mt (Table 8.2). A Lowess smooth of the SR data (Fig. 8.1) is much less sensitive to the additional years of data with an approximate  $SSB_{max}$  slightly less than 200,000 mt (using the 0.01nm<sup>2</sup> footprint).

Discussion of the scaling problems at the SARC led to the general recommendation that the smoothed estimate for the entire data series would be a more appropriate measure of  $SSB_{max}$ , if an empirical model of the SR function were used to provide a biomass reference point.

The Ricker model assumes that the total female biomass is an adequate measure of spawning potential. As described in Section 6.3, the reproductive output of dogfish declines with maternal size with decreases in both numbers and size of pups. The information on decline in pup size in smaller females is an important conclusion in this assessment as it provides a possible explanatory mechanism for the lower than expected pup production since 1997. The SARC requested additional exploration of this mechanism, the results of which are summarized below.

An alternative measure of reproductive potential can be obtained considering the reproductive potential as a function of the maternal size distribution and numbers of pups per female at size. For this analysis, no smoothing of abundance indices was performed. Observed pups were computed as the sum of densities (number per tow) for all catches between 20 and 35 cm. Predicted pups were computed as product of mature female densities at length, predicted numbers of pups per length class and estimated survival rate. The estimated survival rate is computed under two models: a) no maternal effect, b) survival as function of maternal length. Under model (a) the survival function is estimated as  $S_o(L) = 1/(1+\exp(0.5389)) = 0.368$  with a MSE of 0.234 and  $R^2 = 0.456$  (Fig. 8.2). Under model (b) wherein maternal size is assumed to affect pup survival, the resulting function  $S_o(L) = 1/(1+\exp(28.123-0.305*L))$  reduces MSE to 0.196 and increases  $R^2$  to 0.564. Both of these models appear to be superior to the Ricker SR model for predicting recruitment. The limitation of the demographic model is that it does not provide a simple method for defining the optimum level of SSB corresponding to  $R_{max}$ . Instead, the demographic model is unbounded with respect to  $SSB_{max}$ . The results of the demographic recruitment model are incorporated into the stochastic projection scenarios in the following section.

## 9.0 Stochastic projection model

### 9.1 Overview

A length-based stochastic projection model was developed to evaluate effects of alternative fishing mortality scenarios. The model incorporates sex specific rates of growth and fishing mortality. Discard mortality is assumed to act equally all size ranges of both sexes.

Reproduction in the model is assumed to be proportional to stock abundance. The basic model can be written in terms of two matrix equations as

$$N_{f,t+1} = S_{f,Z,t} P_f S_{D,t} N_{f,t} + S_{D,t} N_{f,t}^T P_{up} S_o \phi R_f^o$$

$$N_{m,t+1} = S_{m,Z,t} P_m S_{D,t} N_{m,t} + S_{D,t} N_{f,t}^T P_{up} S_o (1 - \phi) R_m^o$$

where

$N_{f,t}$  = Vector of female population abundance at length. Dimension =  $(l_{\max} - l_{\min} + 1)$

$N_{m,t}$  = Vector of male population abundance at length. Dimension =  $(l_{\max} - l_{\min} + 1)$

$S_{D,t}$  = Diagonal matrix of discard survival rates at time t. Dimensions =  $(l_{\max} - l_{\min} + 1, l_{\max} - l_{\min} + 1)$

$S_{f,Z,t}$  = Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for females at time t. Dimensions =  $(l_{\max} - l_{\min} + 1, l_{\max} - l_{\min} + 1)$

$S_{m,Z,t}$  = Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for males at time t. Dimensions =  $(l_{\max} - l_{\min} + 1, l_{\max} - l_{\min} + 1)$

$R^o$  = Vector of proportions at length of new recruits. Dimension =  $(l_{\max} - l_{\min} + 1)$

$P_f$  = Growth projection matrix for females. Dimensions =  $(l_{\max} - l_{\min} + 1, l_{\max} - l_{\min} + 1)$

$P_m$  = Growth projection matrix for males. Dimensions =  $(l_{\max} - l_{\min} + 1, l_{\max} - l_{\min} + 1)$

$P_{up}$  = Vector of length specific pup production rates for mature females. Dimension =  $(l_{\max} - l_{\min} + 1)$

$S_o$  = Scalar first year survival rate of newborn pups. Derived from analysis of life history model

$T$  = Transpose operator

$\phi$  = proportion of female pups at birth; 0.5 implies an equal sex ratio.

Note that the projection equation for males is a function of the numbers of recruits produced by females.

### Notation Footnote

Vector quantities and operations will be denoted in bold font. As examples, let  $\mathbf{X}$  denote a matrix with  $k \times k$  elements, and  $\mathbf{Y}$  denote a vector with  $k$  elements. Then  $\mathbf{XY}$  would define the matrix multiplication of the vector  $\mathbf{Y}$  by matrix  $\mathbf{X}$  yielding a vector quantity, say  $\mathbf{Z}$ . Similarly,  $\mathbf{Y}^T\mathbf{Y}$ , read as  $\mathbf{Y}$  transpose  $\mathbf{Y}$ , represents the dot product of the elements of  $\mathbf{Y}$  with itself, yielding a scalar quantity. Scalar multiplication of a vector is denoted as  $c\mathbf{Y}$  where  $c$  is an arbitrary constant. By convention, matrix operators proceed from left to right and in general, operations are not commutable.

The elements of a matrix are denoted by appending the appropriate number of identifiers within parentheses following the variable name. Thus,  $X(i,j)$  represents the scalar quantity in the  $i^{\text{th}}$  row and  $j^{\text{th}}$  column of the matrix  $\mathbf{X}$  and  $Y(i)$  represents the  $i^{\text{th}}$  element of the vector  $\mathbf{Y}$ .

The component processes of the matrix model and quantities derived from the population states are described below. The Fortran computer code used to implement the model is provided in Appendix 3.

## 9.2 Processes

### 9.2.1 Growth

Growth in length at age is modeled by the von Bertalanffy equation applied separately to each sex. The model parameters are taken from Nammack et al. (1985). The projection matrices,  $\mathbf{P}_f$  and  $\mathbf{P}_m$  for females and males, respectively, are defined as square matrices consisting of 0, 1 elements. The non-zero elements in cell  $i, j$  indicate the growth of individuals from cell  $i$  to cell  $j$ . The growth of individual dogfish from length  $i$  to length  $j$  is modeled by first inverting the von Bertalanffy equation to obtain the age of individuals of length  $i$  to obtain age  $i$ . The projected length at age $_{i+1}$  is then obtained substituting age $_{i+1}$  back into the von Bertalanffy equation to obtain length  $j$ . The projection matrix algorithm for females can be summarized as follows:

*Step 1. Find age for  $L_i$*

$$a_{f,i} = \frac{\log\left(1 - \frac{L_{f,i}}{L_{f,\infty}}\right)}{K_f} + t_{f,o}$$

*Step 2. Compute  $L$  in next time step*

$$L_{f,j} = L_{f,\infty} (1 - e^{-K_f(a_{f,i+1} - t_{f,o})})$$

*Step 3. Compute element of projection matrix*

$$P_f(\text{int}(L_{f,j}), \text{int}(L_{f,i})) = 1$$

The same algorithm is defined for males by substituting the m for f in the subscript terms of the above equation.

### 9.2.2 Fishing and Natural Mortality

Natural mortality is assumed equal to 0.092 and to be constant over all length classes. Fishing mortality in year t, defined as  $F_t$ , is multiplied by sex-specific selectivity functions (Sec. 7) to estimate the sex- and length-specific fishing mortality rates. The diagonal matrices that decrement the populations for fishing and natural mortality are defined as  $S_{f,Z,t}$  and  $S_{m,Z,t}$  with elements defined by

$$S_{f,Z,t}(\ell, \ell) = e^{-(sel_f(\ell)F_t + M)}$$

$$S_{m,Z,t}(\ell, \ell) = e^{-(sel_m(\ell)F_t + M)}$$

In some scenarios it is desirable to evaluate the effects of a quota rather than a fishing mortality rate. For these scenarios it is necessary to iteratively solve for  $F_t$  sufficient to generate a quota of magnitude  $Q_t$ . A Newton-Raphson algorithm (function `rtsafe`, p 359 in Press et al. 1992) was used to find the value of F. The application to this length-based model is patterned after the approach used in Brodziak et al. 1998. When a quota was too large for the estimated exploitable biomass to support, a default  $F=3.0$  was set as an upper bound.

### 9.2.3 Discard Mortality

Instantaneous discard mortality rates for the entire population were estimated using methodology described in Section 7.. The discard matrix in Eq. 9.1 is a diagonal matrix with principal diagonal elements estimated as

$$S_{D,t}(\ell, \ell) = e^{F_{discard,t}}$$

For all scenarios considered in this report, the discard rate was set equal to the estimate for 2002 (i.e.  $F_{discard} \sim 0.02$ ). Note that the discard rate is assumed to be equal for all length classes. In the model, it is assumed that discard acts as a Ricker Type I fishery in which the discard is assumed to occur before the fishing and natural mortality. This approximation results in a small overestimate of the numbers discarded. Assuming a discard rate of 0.02, the effect on discard numbers would be 4% higher when  $F=0$  and 8% when  $F=0.11$  when comparing a type I and II fishery.

The survivors after discard mortality has occurred is written as

$$N_{f,t+\Delta t} = S_{D,t} N_{f,t}$$

$$N_{m,t+\Delta t} = S_{D,t} N_{m,t}$$

The numbers of discards at length by sex,  $\mathbf{D}_{f,t}$  and  $\mathbf{D}_{m,t}$ , for females and males, respectively, is defined as

$$D_{f,t} = N_{f,t} - N_{f,t+\Delta t}$$

$$D_{m,t} = N_{m,t} - N_{m,t+\Delta t}$$

### 9.2.4 Reproduction

The total number of pups produced is written as the product of the length-specific pup production rates and the number of females alive in year t.

$$Pup_{TOT,t} = S_o N_{f,t+\Delta t}^T Pup$$

The numbers of pups produced by length and size category is estimated by splitting the total pup number by sex and multiplying by the observed proportion of dogfish at length for a lengths assumed to be less than one year old at the time of the survey. The resulting numbers of pups produced is written as:

$$female\ pups = \phi Pup_{TOT,t} R_f^o$$

$$male\ pups = (1 - \phi) Pup_{TOT,t} R_m^o$$

The  $\mathbf{R}_f$  and  $\mathbf{R}_m$  vectors representing the proportions by length class consist of  $(\ell_{max} - \ell_{min} + 1)$  elements of which only elements 1 to k are non-zero. The male and female vectors have equivalent proportions but differ with respect to vector length, owing to the larger maximum size attained by females.

### 9.2.5 Biomass Outputs: Yield, Discards SSB, Exploitable Biomass, Total Biomass

Yield is estimated by applying the catch equation to the number of individuals alive after discarding has occurred. The catch at length by sex is estimated as

$$C_{f,t}(\ell) = \left( \frac{F_t sel_f(\ell)}{F_t sel_f(\ell) + M} \right) \left[ 1 - e^{-(F_t sel_f(\ell) + M)} \right] N_{f,t+\Delta t}(\ell)$$

$$C_{m,t}(\ell) = \left( \frac{F_t sel_m(\ell)}{F_t sel_m(\ell) + M} \right) \left[ 1 - e^{-(F_t sel_m(\ell) + M)} \right] N_{m,t+\Delta t}(\ell)$$

The total yield by sex is computed as the sum of the products of the numbers caught and their average weight . In matrix notation this is written as:

$$Y_{f,t} = C_{f,t}^T W_f$$

$$Y_{m,t} = C_{m,t}^T W_m$$

and

$$Y_t = Y_{f,t} + Y_{m,t}$$

Discards in weight,  $D_{B,t}$  are estimated in a similar fashion such that:

$$D_{B,f,t} = D_{f,t}^T W_f$$

$$D_{B,m,t} = D_{m,t}^T W_m$$

and

$$D_{B,t} = D_{B,f,t} + D_{B,m,t}$$

The total biomass of the population by sex  $B_{f,t}$  and  $B_{m,t}$ , is estimated as the total number alive at the start of the year multiplied by the average weight at length.

$$B_{f,t} = N_{f,t}^T W_f$$

$$B_{m,t} = N_{m,t}^T W_m$$

and

$$B_t = B_{f,t} + B_{m,t}$$

Exploitable biomass is defined as the fraction of the population biomass available to the fishery given the prevailing selectivity pattern. The commercial selectivity pattern by sex is defined in Section 7.2. Exploitable biomass will always be less than total biomass and is computed as follows:



$$B_{Expl,f,t} = \sum_{j=\ell_{\min}}^{\ell_{\max}} sel_f(j)N_{f,t}(j)W_f(j)$$

$$B_{Expl,m,t} = \sum_{j=\ell_{\min}}^{\ell_{\max}} sel_m(j)N_{m,t}(j)W_m(j)$$

and

$$B_{Expl,t} = B_{Expl,f,t} + B_{Expl,m,t}$$

Finally, the spawning stock biomass is expressed in terms of female biomass only and is defined as the sum of mature females. In the projection model, females are assumed to be mature at 80 cm such that the spawning stock biomass can be written as

$$SSB_t = \sum_{j=80}^{\ell_{\max}} N_{f,t}(j)W_f(j)$$

### 9.3 Initial conditions

The initial condition of the population was defined as the 3-yr average (2001-2003) of dogfish abundance in the NEFSC spring R/V trawl survey. Unlike the stochastic estimator of fishing mortality and biomass, the projection model does not incorporate uncertainty in the estimates of discard mortality or the footprint of the survey. Instead, the projection model incorporates the variation in abundance defined by survey abundance. Variation in mean abundance is used to scale the index numbers at length by generating values of mean abundance over 500 equally-spaced probability intervals.

Following the recommendation of the subcommittee, all projections were computed using the minimum footprint size. Use of the minimum footprint increases the biomass estimate and decreases the fishing mortality estimate, relative to the alternative maximum footprint.

### 9.4 Scenarios

A large number of scenarios are possible. Terms of Reference 4 through 6 requested

*4) Estimate yield based on stock status and target mortality rate ( $F = 0.08$ ) for fishing year 2004 (May, 2004 through April, 2005).*

*5) Provide short term projections (2-3 years) of stock status under a variety of TAC/F strategies*

*6) Evaluate existing and alternative rebuilding schedules based on current/projected stock status.*

Items 5 and 6 are closely related but indefinite. To help bound the problem, six projection scenarios were defined. Each was based on previously specified scenarios that have been previously analyzed in committee preparations for the joint MAFMC and NEFSC dogfish management plan for federal waters and/or the ASMFC plan for state waters. Three scenarios utilize an F-based strategy with constant fishing mortality rates over a 30 year projection period. The other three scenarios utilize a fixed quota over a 30 period.

The status quo F scenario assumes that the fishing mortality rate estimate in 2002 would continue through from 2003 to 2032. No assumptions about the relative allocation of yield between the US and Canada are made but the current rate of F is based on the summation of landings from both countries. The rebuilding level of F is based on projection results from an earlier version of the model. Given the initial conditions of the resource in 1997 and the model formulation, a fixed level of  $F = 0.03$  was determined to be adequate to rebuild the stock within the 10-year rebuilding period specified by the Sustainable Fisheries Act (SFA). Finally, an implausible scenario of zero fishing mortality was employed to evaluate the minimum possible rebuilding time. The utility of this scenario is that it provides a benchmark to compare alternative scenarios.

Three quota-based scenarios were also evaluated. In each of these scenarios it was assumed that the future level of landings in Canada would remain near its current value of about 3,400 mt. It was further assumed that landings from the US would be additive. The base quota scenario assumes that US commercial fisheries extract a target quota of 4 M lb (1,814 mt) and Canadian landings remain at 3,400 mt. The “alternative” quota evaluates the effects of an 8.8 M lb (3,992 mt) US commercial landings and 3,400 mt in Canada. Finally, the “No Commercial Quota” scenario assumes that no dogfish would be landed in US fisheries.

The scenarios are designed to evaluate the relative merits of possible alternatives, rather than to accentuate allocation issues. The “status quo F”, “base quota”, “alternative quota” and “No US Commercial Quota” scenarios provide feedback on what might be accomplished under US regulatory measures. The “zero F” and “rebuild F” scenarios would require joint management by the US and Canada.

For all scenarios, it was assumed that the current rate of discard mortality would prevail for the projection period. Moreover, recreational fishery was assumed to consist mainly of discard mortality with no targeted effect of discarding.

The relative merits of each alternative scenario can be evaluated with respect to the magnitude of landings and the attainment of biological reference points. For each year in a scenario, 500 realizations of F and biomass are computed. Each of these is compared to threshold and target F and biomass levels. In addition, each simulated value of F was compared to an  $F_{\text{rebuild}}$  level = 0.03 per the various management plans. The number of times that the F reference points were exceeded divided by the number of bootstrap intervals (500) represents a measure of the probability of exceeding the reference value. Similarly, the count

of Biomass levels above the target level represents probability of restoring the population. Count of biomass above the threshold level could be interpreted as the shift in status from the “overfished” condition.

The projection model output was condensed to provide rapid comparison among alternatives. First, box plots were used to summarize the projected range of model outputs for key management variables {1)Yield (mt total, female, male), 2) Discards (mt), 3) SSB (mt), 4) F, 5) Fraction of the SSB target and 6) Total biomass (mt)}. To further reduce the information, these quantities were tabulated as averages on a decadal time scale (Table 9.1) and as a series of 10 year waypoints (Table 9.2). It should be noted that the current non-equilibrium status of the population induces transient oscillations in abundance. These oscillations should be kept in mind when evaluating the tabulated waypoint data. In particular, it is expected that some scenarios will rapidly attain restoration followed by a decline in abundance at the effects of recent low levels of recruitment feed into the adult stock. The input files and probability output files are included in Appendix 4. The following sections provide additional details on the results of the simulation model.

#### 9.4.1 Status quo F

Under the status quo F scenario, the population exhibits wide variation in SSB and yield. (Figure 9.1). Both of these oscillations are induced by the non equilibrium size structure of the population. The population does not achieve rebuilt status but does stabilize at about 100 k mt of SSB supporting about 8,000 mt of yield. The stabilization occurs because the joint effect of the current fishing mortality rate and discard rate closely approximate the predicted equilibrium threshold F of about 0.11. As a result, population stability is achieved by about 2020.

#### 9.4.2 Rebuild F

The rebuild F option is based on recommended fishing mortality rates specified in the federal FMP. The target rate of  $F=0.03$  is based on an earlier version of the model presented herein. Under this option, the population rebuilds rapidly but then oscillates as the effects of the paucity of 36-79 cm initial population is felt about 10 years into the simulation (Figure 9.2). The effects occur in both the yield and SSB trajectories. Population rebuilding occurs in 2020. The model uses a constant F but presumably a more liberal fishing mortality rate could be applied at that time.

#### 9.4.3 Zero F

The zero F option is designed to benchmark the minimum possible rebuilding time. Under this assumed option the population is predicted to have a 50% of exceeding the target biomass level in 2017 (Figure 9.3)

#### 9.4.4 Base Quota

The baseline quota option represents continuation of the current level of total landings in the US and Canada. The current quota level results in a gradual increase in population size allowing rebuilding by about 2026 (Figure 9.4).

#### 9.4.5 Alternative Quota

The alternative quota option (Figure 9.5) fails to achieve rebuilding over the 30-yr period of the simulation.

#### 9.4.6 No Commercial Quota

This option results in a rebuilding of the population by 2020 (Figure 9.6). The model results suggest that a quota of about 3,400 mt, however allocated, could be harvested without severely delaying the rebuilding time that would occur under the zero F option.

#### 9.4.7 F=0.08 in 2004 and later

This scenario corresponds to the target fishing mortality rate specified in the federal FMP. Yield under this scenario fluctuates around 9,000 mt, but the population never rebuilds over the 30 year horizon.

#### 9.4.8. Status Quo F and Maternal Effect on first year Survival

Projection model simulation results under the assumption that the status quo F continues and first year pup survival is expressed as a function of maternal size (Figure 8.2) are provided in Figure 9.8. This scenario suggests that the population will neither rebuild nor stabilize under the status quo F.

#### 9.4.9 Summary

No density dependent factors associated with high densities are included. This is appropriate for dogfish in view of the low present state of the female spawner biomass and limited range for compensation in terms of growth and pup production. The absence of density-dependent regulation is justified also by the steepness of the SR function at the origin. This projection model is considered adequate for describing the dynamics of the resource up to the point of restoration, i.e., attainment of the biological reference point for biomass.

Important caveats apply to ALL of the above simulations. No assumptions are made about possible size dependent decreases in pup viability. It is assumed that pup survival is constant for pups produced by all females, regardless of maternal size. If the size-dependent decreases in initial survival rates are real, then all of the scenarios would be considered optimistic with respect to rebuilding the populations. Further, it is assumed that the current discard pattern persists into the future. Another important factor is that the minimum footprint is assumed to apply. While the exact expansion factor ( $A/a$ ) is unknown, the true value is likely to be between the min and max footprint assumptions. If so, appropriate caution should be applied when considering long-term quota options. Earlier projections of stock biomass under the max footprint assumption suggested that the range of quota levels that gave increasing versus decreasing populations was fairly narrow.

## **10.0 Simple Mass Balance Models**

The SARC expressed concerns regarding the utility of the nominal footprint ( $0.01 \text{ nm}^2$ ) analyses of survey data as an adequate measure of true stock abundance. The SARC suggested that model-based approaches would be an alternative means of estimating the likely magnitude of  $q$  and therefore, efficiency, defined as the probability of capture given

encounter. To test this concept two alternative mass balance models were applied. The following analyses were conducted during the SARC and are intended to provide an initial exploration of the utility of model-based methods of estimating abundance. A simple Leslie-Davis model, based on a closed population was applied, primarily as a means of circumscribing the possible value of  $q$ . The second model was based on a simplified catch survey analysis, similar to the process model of Collie and Sissenwine.

As in all analyses of survey data for spiny dogfish, data are averaged across years to provide a better estimate of abundance. This tends to dampen interannual changes.

If we consider the reduction of female dogfish abundance since 1989 as a simple depletion experiment wherein the slow growth of dogfish above 80 cm, and low mortality combine to result in low recruitment and biomass production, a Leslie-Davis model is a plausible approach. Under this assumption the change in abundance could be viewed as a simple depletion experiment. If the index data are scaled to the nominal footprint, the slope of the Leslie Davis regression is a measure of the efficiency of the trawl. Results of the Leslie Davis application are provided in Figure 10.1. The slope estimate of 1.23 is consistent with an effective footprint approximately equal to the increased contact time of the trawl. As a very rough approximation, the efficiency of the trawl for dogfish should be on the order of  $0.0123/0.0239 \sim 50\%$ . (Note: the value of  $0.0239 \text{ nm}^2$  corresponds to a trawl footprint defined as the distance between the trawl doors. This indirect measure of trawl efficiency further assumes that dogfish herd in between the doors.)

The Leslie Davis model makes strong, and perhaps untenable, assumptions about constancy of recruitment and offsetting effects of growth and natural mortality. To address these concerns a more complicated mass balance model was devised. The model is similar to that proposed by Collie and Sissenwine, except in this instance, it was assumed that all of the error is process error, rather than observation error. Thus, the model boils down to one parameter as follows.

Define recruits  $R_t$  as the biomass of dogfish in the 79 cm range that will grow into the 80 cm range in the next time step. The biomass of 80+ cm dogfish will change between time steps in response to the growth of individuals ( $G$ ), losses through natural mortality ( $M$ ), and biomass removals by the fishery  $C_t$ . Basing the expanded values of  $B$  and  $R$  on a nominal footprint of 0.01, the model can thus be defined as

$$B_{t+1} = B_t e^{G-M} + R_t - C_t$$

The  $G$  and  $M$  parameters are not separably estimable but their difference can be estimated as a single parameter, say  $\phi$ . The model estimate of  $\phi$  was  $-0.061$  which corresponds well with the assumed natural mortality rate of 0.092 and a very slow adult growth rate. Results of the model fit are summarized in Figure 10.2. The model fits well with no aberrant residual patterns. The model now adequately tracks the recent change in abundance, a small upturn in the last 3 yrs. This appears to be due to a decrease landings, since the difference between the recruitment and the landings becomes positive in 2001 and 2002. (Figure 10.2 bottom panel).

Both the Leslie-Davis and simple mass-balance models support the concept that the nominal footprint assumption adequately characterizes the true size of the population. The rapid change in the size structure, and paucity of pups in recent years also provide evidence that the removals in the directed fishery were sufficient to exert a relative large mortality on the adult stock.

## **11.0 Spiny Dogfish Research Recommendations**

### **New**

- 1) Attempt to allocate landings to statistical area (i.e. attempt proration) using Vessel Trip Report data for 1994 and later years.
- 2) Evaluate the utility of length frequency for spiny dogfish sampled in the NEFSC Observer Program in the most recent years (2001 and later).
- 3) Ensure the inclusion of recent (2000 and later) MADMF Observer sample data for spiny dogfish in the NEFSC database, for more efficient use in future assessments.
- 4) Conduct tagging and genetic studies of spiny dogfish in U.S. and Canadian waters to clarify current assumptions about stock structure.
- 5) Conduct discard mortality studies for spiny dogfish, with consideration of the differences in mortality rates among seasons, areas, and gear types.
- 6) Conduct experimental work on NEFSC trawl survey gear performance, with focus on video work to study the fish herding properties of the gear for species like dogfish and other demersal roundfish.
- 7) Investigate the distribution of spiny dogfish beyond the depth range of current NEFSC trawl surveys, possibly using experimental research or supplemental surveys.
- 8) Initiate ageing studies for spiny dogfish age structures (e.g., fin spines) obtained from NEFSC trawl surveys and other sampling programs. These studies should include additional age validation and age structure exchanges. The WG notes that other aging methodologies (e.g., Canadian studies on radiometry) are also in development.
- 9) Explore an alternative assessment which uses a standard statistical fisheries modeling approach (i.e., data inputs not smoothed before fitting the model, and trawl biomass used as relative indices with a selectivity pattern estimated within the model).

**Old: Pending**

1) Additional analyses of the effects of environmental conditions on survey catch rates should be conducted.

**Old: In Progress**

1) Additional work on the stock-recruitment relationship should also be conducted with an eye toward estimation of the intrinsic rate of population increase.

2) The SARC noted that the increased biological sampling of dogfish should be conducted. Maturation and fecundity estimates by length class will be particularly important to update. Additional work on the survey database should be conducted to recover and encode information on the sex composition prior to 1980.

**Old: Completed**

1) The SARC recommended continued work on the change-in-ratio estimators for mortality rates and suggested several options for analyses.

*The change-in-ratio estimator approach was not successful, and has been dropped from the assessment.*

2) The SARC noted the absence of projections for this species and recommended the development of a projection model.

*Projections are now included in the assessment.*

3) The SARC recommended additional analyses of sea sampling data since 1994. Further analyses of the commercial fishery is also warranted, especially with respect to the effects of gear types, mesh sizes, and market acceptability on the mean size of landed dogfish.

*Discard estimates based on sea sampling (observer) data are now included in the assessment.*

4) The SARC noted the potential importance of dogfish predation in the ecosystem and recommended further work on the diet composition.

*See Link et al, 2002 (N. Am. J. Fish. Mgmt. 22:550-562).*

## 12.0 SARC Comments

### 12.1. Discussion on Life History, Discard Estimation and Survey Trends

The Stock Assessment Review Committee (SARC) discussed the different longevity estimates for the east and west coast. The east coast assumes spiny dogfish live for fifty years, whereas on the west coast it is assumed that dogfish live for 100 years. There is some evidence that the west coast ageing consistently doubles the ages assigned to the rings on the second dorsal spine resulting in a life span twice as long as the east coast. There does not appear to be any evolutionary reason for the Pacific spiny dogfish to live twice as long as the Atlantic spiny dogfish. While there is a need for more ageing work, the SARC determined that a life span of fifty years is the based best available information at this time.

The stock assessment assumes 100% of the spiny dogfish discarded in the recreational fishery are discarded dead. Estimates of discard mortality in the recreational fishery are based on the treatment of dogfish on charter boats. The SARC discussed the appropriateness of the assumed discard mortality rates in the assessment because the commercial hook and line fishery has an assumed discard mortality rate of 25%. Information on discard mortality rates in the spiny dogfish recreational and commercial fisheries is lacking.

Due to recent management decisions to employ a different quota determination methodology to estimate the annual commercial quota, some members of the Committee felt that the SAW/SARC process would have been an appropriate venue to review the new quota determination model. While fishery managers are responsible for selecting the fishery's quota, the SARC could have provided some advice on the potential implications on the stock. The SARC felt it should conduct a technical review of the models used to estimate annual quotas.

Observed patterns from the NEFSC trawl survey show that the number of pups in a litter has changed over time, from 5–15 to 2-10. Litters over ten pups are a rare occurrence. There is some variability in the number of pups in a litter, but, generally, the number of pups in a litter increases with the length of the female.

Biological sampling of spiny dogfish has been sporadic because the species does not have a high priority. Massachusetts Division of Marine Fisheries does perform some port and sea sampling for spiny dogfish, although the timing of commercial landings has challenged the ability to obtain biological samples. Commercial landings come in over a short period of time because of the current management scheme and the low quota.

The Committee discussed the use of inshore surveys, such as the Maine and New Jersey surveys. These surveys would complement the current catch rate information from the NEFSC trawl survey, but would not supplement the information collected on the biological attributes of the resource (e.g. length and sex), which are critical to the stock assessment.

It was suggested that the discard estimates should have confidence intervals, derived from a more robust method such as bootstrapping.



Catch per unit effort should be incorporated into the discard estimation, but defining a standardized unit of effort between the different gear types would be difficult. Much of the data are for short trips, so the definition of a trip for a small gillnet vessel will be different to that of bigger trawl vessels. Future work on estimating discards could include GLM or other models using catch per unit effort, vessel classification and other covariates.

The assessment uses information collected from the NOAA Fisheries Observer Program to determine an estimation of the level of discards associated with different gear types. The catch-based discard estimation focused on three different gear type predominantly used when targeting spiny dogfish; gillnets, hook and line, and trawls. The estimation included only trips where spiny dogfish was not the primary target species, and therefore assumed to be bycatch.

At a previous SARC, the winter, fall, and spring surveys were reviewed to determine the most appropriate survey to characterize the stock. During the time of year that the spring survey is conducted, about 90% of the spiny dogfish population inhabits the same area covered by the survey. This earlier SARC review also revealed that when the abundance dropped in the fall survey, the absent portion of the resource appeared in the Canadian survey. This implies that the US fall survey and the Canadian survey combined may track abundance of the entire population, but NEFSC spring survey alone provided the best representative sample of the entire population.

The assessment did not review the NEFSC trawl survey to determine if there was a spatial trend associated with the characteristics of mean size of females and pups.

The Committee discussed the influence of environmental variation creating a size dependent response. The length frequencies in the survey reveal that the mature females over 80 cm have not been captured by the survey over the last six or seven years. The same evidence is seen in the commercial landings. At one point, it was common for the fishery to harvest females over 100 cm. The males are commonly found along the continental shelf, whereas the females tend to be found inshore. The spatial movements of the sexes might be a reason for the biological characteristics seen in the survey.

Future work on the assessment should include a review of the environmental variables associated with the encounter of spiny dogfish during the NEFSC trawl spring, like temperature and depth. The survey area should be stratified by temperature to determine if the temperature drives the dogfish to a different geographical location each year. Also, if the survey is partitioned into three or four strata, the data may reveal whether the biological characteristics are different in each area.

It was noted that the assessment may overestimate the spawning stock biomass if the pup viability is not taken into account in management decisions.

## **12.2. East Carolina University Spiny Dogfish Tagging Data**

The North Carolina spiny dogfish fishery typically encounters more females than males. The fishery also takes place during the winter when the dogfish have migrated south. The weather during the winter prohibits fishermen from fishing out on the continental shelf. Data from the NEFSC trawl survey shows that the males tend to be in the deep waters off North Carolina at about 200 m.

The majority of the tag returns were in the US; only one or two were captured in Canadian waters. A possible explanation for the low return rate in Canada is the difference in effort. For the time period covered by the study, the US effort was about four to five times the Canadian landings. To determine the migrational patterns in the northern range of the species, tagging studies need to be conducted off Cape Cod, Massachusetts.

The tagging study should consider the associated handling mortality. It is assumed to be low because the dogfish are released soon after they are captured. The condition of the spiny dogfish should be assessed and recorded prior to releasing the fish. There was some concern that recapture of fish released from gillnets was much lower than those released from trawl, which may be due to tag induced mortality.

The tagging study is encountering a considerable number of dogfish that may not be caught by the fishery. The study should determine if there is a difference in size between the fish caught by the different gear types (e.g. trawls versus gillnets).

The population estimate derived from the tagging study is three times the estimate derived from the swept area estimate. The tagging study should factor in the possibility that dogfish are double tagged and tag shedding rates.

The tagging study used two different reward levels. Every tenth tag released was a \$50 reward; all of the remaining tags offer a \$10 reward. The different reward levels did not influence the reporting rate.

The biomass estimates derived from the gillnet study should factor in the probability of being captured associated with the distance from the gillnet.

The tagging work in North Carolina should be combined with the gillnet study to provide a better population estimate.

## **12.3. Discussion on Biological Reference Points and Projections**

The Committee discussed the catchability associated with the trawl survey. The catchability may be influenced by a significant amount of herding in front of the doors.

The current target biomass uses the female spawning stock biomass. The target biomass was selected based on the number of pups that will survive to replace the mature female in the population so that the population remains stable. The Committee suggested using fecundity

as an alternative target to spawning stock biomass. The spawning stock biomass may not be the best target due to the uncertainty associated with the survey area-swept method. The assessment derived a predicted number of pups in the population based on the abundance and length frequencies of the mature females. The predicted number of pups in the population was overestimated compared to the observed number of pups in the survey.

#### Stochastic Biomass Estimates

The stock assessment introduces a new method for estimating biomass to replace the Beverton - Holt method used in previous assessments. The stochastic biomass estimator requires a set of assumptions. The biomass encountered by the NEFSC trawl survey is representative of the entire population and the availability of the resource is assumed to be equal over the entire survey area. The survey biomass also represents the size composition of the population, so all lengths are equally selected by the trawl survey. The length composition of the survey biomass is averaged over 3 years to reduce the survey variability.

It was questioned whether using swept area without taking into account vulnerability (i.e. assuming vulnerability = 1) could be used to obtain realistic biomass estimates. The three components of catchability are vertical availability, area availability and vulnerability to the survey gear. Vertical availability was assumed to be high as dogfish tend not to move far from the sea floor and area availability is already considered in the assessment. The biomass estimates derived in the survey produces a lower and upper bound on the biomass based on the area availability. The spring survey is assumed to encounter about 90% or more of the population.

A range of biomass estimates are produced in the assessment because of the uncertainty associated with the area swept by the survey. The minimum footprint of the survey is based on the area swept between the wings of the net. The minimum footprint translates into the maximum biomass estimate. The maximum footprint uses the area between the doors of the net and is the basis for the minimum biomass estimate. The doors may be creating a herding effect making the effective footprint the area swept between the doors. The Committee suggested the use of underwater video equipment on the net to determine if herding does occur, and, more generally, vulnerability to the gear.

The NEFSC spring survey is assumed to be the best indicator of the overall stock structure. Commercial landings are used to determine the size frequency and commercial selectivity. The assumption is that the commercial gear is fishing in a smaller size range than the entire population. The selectivity in the fishery exists because of market demand for a certain size range of dogfish.

The stochastic biomass estimator shows an increase in exploitable biomass in 1995 and 1996, which coincides with the increase in commercial landings. At this time, a large portion of the landings was male, so the force of mortality was over a greater portion of the entire population, influencing the selectivity for the fishery.

The biomass estimates are being used as absolute abundance estimates, when the estimates are probably relative abundance. It was pointed out that trawl surveys are not usually used to estimate absolute biomass. However, absolute biomass estimates are needed to derive the annual quota and no alternative is currently available. It was suggested that the assessment moved towards a fully age or size structured model and use the trawl survey as an index of relative abundance.

Additional research on ageing spiny dogfish is needed to resolve the ageing discrepancy between the east and west coast. Age information will reduce some of the uncertainties introduced by converting length frequencies to age classes.

It appears that spiny dogfish is a possible candidate for a biomass dynamics model, but the estimates derived in 1994 were poor and the model was not pursued further.

In recent years, the stochastic biomass estimator shows a convergence of the exploitable and spawning stock biomass. Variation in growth rates between individuals in the population should and can be introduced into the model. The current assessment assumes that there is no variation in growth rates. The model also assumes that the population is at equilibrium, although, it is clear that the population has not reached equilibrium.

#### Projections

The projection model should be configured so that the recruits to the population are a function of the population size. This will more accurately model the current condition of recruitment and implication of improved recruitment as the population.

The number of pups in a litter is proportional to the length of the female. An estimate of predicted pups can be derived based on the length frequencies of the females in the population. The pup survival rate is dependent on the average size of pups. The pups produced by smaller females are generally smaller in size, and therefore have a lower survival rate than the pups produced by larger females. Evidence of recruitment failure over the past seven years appears in the declining abundance of the immature dogfish between 50 cm and 60 cm.

The stochastic biomass estimator relies on the catchability of the survey to derive estimates of biomass and fishing mortality. In the interim, a connection should be made between the target female spawning stock biomass and an index of fecundity that could be used in future management decisions. The Committee suggested using pup production per tow or the number of mature females per tow multiplied by the number of pups that can be produced at sizes encountered in the tow.

Uncertainty in the F target has not been explicitly considered. Uncertainty in the target biomass could be characterized using bootstraps or other methods. It was suggested a full risk analysis could be conducted.

The Committee has more confidence in the relative abundance estimates. The relative abundance estimates should be used in the fishery management plans, but it would be acceptable to use both the upper and lower bounds of the absolute biomass estimates. The footprint of the trawl survey creates a lot of uncertainty in the absolute abundance estimates. Further exploration into the use of a fecundity index needs to be conducted and would be recommended index for a biomass rebuilding target.

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Table B4.1. Total spiny dogfish landings (mt, live).

Year	Canada	US	USSR	Other Foreign	US Recreational		Total
					Landed	Discards	
1962	0	235	0	0		NA	235
1963	0	610	0	1		NA	611
1964	0	730	0	16		NA	746
1965	9	488	188	10		NA	695
1966	39	578	9389	0		NA	10006
1967	0	278	2436	0		NA	2714
1968	0	158	4404	0		NA	4562
1969	0	113	8827	363		NA	9303
1970	19	106	4924	716		NA	5765
1971	4	73	10802	764		NA	11643
1972	3	69	23302	689		NA	24063
1973	20	89	14219	4574		NA	18902
1974	36	127	20444	4069		NA	24676
1975	1	147	22331	192		NA	22671
1976	3	550	16681	107		NA	17341
1977	1	931	6942	257		NA	8131
1978	84	828	577	45		NA	1534
1979	1331	4753	105	82		NA	6271
1980	670	4085	351	248		NA	5354
1981	564	6865	516	458	1493	296	10192
1982	953	5411	27	337	70	349	7147
1983		4897	359	105	67	540	5968
1984	4	4450	291	100	91	424	5361
1985	13	4028	694	318	89	964	6107
1986	21	2748	214	154	182	1187	4506
1987	280	2703	116	23	306	1056	4484
1988		3105	574	73	359	876	4987
1989	166	4492	169	87	418	1344	6676
1990	1316	14731	383	10	179	1170	17788
1991	292	13177	218	16	131	1350	15183
1992	829	16858	26	41	215	1019	18987
1993	1411	20643	0	27	120	1110	23311
1994	1819	18800	0	2	154	969	21744
1995	948	22711	0	14	64	628	24365
1996	416	27241	0	236	34	353	28279
1997	446	18352		214	64	749	19825
1998	1079	20628		607	39	610	22962
1999	2467	14860		554	53	532	18466
2000	2677	9257		494	5	604	13036
2001	3755	2294		302	28	2090	8468
2002	3400	2195			225	1698	7518

A. The increase in foreign landings from 1996 on may be other species of squalid sharks. 13016.53  
28279.14  
1534.45

Table B4.2. Spiny dogfish landings (mt, live) by gear type.

Year	Gear Type					Total
	Line Trawl	Otter Trawl	Sink Gill Net	Drift Gill Net	Other Gear	
1962	18.7	78.3	0.0	129.4	8.4	234.9
1963	49.8	85.5	297.2	138.3	38.8	609.6
1964	12.5	75.4	89.5	529.5	23.4	730.4
1965	55.1	52.3	129.8	228.6	22.2	488.0
1966	84.7	95.2	173.2	184.8	40.1	578.1
1967	23.9	110.8	54.9	43.1	44.9	277.5
1968	2.5	78.0	0.0	54.3	23.2	158.0
1969	1.9	88.4	0.5	5.9	16.7	113.4
1970	1.8	80.5	9.6	2.8	11.0	105.7
1971	0.0	53.0	0.6	3.5	16.2	73.3
1972	0.6	53.5	0.6	0.1	14.4	69.2
1973	0.5	76.7	1.3	5.0	5.8	89.4
1974	1.9	79.2	1.1	10.2	34.9	127.3
1975	0.3	89.4	4.1	10.3	42.8	146.9
1976	5.2	71.6	432.9	5.4	34.5	549.6
1977	2.8	102.6	796.1	2.8	27.2	931.4
1978	3.4	121.4	680.8	6.3	16.6	828.4
1979	17.8	3518.0	1251.8	1.5	17.6	4806.5
1980	21.3	3370.1	635.3	4.0	64.7	4095.4
1981	1.0	6287.1	628.2	7.3	8.7	6932.4
1982	2.9	5065.6	310.7	9.4	22.0	5410.6
1983	0.2	3367.5	1517.1	6.6	5.1	4896.5
1984	0.9	2486.0	1949.5	6.1	7.9	4450.4
1985	158.7	2844.4	1007.6	9.8	7.6	4028.0
1986	2.6	1258.1	1467.2	3.1	16.7	2747.6
1987	7.8	1848.1	811.7	2.9	32.8	2703.4
1988	4.7	1589.5	1489.5	12.6	9.0	3105.2
1989	138.2	486.5	3839.0	7.5	20.8	4492.0
1990	16.8	7010.8	7685.2	14.7	3.1	14730.6
1991	31.1	5208.7	7805.8	107.6	23.6	13176.7
1992	9.8	4785.5	11639.7	171.5	251.4	16857.9
1993	250.8	5100.2	15764.9	77.3	22.7	21215.9
1994	482.4	3056.3	14798.2	27.1	134.1	18498.2
1995	1494.3	2818.0	17657.4	340.9	272.1	22582.6
1996	1313.0	3408.2	21088.7	1265.3	99.0	27174.1
1997	1084.6	1800.6	14357.1	1026.4	84.1	18352.9
1998	1410.0	2709.2	15071.4	1315.4	121.6	20627.6
1999	1610.8	2212.5	10462.8	325.4	248.5	14860.0
2000	1776.1	3146.8	4297.6	15.9	20.3	9256.7
2001	1276.3	254.4	749.0	0.7	13.1	2293.6
2002	1044.1	247.7	896.0	0.5	6.5	2194.8

Table B4.3. Spiny dogfish landings (mt, live) by month, 1964-2002.

Year	Month													Total
	Unk	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1964	627.9	7.3	1.4	1.2	-	12.9	31.7	-	4.8	35.9	-	-	7.4	730.3
1965	308.5	0.1	4.1	-	14.9	4.9	34.4	23.1	27.2	30.8	11.9	22.6	5.6	488.1
1966	318.4	1.5	1.8	7.8	7.1	2.1	68.7	82.0	48.9	26.6	5.5	7.6	-	578.1
1967	188.3	-	3.9	-	4.3	6.0	15.9	42.7	5.3	7.2	0.9	2.5	0.8	277.5
1968	157.6	-	-	-	-	0.1	-	-	0.2	-	-	-	-	158.0
1969	113.4	-	-	-	-	-	-	-	-	-	-	-	-	113.4
1970	102.8	-	-	-	-	-	-	0.3	1.0	0.2	0.9	0.4	<0.1	105.6
1971	72.9	<0.1	-	-	-	0.4	-	-	-	-	-	-	-	73.3
1972	60.2	-	-	-	0.1	0.4	0.3	-	-	-	1.8	4.7	1.7	69.2
1973	73.7	2.7	<0.1	-	0.7	2.4	4.3	2.4	0.3	-	1.6	0.8	0.4	89.3
1974	122.6	0.1	-	0.9	-	0.8	0.3	1.1	0.2	0.6	0.4	0.2	0.1	127.3
1975	136.0	0.2	0.1	0.4	2.6	0.3	0.2	0.2	0.1	-	0.1	3.6	2.9	146.9
1976	116.2	0.1	0.5	-	-	-	24.1	126.2	70.9	119.7	91.8	0.1	0.1	549.7
1977	95.4	0.0	-	-	-	30.0	259.9	120.4	169.4	136.7	98.3	4.1	17.3	931.4
1978	140.8	0.1	0.8	5.9	0.1	0.5	85.0	294.5	102.2	54.2	133.0	9.1	2.3	828.5
1979	344.3	-	-	-	-	16.7	292.4	637.0	502.3	1043.1	1137.5	389.8	389.5	4752.7
1980	406.7	26.9	3.3	81.5	0.4	112.3	803.0	540.5	818.9	1087.4	52.2	91.4	60.7	4085.1
1981	1729.4	1.2	0.4	-	0.8	107.6	945.4	1121.0	1156.8	1005.2	698.6	98.0	0.7	6865.0
1982	65.8	143.1	369.6	1287.8	219.4	134.1	830.4	819.7	411.6	517.6	256.4	235.7	119.4	5410.6
1983	45.9	3.7	3.6	-	0.3	55.8	140.8	710.0	963.2	744.5	402.5	169.2	1656.9	4896.5
1984	46.8	-	-	-	0.3	1.4	559.5	2077.1	1111.6	357.8	168.2	103.1	24.5	4450.4
1985	71.1	-	-	0.8	1.9	275.5	690.6	753.2	785.6	588.1	642.6	175.4	43.0	4027.9
1986	13.1	1.0	5.8	2.5	11.8	145.5	483.1	468.0	473.7	622.8	376.9	93.8	49.9	2747.6
1987	6.0	4.8	1.5	4.0	8.6	17.6	397.1	555.8	384.6	440.5	703.6	175.5	3.9	2703.4
1988	49.8	0.6	116.0	27.5	4.4	384.8	566.3	532.4	502.6	508.8	401.1	9.9	0.9	3105.1
1989	15.5	0.2	-	2.0	21.2	296.9	1134.1	713.5	961.4	924.5	374.2	41.7	6.8	4492.0
1990	49.5	290.0	207.8	283.2	318.6	494.2	1137.9	2881.6	2819.3	2079.5	1166.8	959.8	2042.6	14730.6
1991	213.7	1609.9	1105.2	661.4	1298.9	1136.8	624.5	1421.6	962.8	840.1	353.7	965.7	1982.6	13176.6
1992	320.8	2117.3	1620.4	1402.6	703.7	787.5	1083.4	2327.4	1549.7	808.9	1362.7	1887.9	885.8	16857.9
1993	281.7	1516.3	1631.6	834.9	260.7	517.8	2001.0	3423.3	3227.4	2587.2	1983.3	1075.8	1301.8	20642.9
1994	77.1	1277.0	1438.2	1234.9	628.9	653.1	1975.3	3391.2	4204.7	1508.1	878.2	409.5	1123.9	18800.2
1995	28.7	1703.4	1432.8	1150.9	880.3	928.8	3386.9	4181.5	2208.8	1843.9	1887.2	1499.9	1577.6	22710.6
1996	0.2	2628.1	2336.8	2532.1	1695.1	534.5	2221.9	3630.6	2466.7	2143.6	2511.0	2056.9	2483.5	27241.0
1997	0.0	2304.0	1543.4	1468.0	724.0	1419.6	2122.0	2684.4	1917.8	1055.3	1129.3	1070.9	914.2	18352.9
1998	0.0	1652.6	1304.4	1113.9	571.6	572.2	1415.7	2272.8	2983.1	2620.1	2922.1	1965.8	1233.2	20627.6
1999	0.0	1732.1	1701.1	1478.7	869.4	850.5	1761.3	1209.4	995.7	1085.5	1372.3	829.1	974.9	14860.0
2000	0.0	1215.6	1885.1	1771.1	698.1	61.6	595.7	1326.1	1029.7	267.3	222.0	110.1	74.1	9256.7
2001	0.0	5.4	0.0	0.2	17.0	144.6	1048.2	2.2	3.3	1.5	1.0	1070.1	0.1	2293.6
2002	0.0	0.2	0.1	1.2	40.7	489.9	889.0	3.2	3.1	1.0	0.5	725.6	40.3	2194.8

Table B4.4. Landings of spiny dogfish (mt, live) by state (Includes 100% unclassified dogfish).

Year	State											Total
	Connecticut	Delaware	Maine	Maryland	Massachusetts	New Hampshire	New Jersey	New York	North Carolina	Rhode Island	Virginia	
1962	2.6	0.0	21.6	17.4	0.0	0.0	1.6	25.2	0.0	0.1	166.3	234.9
1963	0.1	0.0	343.5	16.5	0.0	0.0	1.9	35.4	0.0	0.1	212.2	609.6
1964	4.7	0.0	102.1	12.4	0.0	0.0	0.2	33.1	0.0	0.4	577.5	730.3
1965	6.9	0.0	171.3	7.2	7.6	0.0	0.7	43.9	0.0	0.7	249.7	488.1
1966	4.9	0.2	259.6	6.7	0.0	0.0	1.5	81.7	0.0	0.1	223.4	578.1
1967	1.6	0.0	82.1	6.5	6.6	0.0	0.1	89.0	0.0	0.5	91.1	277.5
1968	22.8	0.0	0.0	7.2	0.3	0.0	3.3	61.8	0.0	0.1	62.5	158.0
1969	2.2	0.0	0.0	7.9	0.0	0.0	6.1	65.6	0.0	0.1	31.6	113.4
1970	8.0	0.0	0.0	6.1	2.4	0.0	0.6	54.1	0.0	0.7	33.8	105.7
1971	4.1	0.0	0.0	1.5	0.4	0.0	5.6	50.5	0.0	0.1	11.1	73.3
1972	0.0	0.0	0.0	2.4	0.7	0.0	0.1	51.4	0.0	8.3	6.4	69.2
1973	0.1	0.0	0.0	4.5	5.4	0.0	2.5	44.4	0.0	10.4	22.2	89.3
1974	0.0	0.6	0.0	6.5	3.2	0.0	0.3	79.8	0.0	2.2	34.6	127.3
1975	0.0	1.8	0.0	2.6	1.8	0.0	0.9	101.1	0.0	9.1	29.5	146.9
1976	1.1	0.0	428.3	3.1	3.1	0.0	1.7	93.4	0.0	1.7	17.2	549.7
1977	1.0	0.1	792.8	3.6	17.4	0.0	4.7	78.1	0.0	26.4	7.4	931.4
1978	2.2	0.4	647.0	7.5	31.5	31.6	6.4	88.1	0.0	2.8	11.1	828.5
1979	4.1	0.1	1049.6	5.4	2964.9	140.6	392.4	96.7	0.0	1.6	97.6	4752.7
1980	0.1	0.1	619.1	5.0	2794.4	6.7	263.0	104.1	1.3	0.6	290.6	4085.1
1981	2.0	3.8	516.2	695.4	4523.3	0.0	92.5	50.1	2.0	1.7	978.1	6865.0
1982	1.2	1.2	282.6	895.2	2885.3	0.0	2.5	47.4	2.9	1.3	1291.0	5410.6
1983	4.3	2.0	225.0	96.5	4529.9	0.3	0.3	25.8	0.0	0.0	12.4	4896.5
1984	2.4	2.7	565.4	117.6	3703.2	0.1	4.1	35.0	0.0	11.1	8.8	4450.4
1985	4.5	0.0	409.8	76.9	3463.7	0.0	3.8	61.9	0.5	0.7	6.3	4028.0
1986	8.7	0.0	349.1	58.6	2165.6	0.0	24.0	133.9	0.0	2.2	5.5	2747.6
1987	2.9	0.0	271.0	3.5	2335.2	0.0	1.7	70.6	0.0	13.9	4.6	2703.4
1988	42.8	0.0	218.4	10.7	2643.6	0.2	4.6	39.2	136.9	0.3	8.6	3105.1
1989	0.4	0.0	2213.4	1.6	2233.8	0.0	10.3	21.9	0.0	2.0	8.7	4492.0
1990	11.0	0.0	2887.6	989.7	8077.0	84.0	2061.2	8.2	18.8	590.1	3.0	14730.6
1991	4.0	2.6	914.5	2240.4	6572.2	0.0	1231.8	35.0	663.7	1433.5	78.9	13176.6
1992	10.1	0.0	779.9	1389.5	8335.2	182.4	1149.7	70.6	3916.8	919.7	103.9	16857.9
1993	6.8	0.0	1598.9	814.6	12170.4	744.6	349.3	43.3	3994.4	872.9	47.7	20642.9
1994	77.1	0.0	822.5	648.0	10530.0	1178.4	512.5	107.7	4480.5	240.6	203.0	18800.2
1995	133.2	28.5	754.6	1414.1	13045.6	955.4	1083.4	423.9	4244.3	260.3	367.3	22710.6
1996	320.2	0.0	413.3	3243.7	12228.7	489.7	2102.6	602.2	6202.4	511.9	1126.3	27241.0
1997	157.6	0.0	203.5	1917.6	9827.0	746.9	1721.2	16.8	1365.5	629.7	1766.7	18352.4
1998	121.2	0.9	124.2	1088.2	11299.7	960.2	3416.7	3.0	1367.9	843.3	1402.2	20627.6
1999	39.9	0.2	15.8	968.0	6765.5	562.6	1812.3	678.3	1134.7	695.1	2187.8	14860.1
2000	13.7	0.1	3.5	204.0	2613.5	1058.9	2369.9	863.6	1319.9	154.4	655.2	9256.7
2001	3.4	0.0	0.1	0.1	1774.7	243.1	9.1	27.0	4.0	231.1	1.1	2293.6
2002	0.0	0.0	0.3	1.1	1723.1	158.2	0.6	23.6	0.7	284.9	2.2	2194.8

Table B4.5 Number of samples collected and number of individual spiny dogfish measured for length, by sex (U= unspecified; M= male; F= female), from USA commercial landings, by month, year and quarter, 1982-2002.

Year	Sex	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4	Total
1982	# of Samples	2	1	2									1	6	5	0	0	1	6
	U													0	0	0	0	0	0
	M	2		22										24	24	0	0	0	24
	F	198	101	281										100	680	580	0	0	100
1983	# of Samples						1		1	1	1	1		5	0	1	2	2	5
	U													0	0	0	0	0	0
	M													0	0	0	0	0	0
	F						104		118	121	133	134		610	0	104	239	267	610
1984	# of Samples						3	6	3	1				13	0	3	10	0	13
	U													0	0	0	0	0	0
	M						1	3	4	1				9	0	1	8	0	9
	F						286	745	351	117				1499	0	286	1213	0	1499
1985	# of Samples						2	1	3	3	2	2		13	0	2	7	4	13
	U													0	0	0	0	0	0
	M							1	1	14	1	4		21	0	0	16	5	21
	F						267	135	389	368	252	246		1657	0	267	892	498	1657
1986	# of Samples						3	1	4	3	2			13	0	3	8	2	13
	U						232							232	0	232	0	0	232
	M							45	1	10	8			64	0	0	56	8	64
	F						130	129	521	168	217			1165	0	130	818	217	1165
1987	# of Samples						3	6	2	1	2	1		15	0	3	9	3	15
	U													0	0	0	0	0	0
	M						16	4		1	1	9		31	0	16	5	10	31
	F						457	800	257	128	243	115		2000	0	457	1185	358	2000
1988	# of Samples					3	3	2	1	2	4			15	0	6	5	4	15
	U													0	0	0	0	0	0
	M							1	1		5			7	0	0	2	5	7
	F					371	364	238	128	230	433			1764	0	735	596	433	1764
1989	# of Samples						3	1	1	3	3			11	0	3	5	3	11
	U													0	0	0	0	0	0
	M								6	6	23			35	0	0	12	23	35
	F						352	127	137	390	369			1375	0	352	654	369	1375
1990	# of Samples						5	6	3	1	1	1	1	18	0	5	10	3	18
	U													0	0	0	0	0	0
	M							4			1	14		19	0	0	4	15	19
	F						593	775	358	135	111	123	135	2230	0	593	1268	369	2230
1991	# of Samples			1	1		2	4	2		1	1	2	14	1	3	6	4	14
	U							108			109			217	0	0	108	109	217
	M						11	127	12			8	3	161	0	11	139	11	161
	F			101	125		226	396	272			116	282	1518	101	351	668	398	1518
1992	# of Samples				1	2	4	6	4	1	2	4	1	25	0	7	11	7	25
	U						123							123	0	123	0	0	123
	M						2	1				8	1	12	0	2	1	9	12
	F				109	219	409	829	503	124	296	556	142	3187	0	737	1456	994	3187
1993	# of Samples					1	3	5	5	3	4			21	0	4	13	4	21
	U					133								133	0	133	0	0	133
	M								4	19	19			42	0	0	23	19	42
	F						400	683	776	369	545			2773	0	400	1828	545	2773
1994	# of Samples						3	6	4	2				15	0	3	12	0	15
	U							134						134	0	0	134	0	134
	M						2	31	14					47	0	2	45	0	47
	F						423	758	649	262				2092	0	423	1669	0	2092

Table B4.6. Summary of estimated landings of US and Canada commercial fisheries by sex. Port samples from NMFS and MADMF were pooled. Estimated total weights by summation of estimated weights from sampled length frequency distributions. Estimated weights computed from length-weight regressions. Females  $W = \exp(-15.025) * L^{3.606935}$ , Males  $W = \exp(-13.002) * L^{3.097787}$  with weight in kg, length in cm. "Samples" = number of measured dogfish.

year	Composite (NMFS and MADMF) Biological Samples from Ports							Commercial Landings			Prorated Landings By Sex			
	Total Samples Males	Est Tot Wt (kg) Males	Ave Wt (kg) Males	Total Samples (females)	EstTot Wt (kg) females	Est Avg Wt (kg) females	Fraction Females by weight	US Commercial Landings (mt)	Canada Landings (mt)	Total Comm Landings (mt)	Est Landings (mt) of Males	Est. Landings (mt) of females	Number of Males Landed (000)	Number of Females Landed (000)
1988	7	14.8	2.114	1764	7561.4	4.287	0.9980	3105	0	3105	6.1	3098.9	2.9	722.9
1989	35	67.5	1.927	1375	5528.6	4.021	0.9879	4492	166	4658	56.1	4601.9	29.1	1144.5
1990	19	33.7	1.772	2230	8917.5	3.999	0.9962	14731	1316	16047	60.4	15986.6	34.1	3997.8
1991	23	37.8	1.643	1518	5924.5	3.903	0.9937	13177	292	13469	85.4	13383.6	52.0	3429.2
1992	12	22.3	1.861	3187	12181.9	3.822	0.9982	16858	829	17687	32.4	17654.6	17.4	4618.8
1993	42	78.4	1.866	2772	9923.1	3.580	0.9922	20643	1411	22054	172.8	21881.2	92.6	6112.5
1994	47	86.6	1.843	2091	6619.5	3.166	0.9871	18800	1819	20619	266.3	20352.7	144.5	6429.1
1995	25	38.9	1.555	2266	6677.3	2.947	0.9942	22711	948	23659	136.9	23522.1	88.1	7982.4
1996	569	886.7	1.558	1644	4398.0	2.675	0.8322	27241	416	27657	4640.3	23016.7	2977.8	8603.8
1997	303	449.1	1.482	382	780.9	2.044	0.6349	18352	446	18798	6863.4	11934.6	4630.5	5837.8
1998	68	85.4	1.257	683	1434.6	2.100	0.9438	20628	1079	21707	1220.2	20486.8	971.1	9753.4
1999	93	130.3	1.401	311	625.6	2.011	0.8276	14860	2467	17327	2986.8	14340.2	2131.9	7129.2
2000	405	561.2	1.386	5139	12157.9	2.366	0.9559	9257	2677	11934	526.5	11407.5	380.0	4821.8
2001	12	17.1	1.422	215	456.5	2.123	0.9640	2294	3755	6049	217.9	5831.1	153.3	2746.2
2002	65	97.6	1.501	1893	5065.8	2.676	0.9811	2195	3400	5595	105.7	5489.3	70.4	2051.2
formula	A	B	C=B/A	D	E	F=E/D	G=E/(E+B)	H	I	J=H+I	K=(1-G)*J	L=G*J	M=K/C	N=L/F

Table B4.7 Summary of species group assignments applied to landings records.

Lookup Table: Species Code

Sp Code	Group	Species Name	Sp Code	Group	Species Name	Sp Code	Group	Species Name
0	otherFish	UNKNOWN	268	otherFish	LADYFISH__	486	OtherSharks	SHARK_NIGHT__
1	otherFish	ALEWIFE	269	prin ground	POLLOCK__	487	OtherSharks	SHARK_BLACK_TIP__
3	otherFish	AMBER JACK	272	otherFish	POMPANO_COMMON__	488	OtherSharks	SHARK_SPINNER__
6	otherFish	BAY_ANCHOVY	305	otherFish	SALMON_ATLANTIC__	489	OtherSharks	SHARK_BULL__
12	monk	ANGLER	309	otherFish	SALMON_UNCL__	490	OtherSharks	SHARK_WHITETIP_OC__
18	otherFish	BARRACUDA	311	otherFish	PERCH_SAND__	491	OtherSharks	SHARK_TIGER__
19	otherFish	NEEDLEFISH_Atlantic	326	otherFish	SCULPINS__	492	OtherSharks	SHARK_LEMON__
23	otherFish	BLUEFISH	327	otherFish	SEA_RAVEN__	493	OtherSharks	SHARK_BLUE__
24	otherFish	SQUIRRELFISH	329	scupSeaBass	SCUP__	494	OtherSharks	SHARK_ATL_SHARPNOSE__
25	otherFish	SQUIRRELFISH	330	otherFish	PORGY_RED__	495	OtherSharks	SHARK_HAMMERHEAD__
27	otherFish	BARRELFISH	331	otherFish	SCAD_ROUGH__	496	OtherSharks	SHARK_BASKING__
33	otherFish	BONITO	332	otherFish	SCAD_ROUGH__	497	OtherSharks	SHARK_LARGE_COASTAL__
45	otherFish	BULLHEADS	333	otherFish	SCAD_ROUGH__	498	OtherSharks	SHARKS_PELAGIC__
51	squidbutterfish	BUTTERFISH	335	scupSeaBass	SEA_BASS_BLACK__	499	OtherSharks	SHARK_FINETOOTH__
57	otherFish	COBIA	336	otherFish	SNAPPER__	501	OtherSharks	SHARK_SMALL_COASTAL__
63	otherFish	CARP	340	otherFish	SNAPPER__	502	OtherSharks	SHARK RIDGEBACK_LG__
66	otherFish	CATFISH	341	otherFish	SEA_ROBINS__	506	OtherFish	PERCH_WHITE__
81	prin ground	COD	342	otherFish	SEA_ROBINS__	507	smallmeshground	BLK_WHTNG&SLHAKE_MIX__
84	otherFish	CRAPPIE	343	otherFish	SEA_ROBINS__	508	smallmeshground	WHITING_BLACK__
87	otherFish	CREVALLE	344	otherFish	WEAKFISH_SQUETEAGUE__	509	smallmeshground	HAKE_SILVER__
90	otherFish	CROAKER_ATLANTIC	345	otherFish	WEAKFISH_SPOTTED__	512	OtherFish	WOLFFISHES__
93	otherFish	CUNNER	346	OtherSharks	DOGFIH_CHAIN__	513	OtherFish	WRECKFISH__
96	otherFish	CUSK	347	otherFish	SHAD_AMERICAN__	517	OtherFish	PERCH_YELLOW__
98	otherFish	RIBBONFISH	348	OtherSharks	SHARK_NURSE__	524	OtherFish	OTHER GRNDFISH__
104	otherFish	DRUM_NK	349	OtherSharks	SHARK_SAND_TIGER__	525	mollusk	OTHER_PELAGICS__
105	otherFish	DOLPHIN_FISH	350	dogfish	DOGFIH_(NK)	526	mollusk	OTHER_FISH__
106	otherFish	DRUM_BLACK	351	OtherSharks	DOGFIH_SMOOTH__	529	mollusk	OTHER_FISH__
107	otherFish	DRUM_RED	352	dogfish	DOGFIH_SPINY__	700	crustacean	CRAB_BLUE__
112	pelagics	HERRING_BLUE_BACK	353	OtherSharks	SHARK_THRESHER__	701	crustacean	CRAB_LADY__
114	pelagics	HERRING_BLUE_BACK	354	OtherSharks	SHARK_THRESHR_BGEYE__	702	crustacean	CRAB_HERMIT__
115	otherFish	EEL_AMERICAN	355	OtherSharks	SHARK_MAKO_SHORTFIN__	708	crustacean	CRAB_GREEN__
116	otherFish	EEL_CONGER	356	otherFish	SHEEPSHEAD__	710	crustacean	CRAB_RED__
117	otherFish	EEL_CONGER	357	OtherSharks	SHARK_MAKO__	711	crustacean	CRAB_JONAH__
120	flatfish	FLOUNDER_WINTER	358	OtherSharks	SHARK_MAKO_LONGFIN__	712	crustacean	CRAB_ROCK__
121	flake 4spot	FLOUNDER_SUMMER	359	OtherSharks	SHARK_NK__	713	crustacean	713_CRAB_NK__
122	flatfish	FLOUNDER_WITCH	362	otherFish	SILVERSIDE_ATLANTIC__	714	crustacean	CRAB_CANCER__
123	flatfish	FLOUNDER_YELLOWTAIL	365	skates	SKATES__	716	crustacean	CRAB_CANCER__
124	flatfish	FLOUNDER_AM_PLAICE	366	skates	SKATE_LITTLE__	718	crustacean	CRAB_QUEEN_SNOW__
125	flatfish	FLOUNDER_SAND-DAB	367	skates	SKATE_BIG__	724	crustacean	CRAB_HORSESHOE__
126	flatfish	FLOUNDERS_(NK)	368	skates	SKATE_BARNDOOR__	727	crustacean	LOBSTER__
127	flake 4spot	FLOUNDER_FOURSPOT	369	skates	SKATE_BARNDOOR__	733	crustacean	SHRIMP_ROYAL_RED__
128	flatfish	HOGCHOCKER	371	otherFish	SMELT__	735	crustacean	SHRIMP_(NK)
130	flatfish	FLOUNDER_SOUTHERN	374	otherFish	SNAPPER_VERMILLION__	736	crustacean	SHRIMP_(PANDALID)
132	otherFish	MACKEREL_FRIGATE	375	otherFish	SNAPPER_DOG__	737	crustacean	SHRIMP_(MANTIS)
133	otherFish	GARFISH	376	otherFish	SNAPPER_RED__	738	crustacean	SHRIMP_(PENAEID)
134	otherFish	GIZZARD_SHAD	381	otherFish	SPADEFISH__	743	mollusk	743_CLAM_BLOODARC__
138	otherFish	RN_GRENADIER	384	otherFish	MACKEREL_SPAN__	748	mollusk	QUAHOG__
141	otherFish	GROUPE_SNOWY	385	otherFish	ESCOLAR__	754	mollusk	QUAHOG_OCEAN__
142	otherFish	GROUPE_SNOWY	406	otherFish	SPOT__	760	mollusk	CLAM_RAZOR__
144	otherFish	GRUNTS	415	otherFish	TROUT_STEELHEAD__	763	mollusk	763_CLAM_SOFT__
145	otherFish	GRUNTS	418	stripedbass	BASS_STRIPED__	764	mollusk	CLAM_NK__
146	otherFish	GRUNTS	420	sturgeon	STURGEON_ATLANTIC__	765	mollusk	CLAM_SURF_ARTIC__
147	prin ground	HADDOCK	421	sturgeon	STURGEONS__	769	mollusk	CLAM_SURF__
150	otherFish	HAGFISH	422	sturgeon	STURGEON_SHORT-NOSE__	775	mollusk	CONCHS__
152	smallmeshground	HAKE_RED	423	otherFish	SUCKERS__	776	mollusk	WHELK_CHANNELED__
153	prin ground	HAKE_WHITE	426	otherFish	SUNFISHES__	777	mollusk	WHELK_KNOBBED__
155	prin ground	HAKE_MIX_RED_&_WHITE	429	otherFish	PUFFER_NORTHERN__	778	mollusk	WHELK_LIGHTNING__
158	flatfish	HALIBUT_GREENLAND	432	LargePelagic	SWORDFISH__	781	mollusk	MUSSELS__
159	flatfish	HALIBUT_ATLANTIC	435	otherFish	TARPON__	786	mollusk	OCTOPUS__
165	otherFish	HARVEST_FISH	438	otherFish	TAUTOG__	789	mollusk	OYSTERS__
167	AtlHerring	HERRING_(NK)	444	otherFish	TILEFISH_BLUELINS__	792	mollusk	OYSTER_EUROPEAN_FLT__
168	AtlHerring	HERRING_ATLANTIC__	445	otherFish	TILEFISH_SAND__	795	mollusk	SCALLOP_ICELANDIC__
171	otherFish	ARGENTINE__	446	otherFish	TILEFISH_GOLDEN__	796	mollusk	SCALLOPS_NK__
173	otherFish	SHAD_HICKORY__	447	otherFish	TILEFISH__	798	mollusk	PERIWINKLES__
179	otherFish	HOGFISH__	451	otherFish	TOADFISH_OYSTER__	799	mollusk	SCALLOP_BAY__
188	otherFish	JOHN_DORY__	453	otherFish	TOM_COD__	800	scallops	SCALLOP_SEA__

Table B4.8. Summary of gear codes group assignments.

Gear code	Gear Name
0	other
10	hook
20	other
21	hook
30	other
31	other
34	other
40	hook
41	other
50	trawl
51	trawl
52	trawl
55	trawl
56	trawl
58	shrimptrawl
59	trawl
60	other
61	other
62	other
64	other
65	other
66	other
70	other
71	other
80	other
90	other
91	other
100	gillnet
101	gillnet
102	gillnet
103	gillnet
105	gillnet
110	gillnet
112	gillnet
115	gillnet
116	gillnet
119	gillnet

Gear code	Gear Name
120	other
121	other
122	other
123	other
124	other
131	dredge
132	dredge
140	other
141	other
142	other
143	other
160	other
170	other
180	other
181	other
182	other
183	other
184	other
185	other
186	other
190	other
200	other
201	other
202	other
203	other
204	other
205	other
206	other
210	other
211	other
212	other
220	other
221	other
222	other
223	other
230	other
231	other

Gear code	Gear Name
240	other
250	other
251	other
252	other
253	other
254	other
260	other
270	other
281	other
282	other
290	other
300	other
301	other
310	other
320	other
322	other
323	other
330	other
331	other
332	other
340	other
350	other
351	other
360	other
370	other
380	other
381	dredge
382	dredge
383	dredge
384	other
385	other
386	other
387	other
400	dredge
410	other
411	other
412	other

Gear code	Gear Name
413	other
414	other
420	other
430	other
500	other
510	other
520	other
525	other
530	other
563	other
999	other



Table B4.9. Master table of catch ratio based estimates of spiny dogfish discards by target species group and gear types for fishing years 1988-2002

Table updated 5/21/03

Fishing Year	target sp	gear Data									Total Sum of Ntrips	Total Sum of Total Discards in mt	Total Sum of Var Total Discards (mt^2)	SE (mt)	CV
		gillnet			hook			trawl							
		Sum of Ntrips	Sum of Total Discards in mt	Sum of Var Total Discards (mt^2)	Sum of Ntrips	Sum of Total Discards in mt	Sum of Var Total Discards (mt^2)	Sum of Ntrips	Sum of Total Discards in mt	Sum of Var Total Discards (mt^2)					
1988	AtlHerring	0	0	0				0	0	0	0	0	0	0	0
	crustacean	0	0	0				1	0	0	1	0	0	0	0
	dogfish	0	0	0				0	0	0	0	0	0	0	0
	flatfish	0	0	0	0	0	0	6	2910	1234508	6	2910	1234508	1111	0.382
	fluke 4spo	0	0	0				4	4076	4415033	4	4076	4415033	2101	0.515
	mackerel	0	0	0				1	55616	0	1	55616	0	0	0.000
	menhaden	0	0	0				0	0	0	0	0	0	0	0
	monk	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	prin ground	0	0	0	0	0	0	9	289	35641	9	289	35641	189	0.654
	scupSeaB	0	0	0				1	0	0	1	0	0	0	0
	skates	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	smallmesh	0	0	0	0	0	0	6	3043	9848315	6	3043	9848315	3138	1.031
	squidbutter	0	0	0				6	564	73754	6	564	73754	272	0.481
1988 Total		0	0	0	0	0	0	34	66498	15607251	34	66498	15607251	3951	0.059
1989	AtlHerring	0	0	0	0	0	0	6	41	302	6	41	302	17	0.426
	crustacean	0	0	0				3	0	1	3	0	1	1	1.811
	dogfish	5	855	671303	0	0	0	6	234	659	11	1089	671962	820	0.753
	flatfish	20	0	0	0	0	0	47	17103	21574755	67	17103	21574755	4645	0.272
	fluke 4spo	0	0	0	0	0	0	5	56	977	5	56	977	31	0.560
	mackerel	2	2	0	0	0	0	2	2516	9305255	4	2518	9305255	3050	1.212
	menhaden	0	0	0				0	0	0	0	0	0	0	0
	monk	4	1476	730852	0	0	0	5	6789	51652808	9	8265	52383660	7238	0.876
	prin ground	110	4394	1166154	0	0	0	33	4277	1761540	143	8671	2927694	1711	0.197
	scupSeaB	0	0	0	0	0	0	4	3540	2224566	4	3540	2224566	1491	0.421
	skates	0	0	0	0	0	0	5	370	313141	5	370	313141	560	1.514
	smallmesh	0	0	0	0	0	0	41	4585	9146276	41	4585	9146276	3024	0.660
	squidbutter	0	0	0				25	4000	9246438	25	4000	9246438	3041	0.760
1989 Total		141	6727	2568309	0	0	0	182	43509	105226718	323	50236	107795027	10382	0.207
1990	AtlHerring	0	0	0				1	0	0	1	0	0	0	0
	crustacean	0	0	0	0	0	0	4	2	5	4	2	5	2	1.230
	dogfish	10	1344	237682	0	0	0	3	8977	731969	13	10321	969651	985	0.095
	flatfish	22	10	85	0	0	0	30	10420	19482803	52	10430	19482888	4414	0.423
	fluke 4spo	0	0	0	0	0	0	6	3748	3755259	6	3748	3755259	1938	0.517
	mackerel	1	0	0	0	0	0	6	1204	1034466	7	1204	1034466	1017	0.845
	menhaden	0	0	0				0	0	0	0	0	0	0	0
	monk	1	0	0	0	0	0	1	215	0	2	215	0	0	0.000
	pelagics							0	0	0	0	0	0	0	0
	prin ground	84	4612	2697424	1	0	0	30	16808	70395658	115	21420	73093082	8549	0.399
	scupSeaB	0	0	0	0	0	0	8	4792	4705811	8	4792	4705811	2169	0.453
	skates	0	0	0	0	0	0	10	134	8492	10	134	8492	92	0.687
	smallmesh	0	0	0	0	0	0	29	1286	258634	29	1286	258634	509	0.396
	squidbutter	0	0	0	0	0	0	15	36016	1666581822	15	36016	1666581822	40824	1.134
1990 Total		118	5967	2935191	1	0	0	143	83600	1766954920	262	89567	1769890111	42070	0.470

1991	AtlHerring	3	32	1229				2	294	0	5	326	1229	35	0.108
	crustacean	0	0	0	0	0	0	6	0	0	6	0	0	0	0.798
	dogfish	163	1589	515108	0	0	0	7	14367	71710917	170	15956	72226025	8499	0.533
	flatfish	87	592	41738	0	0	0	52	9211	26972910	139	9803	27014648	5198	0.530
	fluke 4spo	0	0	0	0	0	0	24	4564	2206170	24	4564	2206170	1485	0.325
	mackerel	2	0	0	0	0	0	2	3342	29134132	4	3342	29134132	5398	1.615
	menhaden	3	15	278				0	0	0	3	15	278	17	1.112
	monk	51	469	4399	0	0	0	13	1192	883693	64	1661	888092	942	0.567
	pelagics							1	0	0	1	0	0	0	
	prin ground	777	8334	1153238	35	1367	528324	45	10178	9644328	857	19879	11325889	3365	0.169
	scupSeaBa	0	0	0	0	0	0	4	29532	503848575	4	29532	503848575	22447	0.760
	skates	2	94	0	0	0	0	12	622	70781	14	716	70781	266	0.371
	smallmesh	0	0	0	2	0	0	54	946	106723	56	946	106723	327	0.345
	squidbutte	0	0	0				42	2944	2510440	42	2944	2510440	1584	0.538
1991 Total		1088	11125	1715989	37	1367	528324	264	77193	647088669	1389	89685	649332981	25482	0.284
1992	AtlHerring	0	0	0				1	0	0	1	0	0	0	
	crustacean	3	0	0				10	0	0	13	0	0	0	0.061
	dogfish	162	3492	6365059	0	0	0	2	1857	323261	164	5349	6688320	2586	0.483
	flatfish	104	73	3089	0	0	0	11	743	444048	115	816	447138	669	0.820
	fluke 4spo	0	0	0	0	0	0	14	2154	224194	14	2154	224194	473	0.220
	mackerel	13	2	2	0	0	0	3	594	99914	16	596	99916	316	0.530
	menhaden	0	0	0				0	0	0	0	0	0	0	
	monk	52	96	606	0	0	0	5	1	1	57	96	607	25	0.256
	pelagics							0	0	0	0	0	0	0	
	prin ground	773	4002	192509	0	0	0	27	6398	14188876	800	10400	14381385	3792	0.365
	scupSeaBa	1	2	0	0	0	0	0	0	0	1	2	0	0	0.000
	skates	3	24	0	0	0	0	7	11230	25018475	10	11253	25018475	5002	0.444
	smallmesh	1	0	0	0	0	0	46	1506	549887	47	1506	549887	742	0.493
	squidbutte	0	0	0	0	0	0	16	4571	3501286	16	4571	3501286	1871	0.409
1992 Total		1112	7691	6561265	0	0	0	142	29053	44349944	1254	36744	50911208	7135	0.194
1993	AtlHerring	0	0	0	0	0	0	4	0	0	4	0	0	0	
	crustacean	7	0	0				5	233	90907	12	234	90907	302	1.290
	dogfish	118	1962	257956	0	0	0	4	383	3010	122	2345	260966	511	0.218
	flatfish	91	18	48	0	0	0	14	1302	790364	105	1320	790413	889	0.674
	fluke 4spo	0	0	0	0	0	0	15	1201	253507	15	1201	253507	503	0.419
	mackerel	7	1	0	0	0	0	2	66	2154	9	67	2154	46	0.693
	menhaden	2	47	4159				0	0	0	2	47	4159	64	1.368
	monk	54	626	326733	0	0	0	5	616	12	59	1242	326745	572	0.460
	pelagics	1	0	0							1	0	0	0	
	prin ground	459	2902	282835	0	0	0	25	2754	1310655	484	5657	1593490	1262	0.223
	scupSeaBa	0	0	0	0	0	0	4	8851	78590488	4	8851	78590488	8865	1.002
	skates	7	14	26	0	0	0	7	42	120	14	56	146	12	0.216
	smallmesh	0	0	0	0	0	0	31	914	138157	31	914	138157	372	0.406
	squidbutte	0	0	0	0	0	0	16	2254	1058246	16	2254	1058246	1029	0.456
1993 Total		746	5571	871758	0	0	0	132	18618	82237620	878	24188	83109378	9116	0.377
1994	AtlHerring	2	10	12	0	0	0	0	0	0	2	10	12	3	0.333
	crustacean	10	0	0	0	0	0	7	2	1	17	2	1	1	0.666
	dogfish	317	754	8923	0	0	0	5	2010	506037	322	2764	514960	718	0.260
	flatfish	164	0	0	0	0	0	13	785	656711	177	785	656711	810	1.033
	fluke 4spo	0	0	0	0	0	0	22	1219	365002	22	1219	365002	604	0.496
	mackerel	5	57	683	0	0	0	0	0	0	5	57	683	26	0.459
	menhaden	6	0	0				0	0	0	6	0	0	0	
	monk	151	254	27179	0	0	0	11	24	176	162	278	27354	165	0.595
	pelagics	10	0	0				0	0	0	10	0	0	0	
	prin ground	647	74	573	3	204	4604	20	1490	373392	670	1767	378569	615	0.348
	scupSeaBa	0	0	0	0	0	0	1	1632	0	1	1632	0	0	0.000
	skates	18	86	4984	0	0	0	3	2357	7527849	21	2443	7532833	2745	1.123
	smallmesh	1	0	0	0	0	0	1	50	0	2	50	0	0	0.000
	squidbutte	0	0	0	0	0	0	12	6384	7269159	12	6384	7269159	2696	0.422
1994 Total		1331	1235	42353	3	204	4604	95	15952	16698326	1429	17390	16745284	4092	0.235





Table B4.10. Summary of catch-based ratio estimates of dogfish discards by gear group and fishing year. All species groups included.

Fishing Year	gillnet			hook			trawl			Gill net + Hook + Trawl				USA+ Canada+ Recreational Landings
	Sum of Ntrips	Sum of Total Discards in mt gillnet	SE of Total Discards	Sum of Ntrips	Sum of Total Discards in mt Hook	SE of Total Discards	Sum of Ntrips	Sum of Total Discards in mt Trawl	SE of Total Discards	Total Sum of Ntrips	Total Sum of Total Discards in mt	SE of Total Discards	CV total	
1988	0	0	0	0	0	0	34	66498	3951	34	66498	3951	0.059	4987
1989	141	6727	1603	0	0	0	182	43509	10258	323	50236	10382	0.207	6676
1990	118	5967	1713	1	0	0	143	83600	42035	262	89567	42070	0.470	17788
1991	1088	11125	1310	37	1367	727	264	77193	25438	1389	89685	25482	0.284	15183
1992	1112	7691	2561	0	0	0	142	29053	6660	1254	36744	7135	0.194	18987
1993	746	5571	934	0	0	0	132	18618	9068	878	24188	9116	0.377	23311
1994	1331	1235	206	3	204	68	95	15952	4086	1429	17390	4092	0.235	21744
1995	1058	2248	511	1	646	0	205	17477	3850	1264	20371	3884	0.191	24365
1996	998	1327	304	1	0	0	211	26218	3096	1210	27545	3111	0.113	28279
1997	939	425	58	0	0	0	80	11947	8266	1019	12371	8266	0.668	19825
1998	879	421	98	0	0	0	58	7990	2199	937	8411	2202	0.262	22962
1999	747	444	125	0	0	0	166	6758	1511	913	7203	1517	0.211	18466
2000	849	1228	320	4	171	49	256	5518	1092	1109	6917	1139	0.165	13036
2001	578	1005	293	0	0	0	267	12465	2971	845	13471	2985	0.222	8468
2002	380	1730	434	9	1789	1308	382	6471	1511	771	9990	2045	0.205	7518
Grand Total	10964	47143	3931	56	4177	1498	2617	429268	52824	13637	480588	52991	0.110	

Table B4.11. Projected dead discards of spiny dogfish by fishing year. Fraction dead by gear type= 0.75 gill nets, 0.50 trawls, 0.25 Hook gear.  
Standard error computation assumes that coefficient of variation remains constant.

Fishing Year	Gill Net			Hook			Trawl			Gill net + Hook + Trawl			
	Sum of Trips	Dead Discards (mt)	SE (mt)	Sum of Trips	Dead Discards (mt)	SE (mt)	Sum of Trips	Dead Discards (mt)	SE (mt)	Sum of Trips	Dead Discards (mt)	SE (mt)	CV
1988	0	0	0	0	0	0	34	33249	1975	34	33249	1975	0.059
1989	141	5045	1202	0	0	0	182	21755	5129	323	26800	5268	0.197
1990	118	4475	1285	1	0	0	143	41800	21018	262	46275	21057	0.455
1991	1088	8344	982	37	342	182	264	38596	12719	1389	47282	12758	0.270
1992	1112	5768	1921	0	0	0	142	14527	3330	1254	20294	3844	0.189
1993	746	4178	700	0	0	0	132	9309	4534	878	13487	4588	0.340
1994	1331	926	154	3	51	17	95	7976	2043	1429	8953	2049	0.229
1995	1058	1686	383	1	162	0	205	8738	1925	1264	10586	1963	0.185
1996	998	995	228	1	0	0	211	13109	1548	1210	14104	1565	0.111
1997	939	318	44	0	0	0	80	5973	4133	1019	6292	4133	0.657
1998	879	316	74	0	0	0	58	3995	1100	937	4311	1102	0.256
1999	747	333	94	0	0	0	166	3379	756	913	3713	762	0.205
2000	849	921	240	4	43	12	256	2759	546	1109	3723	596	0.160
2001	578	754	220	0	0	0	267	6233	1485	845	6987	1501	0.215
2002	380	1298	326	9	447	327	382	3236	756	771	4981	885	0.178
Grand Total	10964	35358		56	1044		2617	214634		13637	251036	64047	

mean 16736  
min 3713  
max 47282

Table B4.12. Sum of discard estimates (mt) based on trip ratio method.

Year	Dredge	Other	Shrimp Trawls	Hook Gear	Gill Nets	Trawls	Gill Net + Trawl	All Gear	USA Comm Landings (mt)	USA+ Canada+ Recreational
1989	0	0	19	0	6557	27283	33840	33859	4491	6676
1990	0	0	0	0	3495	43181	46676	46676	14742	17788
1991	728	26	3	1580	11984	35497	47481	49818	13154	15183
1992	2310	6763	0	1651	4278	53037	57315	68039	16874	18987
1993	1452	21	0	7	5443	31465	36907	38388	21228	23311
1994	3283	4	23	59	905	66885	67790	71159	18779	21744
1995	1553	135	6	699	1642	28816	30458	32851	21591	24365
1996	605	0	0	0	1464	15859	17324	17929	26944	28279
1997	1177	116	0	0	1489	28072	29561	30854	20412	19825
1998	497	27	0	0	889	23777	24666	25189	21500	22962
1999	107	497	0	0	545	8942	9487	10091	15377	18466
2000	770	19599	0	1249	1305	8563	9869	31487	9571	13036
2001	801	9001	0	0	1051	10494	11544	21347	2294	8468
2002	158	21783	0	5344	1639	10146	11785	39071	2136	7518

Table B4.13. Summary of total number of trips by commercial fishing vessels by year.

Sum of NTRIPS	GearName						
YEAR2	dredge	gillnet	hook	other	shrimptrawl	trawl	Grand Total
1989	23,463	16,081	3,674	23,880	9,113	35,987	112,198
1990	26,266	17,483	4,410	28,955	8,971	35,540	121,624
1991	28,710	18,549	6,340	31,006	7,227	36,997	128,829
1992	28,353	18,833	6,031	30,063	7,119	36,857	127,256
1993	27,908	25,209	5,493	40,432	5,864	37,473	142,379
1994	19,740	30,088	5,486	53,211	7,222	41,803	157,550
1995	14,905	29,196	6,921	53,920	10,309	45,885	161,136
1996	17,808	36,404	4,466	58,235	12,345	47,048	176,306
1997	20,915	50,321	5,236	91,492	13,127	47,274	228,366
1998	21,767	41,248	5,773	89,748	8,330	51,409	218,276
1999	14,051	30,263	3,463	67,436	4,970	33,524	153,707
2000	70,813	34,795	3,687	82,465	6,909	46,906	245,575
2001	78,528	31,104	3,922	79,769	3,617	47,940	244,880
2002	11,125	34,771	3,389	85,605	2,444	45,989	183,323
Grand Total	404,352	414,345	68,291	816,217	107,568	590,632	2,401,405



Table B5.1. Stratified mean number per tow indices for spiny dogfish from NEFSC spring (1968-2000) and autumn (1967-1999) bottom trawl surveys (offshore strata 1-30, 33-40, 61-76; Footnotes A-D).

	Spring			Autumn				
	Unsexed Male	Female	Total	Unsexed Male	Female	Total		
1967				34.0		34.0		
1968	24.3		24.3	19.7		19.7		
1969	13.3		13.3	27.7		27.7		
1970	15.3		15.3	16.6		16.6		
1971	15.9		15.9	12.9		12.9		
1972	27.6		27.6	10.5		10.5		
1973	35.6		35.6	15.0		15.0		
1974	39.1		39.1	4.7		4.7		
1975	35.4		35.4	17.7		17.7		
1976	23.1		23.1	14.9		14.9		
1977	13.1		13.1	6.8		6.8		
1978	22.5		22.5	26.0		26.0		
1979	10.1		10.1	22.0		22.0		
1980	6.1	12.9	10.0	29.0	0.0	1.4	3.8	5.1
1981	0.5	18.2	23.0	41.7	0.0	36.0	39.7	75.7
1982		23.7	27.8	51.6		6.9	6.8	13.7
1983	0.0	23.6	18.1	41.7	0.0	14.3	18.0	32.4
1984		13.3	9.2	22.5		10.6	11.9	22.5
1985	0.0	80.2	37.1	117.3	0.0	19.0	19.7	38.7
1986		9.5	19.3	28.7		12.3	15.2	27.4
1987		39.3	25.8	65.1		16.5	16.3	32.8
1988	0.0	29.5	35.1	64.6		15.5	19.9	35.3
1989		29.6	27.1	56.7		6.7	6.0	12.8
1990		47.8	44.0	91.8		14.7	11.5	26.1
1991		32.3	30.0	62.3		20.9	17.4	38.4
1992		38.2	41.3	79.5		12.9	26.2	39.1
1993		32.6	28.3	60.9		4.5	2.4	6.9
1994		53.4	38.1	91.5		16.6	14.2	30.9
1995		25.8	25.0	50.8		16.9	13.7	30.6
1996		52.6	44.6	97.3		12.8	20.1	32.8
1997		29.6	29.1	58.7		17.6	10.4	27.9
1998		32.4	11.1	43.5		8.8	13.2	22.0
1999		35.4	21.4	56.8		9.2	8.7	17.9
2000	0.3	22.2	15.4	37.9		17.1	5.7	22.8
2001		20.3	10.9	31.2		16.5	18.5	35.0
2002		32.2	18.7	50.9		15.8	15.4	31.2
2003		32.5	17.5	49.9				

A. 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 adjustments have been made because no significant difference was found between the two types of doors for spiny dogfish (NEFSC 1991)

B. Spring surveys from 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. A factor of 0.71 was applied to all tows in these years (Sissenwine and Bowman, 1978).

C. During the fall of 1970, 1975, 1978, 1979, 1980, 1981, 1985, 1986, 1988, 1989, 1990, 1991, and 1993 and the springs of 1973, 1976, 1977, 1979, 1980, 1981, 1982, 1987, 1989, 1990, 1991, and 1994 the Delaware II was used entirely or in part to conduct the survey. All other years, the Albatross IV was the only vessel used for the survey. A factor of 0.79 was applied to all Delaware II tows (NEFSC 1991).

D. During the spring of 2003, the Delaware II was used to conduct the survey. Since the vessel was remodeled in 1995, it was unclear whether the conversion factors applied in earlier years were still appropriate. Therefore no conversion factor was applied.

Table B5.2. Stratified mean weight per tow (kg) indices for spiny dogfish from NEFSC spring (1968-2002) and autumn (1967-2002) bottom trawl surveys (offshore strata 1-30, 33-40, 61-76; Footnotes A-E).

	Spring			Autumn				
	Unsexed Male	Female	Total	Unsexed Male	Female	Total		
1967				34.9		34.9		
1968	25.8		25.8	22.4		22.4		
1969	16.1		16.1	55.3		55.3		
1970	13.3		13.3	23.8		23.8		
1971	24.0		24.0	15.5		15.5		
1972	49.0		49.0	16.1		16.1		
1973	57.1		57.1	21.7		21.7		
1974	67.0		67.0	8.1		8.1		
1975	45.6		45.6	20.9		20.9		
1976	37.0		37.0	19.8		19.8		
1977	24.1		24.1	16.1		16.1		
1978	36.3		36.3	19.3		19.3		
1979	13.4		13.4	26.6		26.6		
1980	13.4	34.2	1.6	49.1	0.0	4.0	15.1	19.1
1981	0.6	20.4	48.2	69.2	0.0	12.7	34.9	47.6
1982		31.1	86.0	117.0		5.2	9.7	14.9
1983	0.0	21.1	17.7	38.9	0.0	13.7	22.1	35.8
1984		19.3	23.0	42.4		8.7	13.9	22.5
1985	0.0	100.4	66.7	167.1	0.0	14.6	25.0	39.7
1986		5.8	39.0	44.9		13.4	23.7	37.1
1987		40.6	61.7	102.3		10.6	11.2	21.8
1988	0.0	26.9	77.4	104.4		15.3	24.3	39.6
1989		34.8	43.1	77.8		6.1	5.5	11.5
1990		60.6	89.2	149.8		14.9	14.9	29.8
1991		36.5	53.0	89.5		24.6	26.7	51.3
1992		44.8	70.1	114.9		14.1	41.6	55.7
1993		35.7	52.2	87.9		5.1	2.1	7.2
1994		49.9	35.3	85.1		18.5	14.2	32.8
1995		34.8	40.0	74.8		16.7	11.4	28.0
1996		59.0	60.5	119.5		14.4	26.7	41.1
1997		37.5	44.9	82.4		19.9	10.0	29.9
1998		43.4	15.5	58.9		10.7	21.6	32.3
1999		46.3	32.5	78.8		12.3	12.7	25.1
2000	0.4	29.7	29.2	59.4		25.5	9.2	34.7
2001		29.5	19.8	49.3		20.8	27.0	47.8
2002		42.9	32.2	75.0		22.2	25.2	47.4
2003		45.2	29.7	74.8				

A. 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 adjustments have been made because no significant difference was found between the two types of doors for spiny dogfish (NEFSC 1991)

min fem sp 15.5  
max fem sp 89.2  
mean fem : 46.4

B. Spring surveys from 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. A factor of 0.69 was applied to all tows in these years (Sissenwine and Bowman, 1978).

C. During the fall of 1970, 1975, 1978, 1979, 1980, 1981, 1985, 1986, 1988, 1989, 1990, 1991, and 1993 and the springs of 1973, 1976, 1977, 1979, 1980, 1981, 1982, 1987, 1989, 1990, 1991, and 1994 the Delaware II was used entirely or in part to conduct the survey. All other years, the Albatross IV was the only vessel used for the survey. A factor of 0.81 was applied to all Delaware II tows (NEFSC 1991).

D. During the spring of 2003, the Delaware II was used to conduct the survey. Since the vessel was remodeled in 1995, it was unclear whether the conversion factors applied in earlier years were still appropriate. Therefore no conversion factor was applied.

E. In 1980, dogfish were often measured and counted by sex but only one weight recorded. This weight was always recorded under males.

Table B5.3. Indices for spiny dogfish from NEFSC winter (1992-2002)  
(offshore strata 1-3, 5-7, 9-11, 13-14, 16, 61-63, 65-67, 69-71,73-75).

	Number/Tow			Weight/Tow		
	Male	Female	Total	Male	Female	Total
1992	123.9	74.7	198.7	168.3	172.6	340.9
1993	225.2	103.1	328.2	274.8	145.1	419.9
1994	154.9	153.1	308.1	169.8	219.7	389.5
1995	198.3	124.6	322.8	195.9	103.2	299.1
1996	87.6	48.3	135.9	116.2	76.1	192.2
1997	75.3	69.1	144.3	91.9	107.7	199.6
1998	76.1	43.5	119.6	101.6	62.8	164.4
1999	193.0	110.8	303.8	203.0	120.6	323.5
2000	102.1	39.6	141.7	129.8	53.6	183.4
2001	76.4	47.2	123.5	102.1	66.4	168.5
2002	144.3	65.4	209.7	192.7	115.3	308.1
2003	87.8	56.6	144.4	122.8	112.6	235.4

Table B5.4. Number per tow indices for spiny dogfish from the state of Massachusetts spring and autumn inshore bottom trawl surveys.

	Spring			Autumn		
	Unsexed Male	Female	Total	Unsexed Male	Female	Total
1978	10.9		10.9	149.1		149.1
1979	1.9		1.9	12.6		12.6
1980	1.7		1.7	0.0	0.1	4.7
1981	0.5	1.0	1.6	11.2	0.1	0.3
1982		0.0	2.0		8.2	45.9
1983		0.0	0.8		3.1	11.5
1984		1.4	5.5		51.1	17.4
1985		0.1	0.8		12.5	116.6
1986		0.1	2.2		45.2	77.9
1987		0.0	0.2		14.1	36.8
1988		1.5	11.5		34.0	181.9
1989		9.2	16.4		256.7	764.6
1990			2.3		16.3	41.5
1991		0.0	0.9		2.8	25.6
1992			2.2		51.4	67.6
1993		9.4	10.5		15.8	93.9
1994			0.2		18.7	1.3
1995		7.5	21.2		40.0	33.1
1996		0.0	0.0		14.2	21.1
1997		2.1	11.1		9.5	46.4
1998		0.8	3.0		3.4	19.4
1999		0.3	4.1		8.4	55.8
2000		0.1	1.0		1.3	13.9
2001		1.5	4.1		22.8	77.7
2002		0.0	4.4		9.6	49.0

Table B5.5. Weight per tow (kg) indices for spiny dogfish from the state of Massachusetts spring and autumn inshore bottom trawl surveys.

	Spring			Autumn			
	Unsexed Male	Female	Total	Unsexed Male	Female	Total	
1978	22.9		22.9	225.7		225.7	
1979	6.4		6.4	40.2		40.2	
1980	6.1		6.1	0.1	0.1	17.8	18.1
1981	2.6	4.3	6.9	44.9	0.2	1.3	46.4
1982		0.1	9.2	9.3	14.2	166.2	180.4
1983		0.0	3.2	3.3	5.0	35.6	40.6
1984		1.6	10.8	12.4	80.6	43.7	124.2
1985		0.1	3.4	3.5	18.0	297.5	315.5
1986		0.1	9.7	9.7	70.4	224.1	294.6
1987		0.0	0.9	0.9	20.9	105.3	126.2
1988		1.9	39.3	41.2	47.2	560.4	607.6
1989		4.8	14.0	18.9	328.9	1546.2	1875.1
1990			9.4	9.4	22.6	95.0	117.6
1991		0.0	4.5	4.5	3.4	80.7	84.1
1992			8.5	8.5	68.6	107.0	175.6
1993		10.4	19.5	29.9	23.3	211.7	235.0
1994			0.8	0.8	30.8	2.8	33.6
1995		9.5	34.1	43.7	59.6	63.6	123.2
1996		0.0	0.1	0.1	20.8	44.4	65.2
1997		2.4	20.5	22.9	13.5	87.2	100.7
1998		1.0	5.8	6.8	4.5	41.9	46.4
1999		0.4	8.5	8.8	12.9	116.0	128.9
2000		0.1	2.7	2.9	2.2	29.0	31.2
2001		2.4	9.3	11.7	31.2	157.8	189.0
2002		0.0	11.5	11.6	15.3	109.7	125.0

Table B6.1. Biomass estimates for spiny dogfish (thousands of metric tons) based on area swept by NEFSC trawl during spring surveys, 1968-2003.

Year	Lengths >= 80 cm			Lengths 36 to 79 cm			Length <= 35 cm			All Lengths
	Females	Males	Total	Females	Males	Total	Females	Males	Total	
1968			41.4			110.4			1.52	153.3
1969			27.4			69.3			0.66	97.3
1970			36.7			33.0			3.19	72.9
1971			103.8			27.6			2.76	134.2
1972			126.6			145.9			1.55	274.1
1973			178.7			165.3			2.58	346.5
1974			221.9			179.6			2.66	404.1
1975			105.1			125.0			3.97	234.0
1976			96.3			120.8			1.20	218.3
1977			77.3			68.0			0.53	145.9
1978			87.4			131.2			1.24	219.8
1979			52.3			18.6			1.82	72.7
1980	104.7	15.3	168.1	16.8	72.2	123.5	0.32	0.39	0.84	292.4
1981	266.5	24.4	293.8	25.5	75.1	100.6	2.14	2.80	5.06	399.5
1982	454.0	34.6	488.6	61.6	143.3	204.9	0.48	0.69	1.17	694.6
1983	77.7	30.1	107.8	36.7	98.5	135.3	3.09	3.95	7.03	250.1
1984	115.6	27.5	143.1	33.4	88.0	121.4	0.14	0.21	0.35	264.9
1985	317.0	125.5	442.6	102.5	502.5	605.0	4.01	5.10	9.10	1056.7
1986	191.3	3.5	194.8	51.9	29.6	81.5	0.84	1.11	1.96	278.2
1987	219.1	90.5	309.6	61.5	171.7	233.1	2.46	4.76	7.22	550.0
1988	433.1	26.2	459.4	93.3	153.6	247.0	0.89	1.09	1.98	708.4
1989	162.1	40.5	202.6	100.4	158.2	258.6	1.14	1.54	2.68	463.9
1990	400.3	70.7	471.0	163.5	303.1	466.6	0.68	1.03	1.71	939.3
1991	220.4	30.0	250.3	108.4	186.3	294.7	0.98	1.43	2.41	547.4
1992	280.5	41.9	322.4	179.9	231.9	411.8	0.73	1.00	1.73	735.9
1993	234.6	27.8	262.5	104.1	198.5	302.6	0.55	0.65	1.21	566.3
1994	105.3	37.1	142.4	108.3	254.2	362.5	4.28	5.54	9.82	514.8
1995	102.4	29.5	131.9	154.0	174.5	328.5	0.25	0.35	0.59	460.9
1996	196.5	33.4	229.9	201.7	334.8	536.4	0.98	1.14	2.12	768.5
1997	83.7	17.5	101.2	205.2	209.1	414.3	0.05	0.05	0.10	515.5
1998	26.7	22.9	49.7	69.0	236.4	305.4	0.05	0.08	0.13	355.2
1999	62.7	20.4	83.1	140.8	256.4	397.2	0.02	0.03	0.05	480.4
2000	85.8	11.7	97.5	91.5	166.2	257.7	0.07	0.09	0.16	355.4
2001	56.7	16.7	73.4	71.4	160.5	231.9	0.04	0.03	0.07	305.4
2002	75.2	19.0	94.2	131.5	246.3	377.8	0.06	0.06	0.12	472.1
2003	64.5	22.5	87.1	125.5	256.3	381.8	0.13	0.14	0.27	469.1

Notes: Total equals sum of males and females plus unsexed dogfish. Data for dogfish prior to 1980 are currently not available by sex.

Table B6.2. Biomass estimates for spiny dogfish (thousands of metric tons) based on area swept by NEFSC trawl during spring surveys, 1968-2003, adjusted for 0.012 nm sq footprint.

Year	Lengths >= 80 cm			Lengths 36 to 79 cm			Length <= 35 cm			All Lengths
	Females	Males	Total	Females	Males	Total	Females	Males	Total	
1968			34.5			92.0			1.26	127.8
1969			22.8			57.8			0.55	81.1
1970			30.6			27.5			2.66	60.8
1971			86.5			23.0			2.30	111.8
1972			105.5			121.6			1.29	228.4
1973			148.9			137.7			2.15	288.8
1974			184.9			149.7			2.22	336.8
1975			87.6			104.1			3.31	195.0
1976			80.3			100.7			1.00	181.9
1977			64.4			56.7			0.44	121.6
1978			72.8			109.3			1.04	183.2
1979			43.6			15.5			1.52	60.6
1980	87.2	12.7	140.1	14.0	60.2	102.9	0.27	0.33	0.70	243.7
1981	222.1	20.3	244.8	21.2	62.6	83.9	1.78	2.33	4.21	332.9
1982	378.3	28.8	407.1	51.3	119.4	170.7	0.40	0.57	0.97	578.8
1983	64.8	25.1	89.8	30.6	82.1	112.7	2.57	3.29	5.86	208.4
1984	96.3	22.9	119.3	27.9	73.3	101.2	0.11	0.18	0.29	220.7
1985	264.2	104.6	368.8	85.4	418.8	504.2	3.34	4.25	7.58	880.6
1986	159.4	3.0	162.3	43.2	24.6	67.9	0.70	0.93	1.63	231.8
1987	182.6	75.4	258.0	51.2	143.0	194.3	2.05	3.97	6.02	458.3
1988	361.0	21.8	382.9	77.8	128.0	205.8	0.74	0.91	1.65	590.4
1989	135.1	33.7	168.8	83.7	131.9	215.5	0.95	1.28	2.24	386.6
1990	333.6	58.9	392.5	136.2	252.6	388.8	0.57	0.86	1.43	782.7
1991	183.6	25.0	208.6	90.4	155.2	245.6	0.81	1.19	2.00	456.2
1992	233.8	34.9	268.6	149.9	193.2	343.2	0.61	0.83	1.44	613.2
1993	195.5	23.2	218.7	86.8	165.4	252.2	0.46	0.54	1.00	471.9
1994	87.8	30.9	118.7	90.2	211.9	302.1	3.57	4.62	8.19	429.0
1995	85.4	24.5	109.9	128.3	145.4	273.7	0.21	0.29	0.49	384.1
1996	163.7	27.8	191.6	168.1	279.0	447.0	0.82	0.95	1.77	640.4
1997	69.7	14.6	84.3	171.0	174.2	345.2	0.04	0.04	0.08	429.6
1998	22.3	19.1	41.4	57.5	197.0	254.5	0.04	0.06	0.11	296.0
1999	52.2	17.0	69.3	117.4	213.6	331.0	0.01	0.03	0.04	400.3
2000	71.5	9.7	85.9	76.2	138.5	214.8	0.06	0.07	0.13	300.9
2001	47.2	14.0	61.2	59.5	133.7	193.3	0.04	0.03	0.06	254.5
2002	62.6	15.8	78.5	109.5	205.3	314.8	0.05	0.05	0.10	393.4
2003	53.8	18.8	72.5	104.6	213.6	318.1	0.11	0.12	0.23	390.9

Notes: Total equals sum of males and females plus unsexed dogfish. Data for dogfish prior to 1980 are currently not available by sex.

Table B6.3. Number of female spiny dogfish examined by year and season  
(T = total number examined, FE = Number with free embryos).

		1998	1999	2000	2001	2002	Total
Winter	T	246	552	497	726	301	2322
	FE	59	132	84	110	42	427
Spring	T	283	926	786	582	557	3134
	FE	60	167	96	69	70	462
Autumn	T	391	505	416	713		2025
	FE	115	162	51	73		401
Total	T	920	1983	1699	2021	858	7481
	FE	234	461	231	252	112	1291



Table B7.1 Summary of 3yr moving average survey mean numbers per tow and SE for female and male dogfish caught in the NEFSC spring survey.

All offshore strata included.

<<<<<FEMALES>>>>>

Spring data All offshore strata

Sex	year	mean	variance	SE	CV	Pop Var	Pop	Var(pop)	Low CI	High CI	3-yrMean	3-yrVar	3-yr SE	3-yrCV
Females	1980	10.015	5.04E+00	2.25E+00	22.4	2.00E+03	6.49E+07	2.11E+14	5.615	14.415				
Females	1981	22.993	2.24E+01	4.74E+00	20.6	1.81E+04	1.49E+08	9.36E+14	13.71	32.275				
Females	1982	27.845	8.65E+01	9.30E+00	33.4	2.83E+04	1.80E+08	3.63E+15	9.617	46.074	20.28433	3.80E+01	6.163497	30.38551
Females	1983	18.075	1.70E+01	4.13E+00	22.8	1.34E+04	1.17E+08	7.15E+14	9.986	26.164	22.971	4.20E+01	6.479686	28.20812
Females	1984	9.155	3.13E+00	1.77E+00	19.3	1.19E+03	5.93E+07	1.31E+14	5.689	12.62	18.35833	3.56E+01	5.962519	32.47854
Females	1985	37.114	1.21E+02	1.10E+01	29.6	3.37E+04	2.40E+08	5.08E+15	15.552	58.675	21.448	4.71E+01	6.860002	31.98435
Females	1986	19.256	9.12E+00	3.02E+00	15.7	5.16E+03	1.25E+08	3.83E+14	13.335	25.176	21.84167	4.44E+01	6.665103	30.51554
Females	1987	25.824	4.15E+01	6.44E+00	24.9	1.27E+04	1.66E+08	1.71E+15	13.203	38.444	27.398	5.72E+01	7.563198	27.60493
Females	1988	35.095	1.06E+02	1.03E+01	29.4	3.01E+04	2.25E+08	4.36E+15	14.905	55.286	26.725	5.22E+01	7.227399	27.04359
Females	1989	27.115	2.77E+01	5.26E+00	19.4	2.36E+04	1.72E+08	1.11E+15	16.801	37.429	29.34467	5.84E+01	7.643559	26.04752
Females	1990	44.008	1.93E+02	1.39E+01	31.6	6.94E+04	2.82E+08	7.91E+15	16.781	71.234	35.406	1.09E+02	10.43665	29.47707
Females	1991	29.994	3.07E+01	5.54E+00	18.5	1.05E+04	1.93E+08	1.26E+15	19.141	40.848	33.70567	8.38E+01	9.152686	27.15474
Females	1992	41.305	1.01E+02	1.01E+01	24.4	2.44E+04	2.58E+08	3.96E+15	21.583	61.027	38.43567	1.08E+02	10.40631	27.07462
Females	1993	28.33	2.22E+01	4.72E+00	16.6	7.01E+03	1.81E+08	9.10E+14	19.087	37.573	33.20967	5.14E+01	7.168263	21.58487
Females	1994	38.115	4.39E+01	6.63E+00	17.4	3.54E+04	2.44E+08	1.80E+15	25.124	51.105	35.91667	5.58E+01	7.470252	20.79885
Females	1995	25.032	3.29E+01	5.73E+00	22.9	7.88E+03	1.61E+08	1.36E+15	13.794	36.27	30.49233	3.30E+01	5.745723	18.84317
Females	1996	44.625	2.86E+02	1.69E+01	37.9	9.13E+04	2.87E+08	1.18E+16	11.466	77.785	35.924	1.21E+02	11.00033	30.62113
Females	1997	29.058	2.22E+01	4.72E+00	16.2	6.06E+03	1.86E+08	9.09E+14	19.815	38.3	32.905	1.14E+02	10.66666	32.41654
Females	1998	11.143	5.45E+00	2.33E+00	20.9	1.41E+03	7.15E+07	2.24E+14	6.569	15.717	28.27533	1.05E+02	10.22909	36.17674
Females	1999	21.351	1.10E+01	3.32E+00	15.6	3.37E+03	1.34E+08	4.35E+14	14.839	27.862	20.51733	1.29E+01	3.592585	17.51
Females	2000	15.421	2.42E+01	4.92E+00	31.9	5.20E+03	9.90E+07	9.99E+14	5.771	25.07	15.97167	1.36E+01	3.684291	23.06767
Females	2001	10.884	1.39E+01	3.73E+00	34.2	3.18E+03	6.99E+07	5.73E+14	3.578	18.19	15.88533	1.64E+01	4.048456	25.4855
Females	2002	18.769	1.54E+01	3.92E+00	20.9	9.28E+03	1.21E+08	6.34E+14	11.084	26.454	15.02467	1.78E+01	4.223269	28.1089
Females	2003	17.474	5.86E+00	2.42E+00	13.9	9.30E+03	1.12E+08	2.42E+14	12.73	22.218	15.709	1.17E+01	3.421905	21.78309

Sex	year	mean	variance	SE	CV	Pop Var	Pop	Var(pop)	Low CI	High CI	3-yrMean	3-yrVar	3-yr SE	3-yrCV
Males	1980	12.859	9.87E+00	3.14E+00	24.4	4.05E+03	8.33E+07	4.14E+14	6.7	19.017				
Males	1981	18.249	1.61E+01	4.01E+00	22	1.37E+04	1.18E+08	6.71E+14	10.391	26.108				
Males	1982	23.705	4.25E+01	6.52E+00	27.5	1.67E+04	1.54E+08	1.78E+15	10.93	36.48	18.271	2.28E+01	4.775971	26.13963
Males	1983	23.622	1.81E+01	4.26E+00	18	7.94E+03	1.53E+08	7.60E+14	15.279	31.965	21.85867	2.56E+01	5.055525	23.12824
Males	1984	13.338	2.34E+01	4.84E+00	36.3	8.51E+03	8.64E+07	9.83E+14	3.85	22.826	20.22167	2.80E+01	5.292542	26.17263
Males	1985	80.175	7.34E+02	2.71E+01	33.8	1.82E+05	5.19E+08	3.08E+16	27.073	133.277	39.045	2.59E+02	16.07877	41.18011
Males	1986	9.457	7.33E+00	2.71E+00	28.6	3.52E+03	6.13E+07	3.08E+14	4.151	14.764	34.32333	2.55E+02	15.96656	46.5181
Males	1987	39.298	2.19E+02	1.48E+01	37.7	5.66E+04	2.52E+08	9.04E+15	10.269	68.326	42.97667	3.20E+02	17.89516	41.63925
Males	1988	29.467	1.28E+02	1.13E+01	38.4	7.16E+04	1.89E+08	5.25E+15	7.302	51.632	26.074	1.18E+02	10.87153	41.6949
Males	1989	29.574	7.58E+01	8.71E+00	29.4	2.05E+04	1.87E+08	3.04E+15	12.505	46.642	32.77967	1.41E+02	11.87541	36.22797
Males	1990	47.791	6.32E+02	2.51E+01	52.6	2.38E+05	3.06E+08	2.59E+16	-1.484	97.066	35.61067	2.79E+02	16.69088	46.87044
Males	1991	32.294	8.47E+01	9.21E+00	28.5	2.70E+04	2.07E+08	3.49E+15	14.251	50.337	36.553	2.64E+02	16.25431	44.46779
Males	1992	38.223	6.45E+01	8.03E+00	21	2.76E+04	2.39E+08	2.52E+15	22.487	53.958	39.436	2.60E+02	16.1372	40.91998
Males	1993	32.57	2.23E+02	1.49E+01	45.9	6.04E+04	2.08E+08	9.13E+15	3.297	61.843	34.36233	1.24E+02	11.13954	32.41788
Males	1994	53.391	7.91E+01	8.89E+00	16.7	4.23E+04	3.42E+08	3.24E+15	35.961	70.821	41.39467	1.22E+02	11.05459	26.70535
Males	1995	25.754	2.46E+01	4.96E+00	19.3	5.68E+03	1.65E+08	1.02E+15	16.029	35.48	37.23833	1.09E+02	10.43676	28.02693
Males	1996	52.633	1.94E+02	1.39E+01	26.4	6.09E+04	3.38E+08	7.98E+15	25.362	79.904	43.926	9.91E+01	9.954865	22.66281
Males	1997	29.594	2.89E+01	5.37E+00	18.2	6.69E+03	1.89E+08	1.18E+15	19.065	40.123	35.99367	8.24E+01	9.075057	25.21293
Males	1998	32.353	6.71E+01	8.19E+00	25.3	2.13E+04	2.08E+08	2.76E+15	16.293	48.413	38.19333	9.65E+01	9.824951	25.72426
Males	1999	35.452	4.09E+01	6.40E+00	18	1.38E+04	2.23E+08	1.61E+15	22.915	47.989	32.46633	4.56E+01	6.75559	20.80799
Males	2000	22.24	3.49E+01	5.91E+00	26.6	7.24E+03	1.43E+08	1.44E+15	10.657	33.824	30.015	4.77E+01	6.903767	23.00106
Males	2001	20.345	3.11E+01	5.57E+00	27.4	1.02E+04	1.31E+08	1.28E+15	9.418	31.272	26.01233	3.56E+01	5.970036	22.95079
Males	2002	32.174	3.76E+01	6.13E+00	19	1.83E+04	2.07E+08	1.55E+15	20.162	44.186	24.91967	3.45E+01	5.875656	23.57839
Males	2003	32.45	2.51E+01	5.01E+00	15.4	7.09E+04	2.08E+08	1.03E+15	22.637	42.262	28.323	3.12E+01	5.588798	19.73237

Table B7.2 Summary of input values for swept area scenarios.

(These estimates of wing spread, door spread, and tow length are provisional and subject to change per further analysis)

(The data are incorporated as part of this assessment complements of Henry Milliken, NEFSC)

	<b>door spread(m)</b>	<b>wing spread (m)</b>	<b>mid range (m)</b>
<b>ave Albatross</b>	22.98	11.07	17.02
<b>sd Albatross</b>	1.34	0.64	0.99
<b>CV Albatross</b>	0.06	0.06	0.06

<b>Distance per tow</b>	<b>nautical mile</b>
mean	1.874
std dev	0.112
CV	0.060

Conversion Factor	1m =	0.000539957 nautical miles
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Estimated area swept per tow

<b>Area per tow (nm^2)</b>	<b>Max (based on Door)</b>	<b>Min(based on wing spread)</b>	<b>Midrange</b>
mean	0.02325	0.01120	0.01722
std dev= (CV*mean)	0.00140	0.00067	0.00103
CV(fixed at 0.06 per above)	0.06	0.06	0.06

**Max/min**  
2.076455081

Table B7.3. Summary of stochastic biomass estimates (mt) based on minimum footprint assumption

year	Total Exploitable Biomass				Exploitable Biomass Females				Exploitable Biomass Males			
	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75
1990	158675	128000	157000	187000	142228	116000	141000	166000	15947	10000	15000	20000
1991	154569	123000	153000	183000	122742	100000	121000	143000	31327	22000	30000	39000
1992	151735	127000	150000	174000	116977	99000	116000	132000	34259	26000	33000	40000
1993	126194	107000	125000	143000	110008	94000	109000	124000	15686	12000	15000	17000
1994	92274	79000	91000	103000	80084	69000	79000	89000	11690	8000	11000	13000
1995	100649	80000	99000	119000	88312	70000	87000	105000	11837	9000	11000	13000
1996	234061	190000	232000	276000	104655	82000	103000	125000	128906	107000	128000	149000
1997	215815	173000	214000	256000	80225	60000	79000	98000	135090	111000	134000	156000
1998	143733	124000	142000	161000	64280	56000	63000	71000	78954	67000	78000	89000
1999	134714	113000	133000	154000	61030	51000	60000	69000	73184	61000	72000	83000
2000	131675	110000	130000	151000	64707	53000	64000	74000	66468	55000	65000	75000
2001	143773	118000	142000	167000	77513	62000	76000	90000	65761	54000	65000	75000
2002	139833	120000	138000	158000	59769	50000	59000	67000	79564	68000	78000	89000

148285

Year	Total biomass (both sexes)				SSB (females >80 cm)			
	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75
1990	582274	453000	579000	708000	234229	192000	232000	274000
1991	664850	524000	662000	801000	269624	221000	268000	315000
1992	553731	459000	551000	644000	220002	188000	218000	250000
1993	544415	460000	542000	625000	186132	159000	185000	210000
1994	460932	390000	459000	529000	133264	115000	132000	149000
1995	519920	428000	517000	608000	120664	96000	119000	143000
1996	520782	421000	518000	617000	114091	89000	113000	137000
1997	489233	391000	487000	584000	91458	69000	90000	112000
1998	406287	353000	404000	456000	51821	45000	51000	57000
1999	358185	303000	356000	410000	52562	44000	51000	59000
2000	343602	288000	342000	396000	61552	50000	60000	71000
2001	337686	280000	336000	392000	64844	52000	64000	76000
2002	371200	319000	369000	420000	58376	49000	57000	66000

min	337686	51821
max	664850	269624
average	473315	127586

Table B7.4. Summary of stochastic biomass estimates (mt) based on maximum footprint assumption

year	Total Exploitable Biomass				Exploitable Biomass Females				Exploitable Biomass Males			
	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75
1990	76157	61000	75000	89000	68236	55000	67000	79000	7422	4000	6000	9000
1991	74180	59000	73000	87000	58852	47000	58000	68000	14828	10000	14000	18000
1992	72815	60000	72000	83000	56076	47000	55000	63000	16239	12000	15000	19000
1993	60514	51000	59000	68000	52719	44000	52000	59000	7295	5000	6000	8000
1994	44179	37000	43000	49000	38309	32000	37000	42000	5370	3000	4000	5000
1995	48212	38000	47000	56000	42271	33000	41000	50000	5441	4000	4000	5000
1996	112462	91000	111000	132000	50142	39000	49000	60000	61821	51000	61000	71000
1997	103675	83000	102000	122000	38376	28000	37000	46000	64799	53000	64000	75000
1998	68961	59000	68000	77000	30697	26000	30000	33000	37764	31000	37000	42000
1999	64618	54000	63000	73000	29133	24000	28000	33000	34985	29000	34000	39000
2000	63154	52000	62000	72000	30903	25000	30000	35000	31751	26000	31000	36000
2001	68981	56000	68000	80000	37070	29000	36000	43000	31411	25000	30000	35000
2002	67083	57000	66000	75000	28525	23000	27000	32000	38058	32000	37000	42000

Year	Total biomass (both sexes)				SSB (females >80 cm)			
	mean	0.25	0.5	0.75	mean	0.25	0.5	0.75
1990	280158	217000	278000	340000	112543	92000	111000	131000
1991	319926	252000	318000	385000	129589	106000	128000	151000
1992	266412	220000	265000	309000	105692	90000	104000	119000
1993	261926	221000	260000	300000	89380	76000	88000	100000
1994	221721	187000	220000	254000	63920	55000	63000	71000
1995	250129	206000	248000	292000	57851	45000	57000	68000
1996	250544	202000	249000	296000	54686	42000	54000	65000
1997	235351	187000	234000	280000	43786	32000	43000	53000
1998	195405	169000	194000	219000	24697	21000	24000	27000
1999	172239	145000	171000	197000	25054	20000	24000	28000
2000	165216	138000	164000	190000	29383	23000	28000	33000
2001	162367	134000	161000	188000	30969	24000	30000	36000
2002	178507	153000	177000	201000	27854	23000	27000	31000

Table B7.5. Summary of Stochastic F estimates based on assumed minimum footprint

year	F1: F on Exploitable Biomass				F2: Discard F on Total Biomass				Biomass Weighted F (F1,F2)			
	average	0.25	0.5	0.75	average	0.25	0.5	0.75	average	0.25	0.5	0.75
1990	0.108	0.084	0.100	0.123	0.091	0.055	0.080	0.113	0.122	0.080	0.108	0.146
1991	0.094	0.071	0.086	0.106	0.080	0.056	0.072	0.095	0.103	0.073	0.092	0.120
1992	0.122	0.099	0.115	0.136	0.041	0.031	0.037	0.046	0.075	0.059	0.069	0.084
1993	0.181	0.151	0.173	0.201	0.028	0.019	0.026	0.033	0.070	0.056	0.066	0.079
1994	0.230	0.195	0.221	0.255	0.022	0.017	0.020	0.025	0.069	0.056	0.065	0.077
1995	0.253	0.195	0.233	0.288	0.023	0.016	0.020	0.025	0.071	0.056	0.066	0.080
1996	0.126	0.098	0.117	0.143	0.030	0.022	0.026	0.033	0.087	0.067	0.080	0.098
1997	0.094	0.072	0.086	0.106	0.015	0.007	0.013	0.020	0.057	0.042	0.052	0.066
1998	0.155	0.132	0.149	0.171	0.012	0.009	0.011	0.013	0.067	0.057	0.064	0.074
1999	0.134	0.110	0.127	0.150	0.012	0.009	0.011	0.013	0.063	0.051	0.059	0.070
2000	0.095	0.077	0.089	0.106	0.013	0.009	0.011	0.014	0.049	0.039	0.046	0.055
2001	0.044	0.034	0.041	0.049	0.028	0.021	0.026	0.032	0.047	0.037	0.043	0.053
2002	0.041	0.034	0.038	0.045	0.019	0.015	0.017	0.020	0.034	0.028	0.032	0.038

year	F3: (Fem Landings)/Female Expl. Biomass				F4: (Male Landings)/Male Expl. Biomass			
	average	0.25	0.5	0.75	average	0.25	0.5	0.75
1990	0.119	0.094	0.111	0.135	0.004	0.001	0.002	0.004
1991	0.115	0.091	0.107	0.130	0.003	0.001	0.001	0.002
1992	0.156	0.130	0.149	0.174	0.000	#N/A	#N/A	0.000
1993	0.205	0.173	0.197	0.228	0.011	0.008	0.009	0.011
1994	0.260	0.224	0.252	0.287	0.023	0.017	0.020	0.025
1995	0.288	0.220	0.264	0.329	0.011	0.008	0.010	0.012
1996	0.241	0.180	0.218	0.276	0.037	0.029	0.034	0.041
1997	0.167	0.119	0.147	0.191	0.053	0.042	0.049	0.059
1998	0.324	0.282	0.316	0.357	0.015	0.012	0.014	0.016
1999	0.244	0.201	0.232	0.273	0.042	0.034	0.039	0.046
2000	0.185	0.149	0.174	0.208	0.008	0.005	0.006	0.008
2001	0.080	0.062	0.073	0.090	0.003	0.001	0.002	0.002
2002	0.094	0.078	0.090	0.105	0.001	0.000	0.000	0.000

average 0.191

Table B7.6. Summary of Stochastic F estimates based on assumed maximum footprint

year	F1: F on Exploitable Biomass				F2: Discard F on Total Biomass				Biomass Weighted F (F1,F2)			
	average	0.25	0.5	0.75	average	0.25	0.5	0.75	average	0.25	0.5	0.75
1990	0.225	0.175	0.208	0.256	0.189	0.116	0.169	0.237	0.251	0.168	0.226	0.306
1991	0.195	0.15	0.179	0.222	0.167	0.117	0.151	0.198	0.214	0.154	0.193	0.25
1992	0.253	0.208	0.241	0.285	0.085	0.065	0.079	0.098	0.155	0.123	0.146	0.177
1993	0.376	0.316	0.361	0.42	0.058	0.042	0.055	0.07	0.147	0.118	0.139	0.166
1994	0.471	0.407	0.461	0.531	0.047	0.036	0.044	0.054	0.144	0.118	0.137	0.162
1995	0.487	0.407	0.486	0.598	0.047	0.036	0.044	0.054	0.148	0.117	0.138	0.168
1996	0.263	0.206	0.244	0.299	0.062	0.047	0.056	0.07	0.181	0.14	0.167	0.206
1997	0.195	0.15	0.18	0.222	0.033	0.017	0.029	0.042	0.119	0.088	0.109	0.138
1998	0.322	0.276	0.312	0.357	0.026	0.02	0.024	0.029	0.140	0.119	0.135	0.155
1999	0.278	0.23	0.265	0.312	0.026	0.019	0.023	0.029	0.131	0.107	0.124	0.146
2000	0.197	0.161	0.187	0.221	0.027	0.021	0.025	0.03	0.103	0.083	0.097	0.115
2001	0.092	0.073	0.086	0.103	0.059	0.045	0.055	0.067	0.098	0.078	0.092	0.111
2002	0.085	0.072	0.082	0.094	0.040	0.032	0.037	0.044	0.072	0.06	0.069	0.08

year	F3: (Fem .Landings)/Female Expl. Biomass				F4: (Male Landings)/Male Expl. Biomass			
	average	0.25	0.5	0.75	average	0.25	0.5	0.75
1990	0.248	0.197	0.232	0.281	0.009	0.004	0.006	0.009
1991	0.240	0.191	0.225	0.272	0.006	0.003	0.004	0.006
1992	0.324	0.272	0.312	0.362	0.002	0	0	0.001
1993	0.424	0.361	0.411	0.475	0.023	0.017	0.021	0.025
1994	0.521	0.466	0.525	0.598	0.048	0.037	0.044	0.054
1995	0.525	0.459	0.55	0.598	0.024	0.019	0.022	0.026
1996	0.463	0.375	0.454	0.574	0.078	0.063	0.073	0.088
1997	0.338	0.248	0.307	0.399	0.111	0.089	0.104	0.125
1998	0.585	0.588	0.598	0.598	0.033	0.027	0.03	0.035
1999	0.489	0.42	0.484	0.569	0.088	0.072	0.083	0.098
2000	0.382	0.311	0.363	0.434	0.017	0.013	0.015	0.018
2001	0.166	0.13	0.154	0.188	0.007	0.004	0.005	0.007
2002	0.197	0.164	0.188	0.219	0.002	0.001	0.001	0.002

Table B8.1 Summary of input data for stock recruitment analyses of spiny dogfish.

Year	Survey Data				Survey Data Scaled to Nominal Footprint (0.01 nm <sup>2</sup> )	
	Raw Data		2-Pt Moving Average		2 -yr moving average	
	Recruits (Num/Tow)	SSB (kg/tow)	Recruits (Num/tow)	SSB (kg/tow)	Recruits (000's)	SSB (mt)
1968	2.881	5.37				
1969	1.248	3.55	2.065	4.46	13,374	28,884
1970	8.250	4.76	4.749	4.16	30,760	26,916
1971	5.905	13.47	7.077	9.11	45,841	59,034
1972	3.909	16.43	4.907	14.95	31,785	96,814
1973	5.183	23.18	4.546	19.81	29,445	128,278
1974	5.948	28.78	5.565	25.98	36,046	168,294
1975	7.851	13.63	6.899	21.21	44,686	137,366
1976	2.718	12.49	5.285	13.06	34,229	84,616
1977	1.110	10.03	1.914	11.26	12,399	72,952
1978	2.759	11.34	1.934	10.69	12,530	69,205
1979	3.883	6.79	3.321	9.06	21,510	58,688
1980	1.356	16.16	2.620	11.47	18,069	78,154
1981	8.853	41.25	5.104	28.71	35,110	189,423
1982	2.459	70.09	5.656	55.67	37,580	360,246
1983	12.990	12.00	7.725	41.05	50,033	265,861
1984	0.744	17.84	6.867	14.92	44,478	96,647
1985	19.799	48.95	10.272	33.40	66,530	216,304
1986	3.982	29.53	11.891	39.24	77,017	254,141
1987	12.942	34.13	8.462	31.83	54,443	205,196
1988	3.671	67.57	8.306	50.85	53,313	326,141
1989	5.482	25.59	4.576	46.58	29,128	297,611
1990	3.841	62.51	4.661	44.05	29,661	281,184
1991	4.548	34.32	4.195	48.42	26,899	310,322
1992	3.663	44.41	4.105	39.36	26,170	250,438
1993	3.060	36.68	3.362	40.54	21,357	257,578
1994	15.840	16.45	9.450	26.56	60,501	169,975
1995	1.151	15.95	8.496	16.20	54,408	103,872
1996	5.276	30.60	3.214	23.28	20,634	149,461
1997	0.281	13.09	2.778	21.85	17,835	140,080
1998	0.454	4.16	0.367	8.63	2,353	55,188
1999	0.143	9.98	0.299	7.07	1,907	44,692
2000	0.479	13.36	0.311	11.67	1,990	74,239
2001	0.208	8.83	0.344	11.10	2,207	71,235
2002	0.297	11.71	0.253	10.27	1,622	65,921
2003	0.825	10.05	0.561	10.88	3,602	69,860



Table B8.2. Summary of parameter estimates for Ricker stock-recruitment model

Years Included	Data	Units	Parameter	Estimate	Asymptotic SE	95% Confidence Interval	
						Lower Bound	Upper Bound
1968-96	Swept Area 2-yr avg.	thousands mt	A	0.541578	0.109155	0.31761	0.765546
			B	-0.000005	0.000001	-0.000007	-0.000003
			RMAX (000')	42,839	3,517	35,622	50,055
			SSBMAX (mt)	215,014	43,749	125,249	304,780
			R-sqr	0.172			
	MSE	7.925 E+9					
	Raw (2-yr avg.)	num/tow kg/tow	A	0.543445	0.108853	0.320097	0.766793
			B	-0.030141	0.006055	-0.042565	-0.017717
			RMAX	6.632914	0.542621	5.519549	7.74628
SSBMAX			33.177455	6.665081	19.501838	46.853071	
R-sqr			0.178				
MSE	190.97						
Raw	num/tow kg/tow	A	0.521389	0.16949	0.174204	0.868574	
		B	-0.027862	0.009425	-0.047169	-0.008555	
		RMAX	6.884334	1.118478	4.593236	9.175431	
		SSBMAX	35.891764	12.141952	11.020103	60.763425	
		R-sqr	0.055				
MSE	625.76						
1968-2003	Swept Area 2-yr avg.	thousands mt	A	0.391858	0.085433	0.218043	0.565672
			B	-0.000003	0.000001	-0.000005	-0.000001
			RMAX	42,388	5,296	31,614	53,162
			SSBMAX	294,040	84,867	121,377	466,702
			R-sqr	3.28E-01			
	MSE	1.349 E+10					
	Raw (2-yr avg.)	num/tow kg/tow	A	0.392663	0.085433	0.218849	0.566477
			B	-0.022092	0.006306	-0.034922	-0.009263
			RMAX	6.538571	0.806394	4.897951	8.179192
SSBMAX			45.264321	12.920044	18.978295	71.550348	
R-sqr			0.327				
MSE	323.48						
Raw	num/tow kg/tow	A	0.415334	0.128512	0.154166	0.676502	
		B	-0.023003	0.008578	-0.040436	-0.00557	
		RMAX	6.642318	1.218106	4.16683	9.117807	
		SSBMAX	43.472882	16.211689	10.526764	76.418999	
		R-sqr	0.125				
MSE	750.306						

Table B9.1. Summary of Projection model comparisons, assuming the minimum footprint

Scenario	decade	Average over Decade								
		Average of F	SSB (mt)	Probability of exceeding Target Biomass	Probability of exceeding Threshold biomass	Yield (mt)	Exploitable Biomass of Females (mt)	Exploitable Biomass of Males (mt)	Total Biomass of Females (mt)	Total Biomass (mt)
Rebuild_F	2003-2012	0.03	122,102	0.0426	0.8042	3,873		24,684	167,868	414,500
	2013-2022	0.03	148,872	0.2118	0.9452	4,387	137,585	17,292	233,454	424,223
	2023-2033	0.03	214,573	0.7416	1	6,109	199,706	16,079	326,661	537,313
SQ_F	2003-2012	0.094	98,163	0	0.5724	9,851	89,310	23,929	141,334	380,065
	2013-2022	0.094	89,465	0	0.4576	8,367	81,282	15,077	149,051	304,816
	2023-2033	0.094	97,861	0	0.6394	8,773	90,040	11,228	158,649	291,472
ZeroF	2003-2012	0	136,277	0.1362	0.8436	-	125,382	25,051	183,419	434,000
	2013-2022	0	193,121	0.519	0.9946	-	179,924	18,497	294,071	505,973
	2023-2033	0	318,682	0.9852	1	-	298,226	19,343	471,684	739,736
alt_Q	2003-2012	0.0676	107,748	0.014	0.672	7,253	98,422	24,210	151,641	393,120
	2013-2022	0.0731	110,660	0.050	0.665	7,253	101,382	15,900	180,284	349,506
	2023-2033	0.0647	143,451	0.247	0.813	7,253	132,896	13,103	223,107	385,362
Base_Q	2003-2012	0.0446	116,003	0.031	0.746	5,116	106,211	24,478	160,846	405,147
	2013-2022	0.0417	134,540	0.146	0.844	5,116	124,020	16,755	213,223	395,519
	2023-2033	0.0306	194,681	0.557	0.971	5,116	181,175	15,036	295,750	489,638
NoComm	2003-2012	0.0276	122,984	0.055	0.793	3,336	112,806	24,687	168,624	415,178
	2013-2022	0.0235	154,741	0.264	0.935	3,336	143,252	17,401	241,092	433,903
	2023-2033	0.0174	225,626	0.757	0.975	3,337	210,594	16,292	342,758	559,116

Tabel B9.2. Comparison of projection model results at decadal waypoints.

Scenario	Year	Average value in the year specified								
		Average of F	SSB (mt)	Probability of exceeding Target Biomass	Probability of exceeding Threshold biomass	Yield (mt)	Exploitable Biomass of Females (mt)	Exploitable Biomass of Males (mt)	Total Biomass of Females (mt)	Total Biomass (mt)
Rebuild_F	2003	0.03	57,608	0	0	2,290	58,132	22,346	153,665	453,134
	2012	0.03	113,641	0	0.842	3,892	114,842	22,618	184,792	391,624
	2022	0.03	189,434	0.566	1	5,365	174,013	15,484	270,538	458,263
	2032	0.03	250,959	0.914	1	7,038	231,452	17,137	381,388	616,705
SQ_F	2003	0.094	57,608	0	0	7,070	58,132	22,346	153,665	453,134
	2012	0.094	71,971	0	0.1	8,212	73,562	21,136	133,638	322,779
	2022	0.094	103,262	0	0.726	9,207	93,922	12,378	152,158	289,445
	2032	0.094	104,320	0	0.742	9,106	94,460	10,627	165,940	297,200
ZeroF	2003	0	57,608	0	0	-	58,132	22,346	153,665	453,134
	2012	0	141,174	0.066	0.974	-	142,109	23,352	217,512	433,562
	2022	0	256,575	0.928	1	-	237,067	17,309	361,259	582,012
	2032	0	392,134	1	1	-	364,623	21,883	581,444	899,398
alt_Q	2003	0.0984	57,608	0.000	0.000	7,252	58,132	22,346	153,665	453,134
	2012	0.0723	90,693	0.000	0.496	7,253	92,056	21,773	155,487	351,691
	2022	0.0641	135,518	0.162	0.828	7,253	123,487	13,558	196,257	352,643
	2032	0.0624	161,989	0.384	0.838	7,254	148,540	13,130	250,646	421,805
Base_Q	2003	0.0689	57,608	0.000	0.000	5,116	58,132	22,346	153,665	453,134
	2012	0.0442	105,191	0.000	0.702	5,116	106,428	22,292	173,358	375,750
	2022	0.0342	170,904	0.402	0.964	5,116	156,599	14,761	244,281	420,105
	2032	0.0266	229,430	0.728	0.986	5,116	211,747	15,802	347,569	562,445
NoComm	2003	0.0447	57,608	0.000	0.000	3,336	58,132	22,346	153,665	453,134
	2012	0.0259	117,536	0.000	0.836	3,337	118,667	22,687	188,530	395,837
	2022	0.0186	200,603	0.634	1.000	3,335	184,461	15,688	284,733	476,376
	2032	0.0198	234,721	0.777	0.890	3,337	217,311	16,891	371,947	610,667

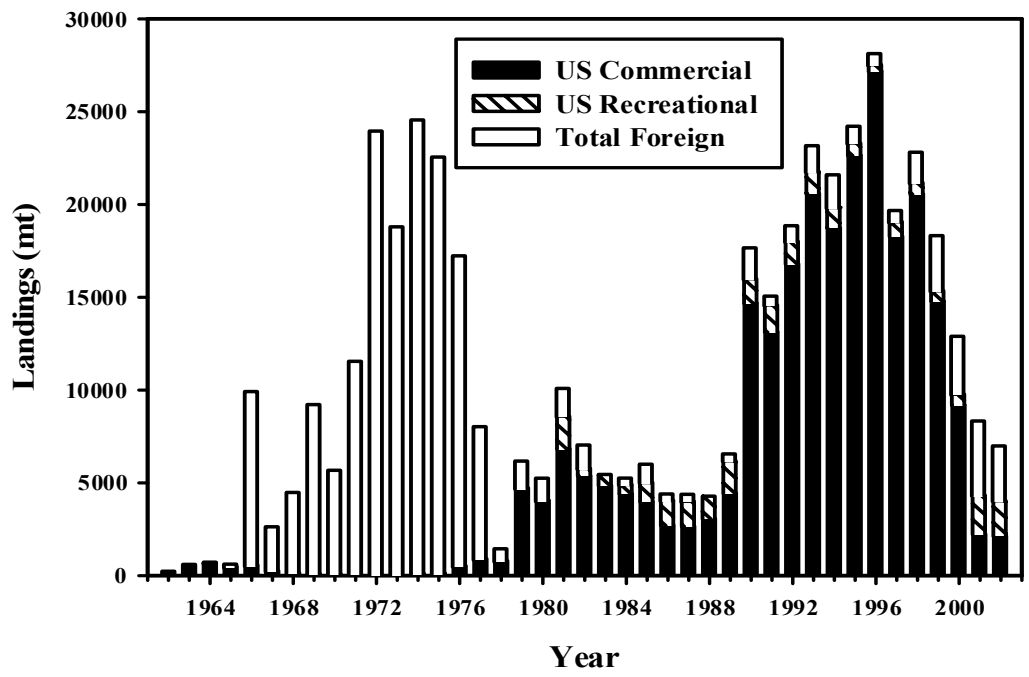


Figure B4.1. Commercial landings (metric tons) and recreational catch of spiny

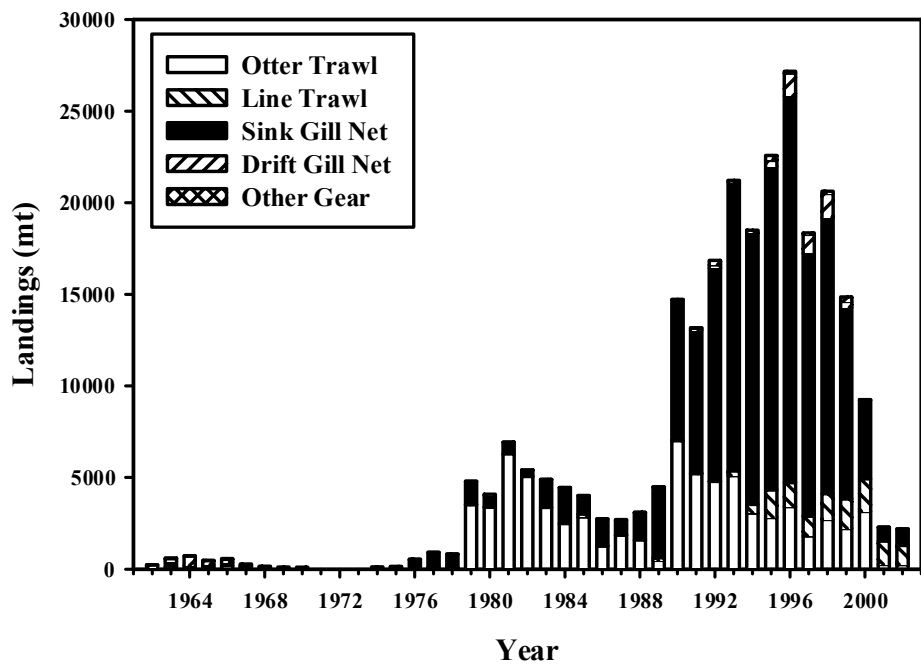


Figure B4.2. U. S. Landings of spiny dogfish from NAFO subareas 2-6 by gear type, 1962-2002.

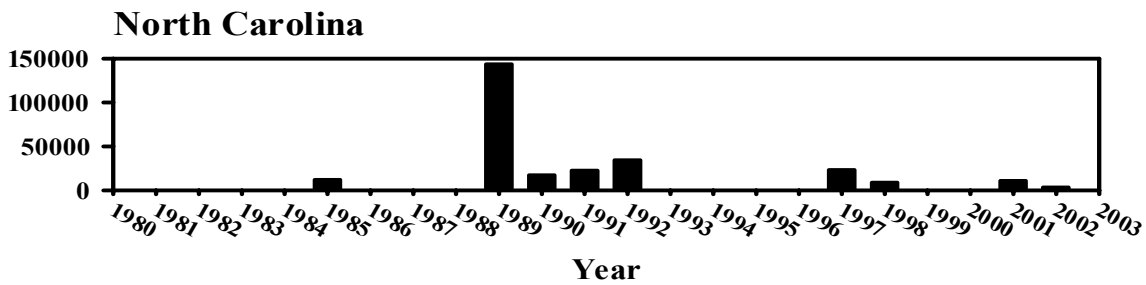
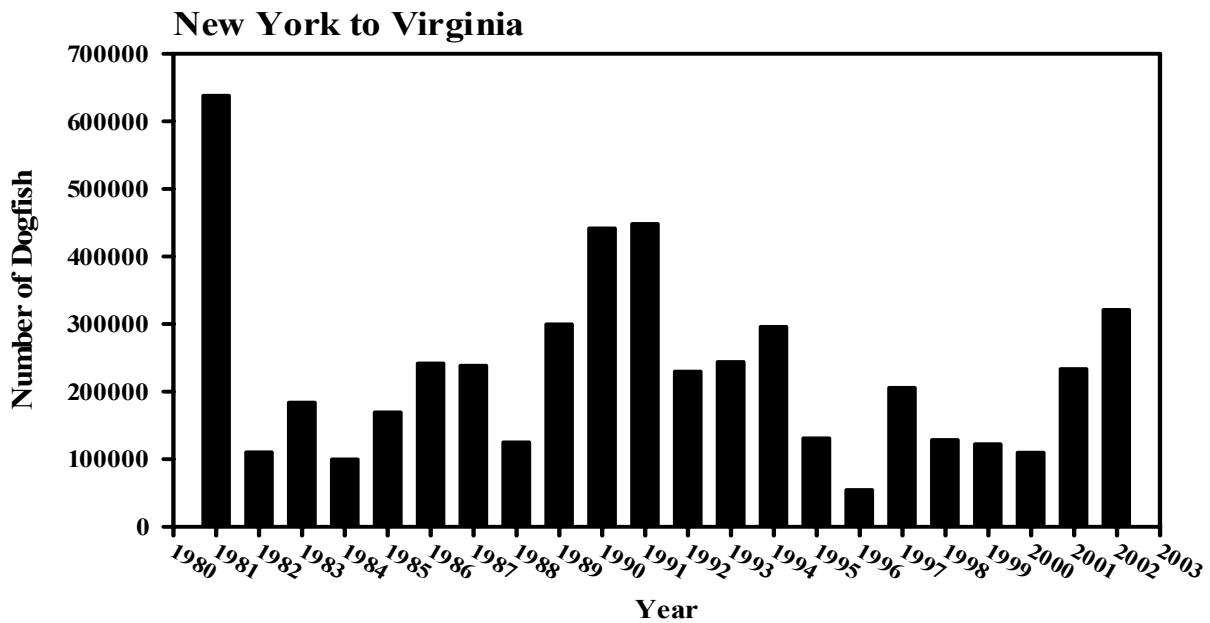
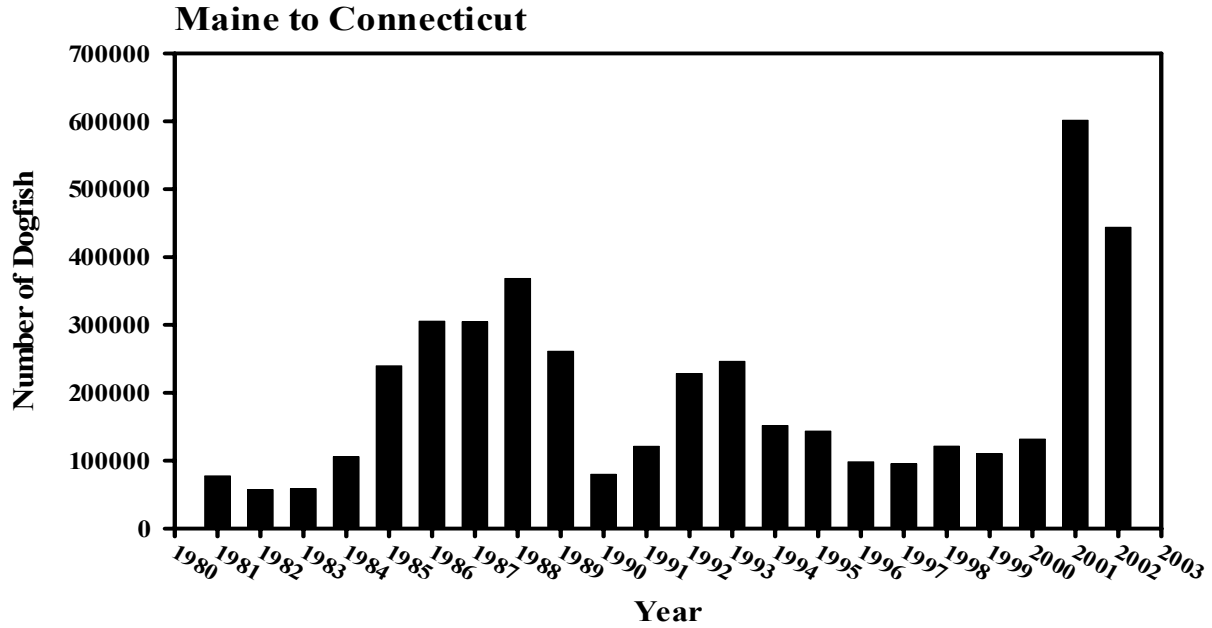
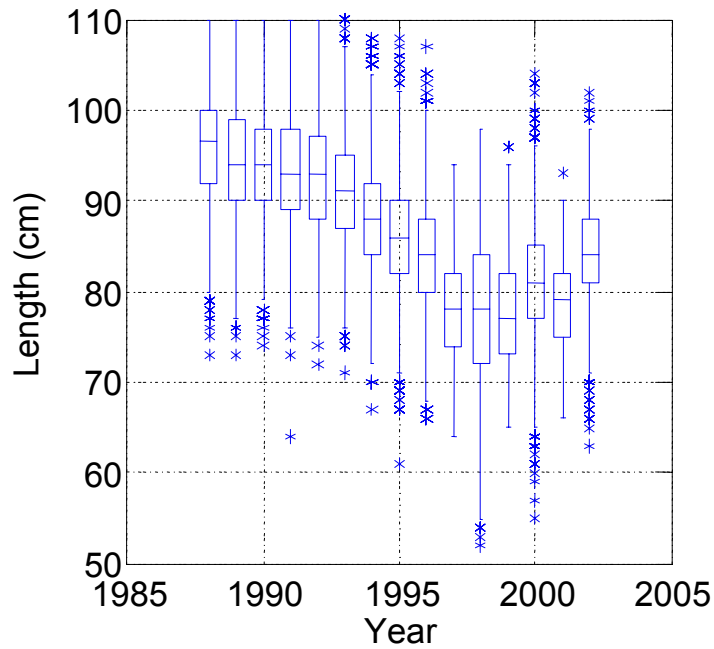


Table B4.3. Estimated total recreational catch of spiny dogfish (numbers of fish) by geographical area, 1981-2002.

## Female Size Composition, Commercial Samples



## Male Size Composition, Commercial Samples

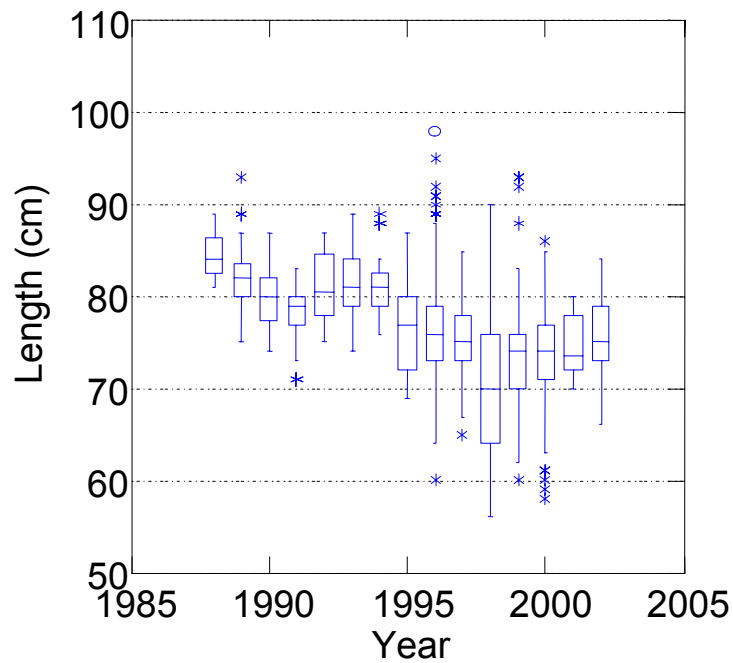
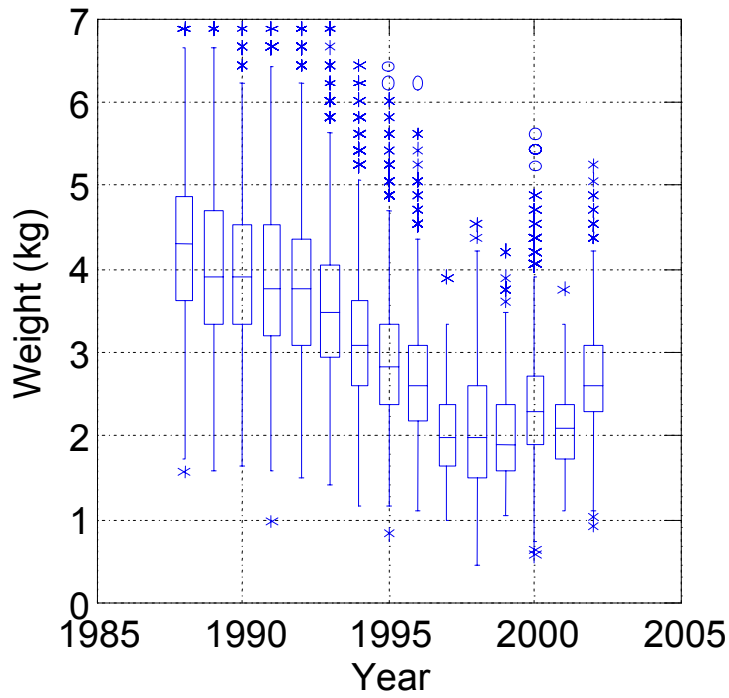


Fig. B4.4 Box plots of length (cm) frequency of female and male dogfish in commercial fishery samples.

## Female Weight Composition, Commercial



## Male Weight Composition, Commercial

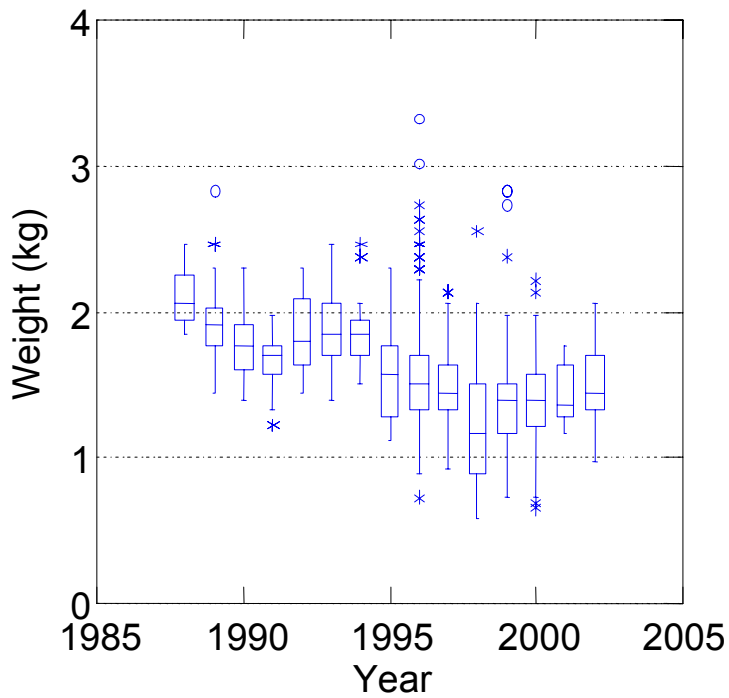


Fig. B4.5 Box plots of average weight (kg) of female and male dogfish in commercial fishery samples.

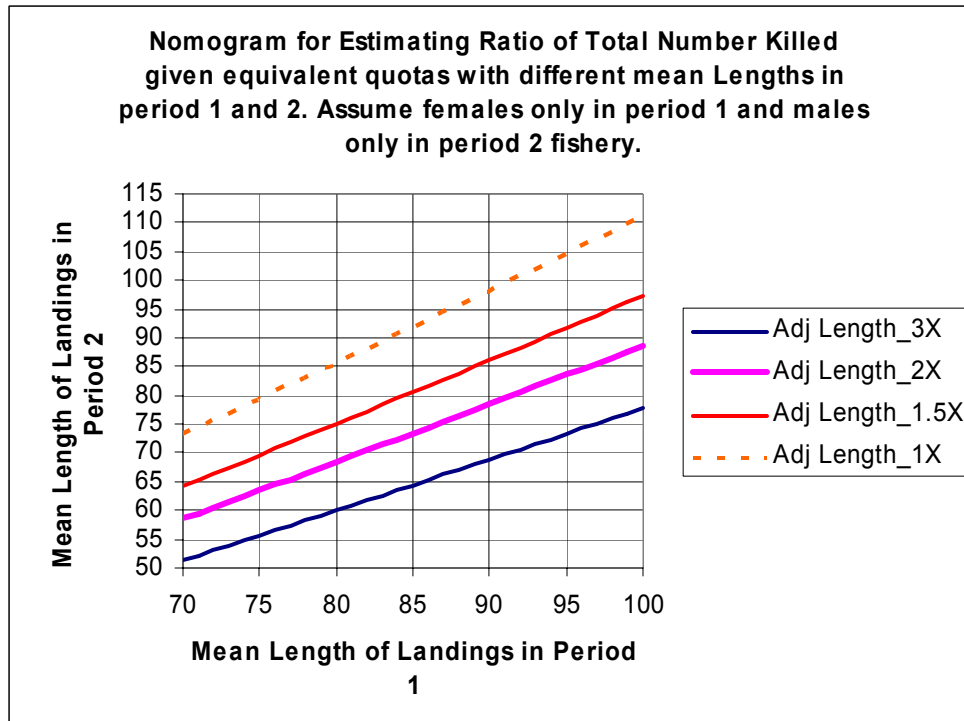
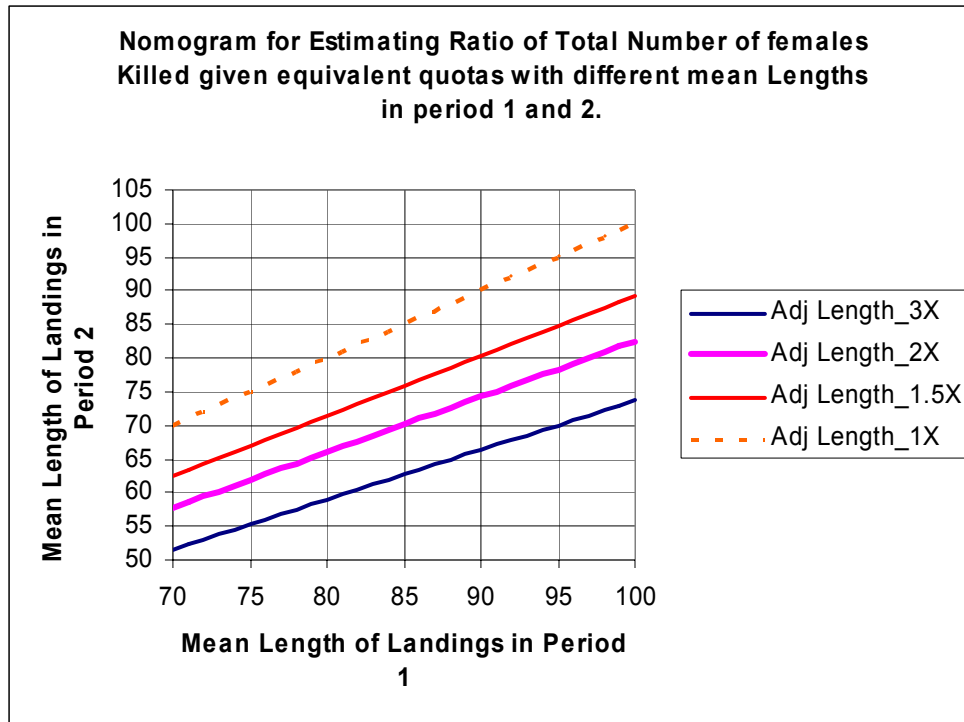
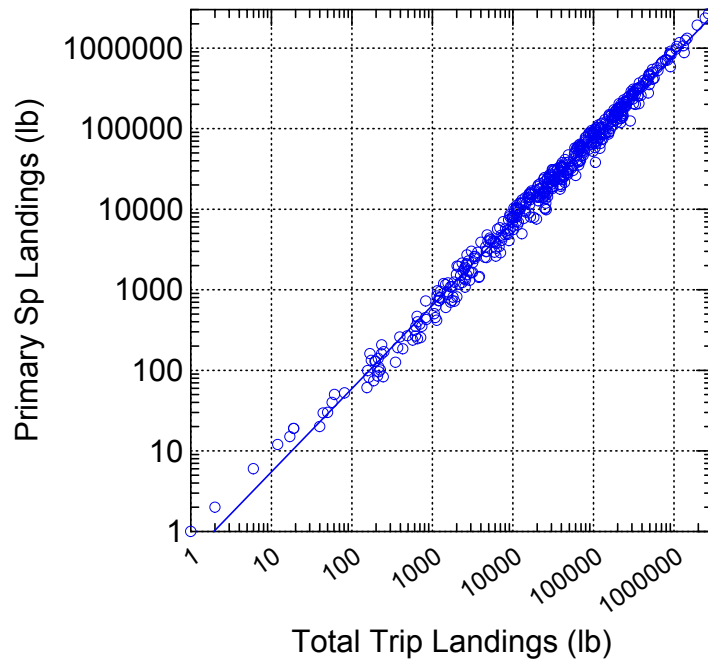


Fig. B4.6 Nomograms illustrating the increase in numbers of dogfish killed with alternative average sizes of dogfish in two landings periods.



### All Gears and Species: Primary Sp.Group vs Tot Landings (lb)



### All Gears and Species: Secondary Sp.Group vs Tot Landings (lb)

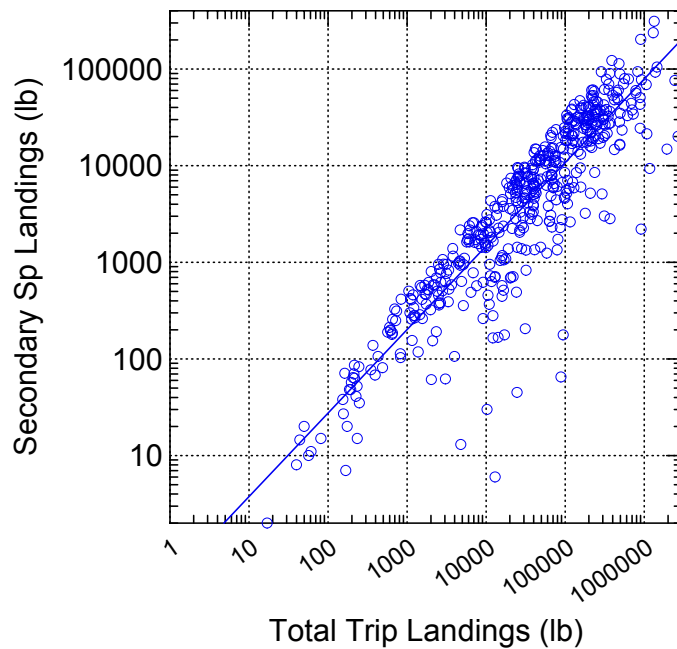
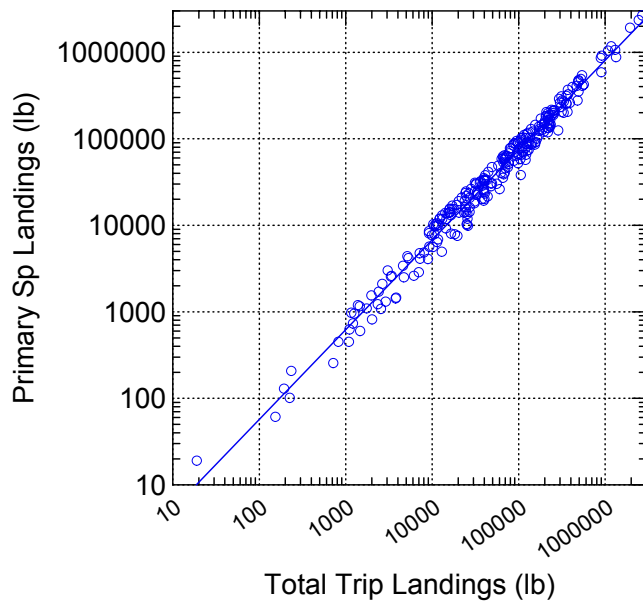


Fig B4.7. Relationship between total landings of all species and the landings of the primary species group (top) and secondary species group (bottom) on commercial vessel trips. At sea observers were onboard. All gears combined.

Trawls, All Species: Primary Sp.Group vs Tot Landings (lb)



Trawls, All Species: Secondary Sp.Group vs Tot Landings (lb)

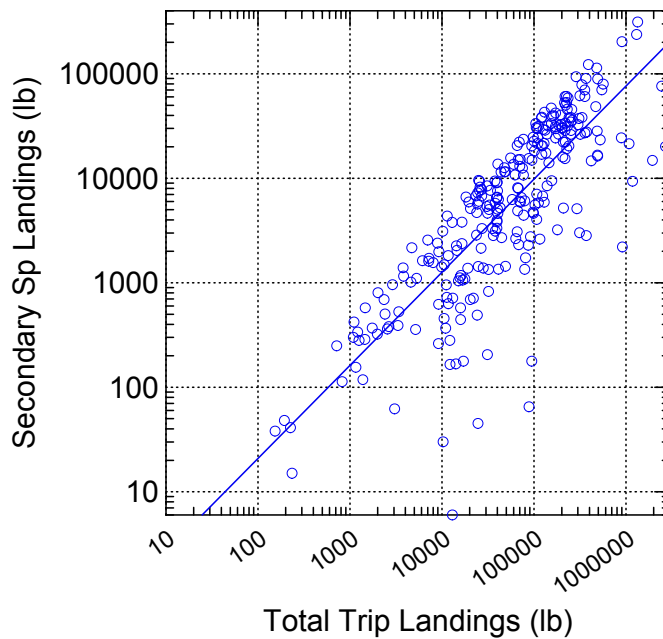
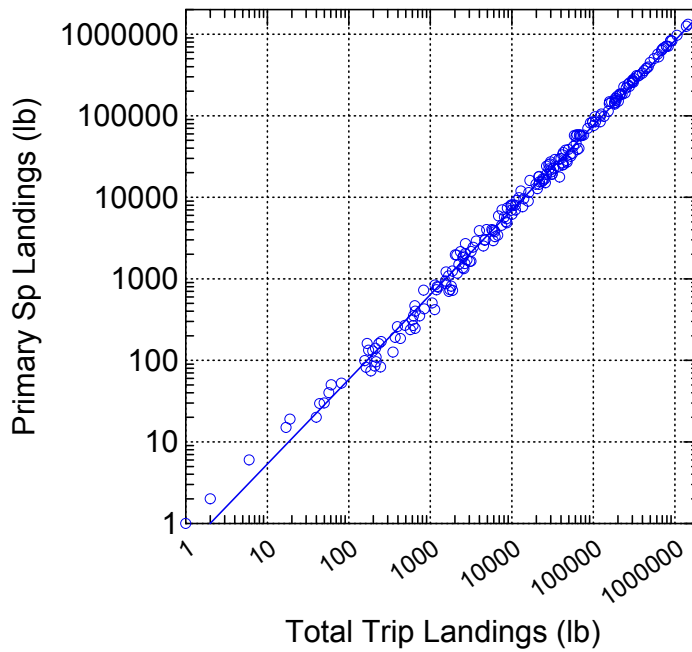


Fig B4.8. Relationship between total landings of all species and the landings of the primary species group (top) and secondary species group (bottom) on commercial vessel trips using trawls. At sea observers were onboard

### Gill Nets, All Species: Primary Sp.Group vs Tot Landings (lb)



### Gill Nets, All Species: Secondary Sp.Group vs Tot Landings (lb)

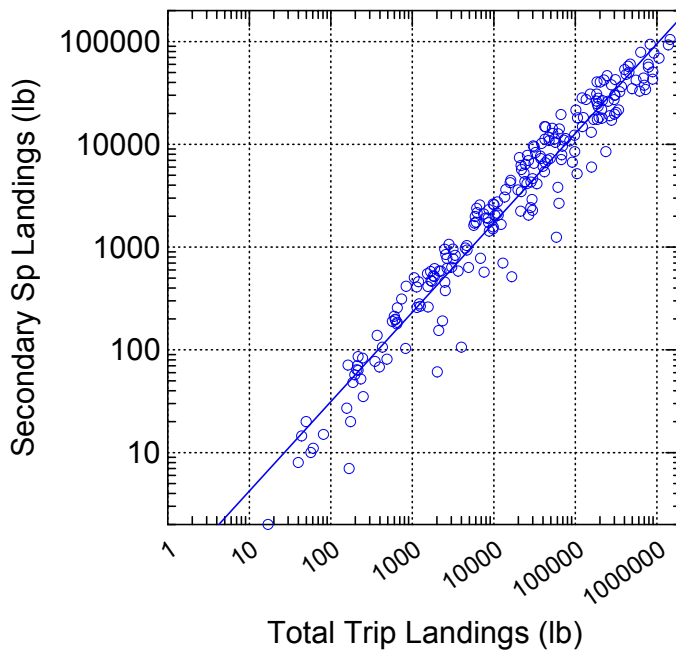


Fig B4.9. Relationship between total landings of all species and the landings of the primary species group (top) and secondary species group (bottom) on commercial vessel trips using gill nets. At sea observers were onboard

## All Gears and Sp.Grps: Dog discard vs primary sp landed

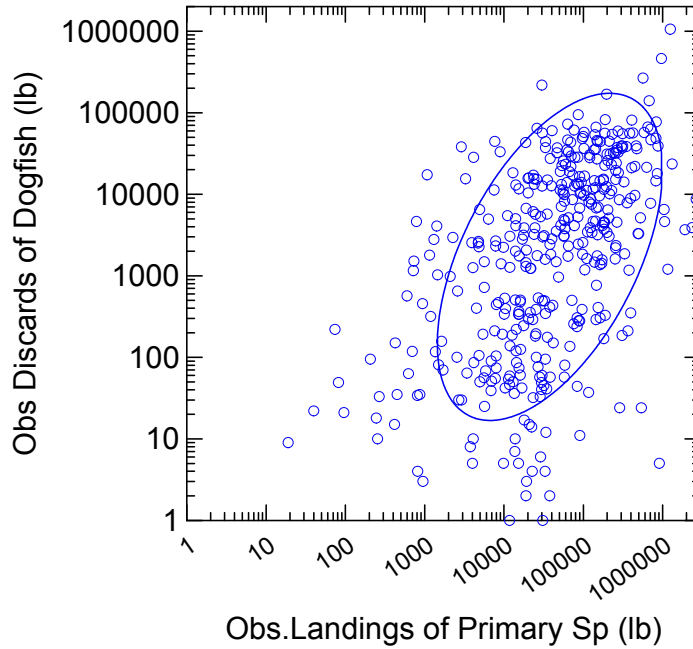
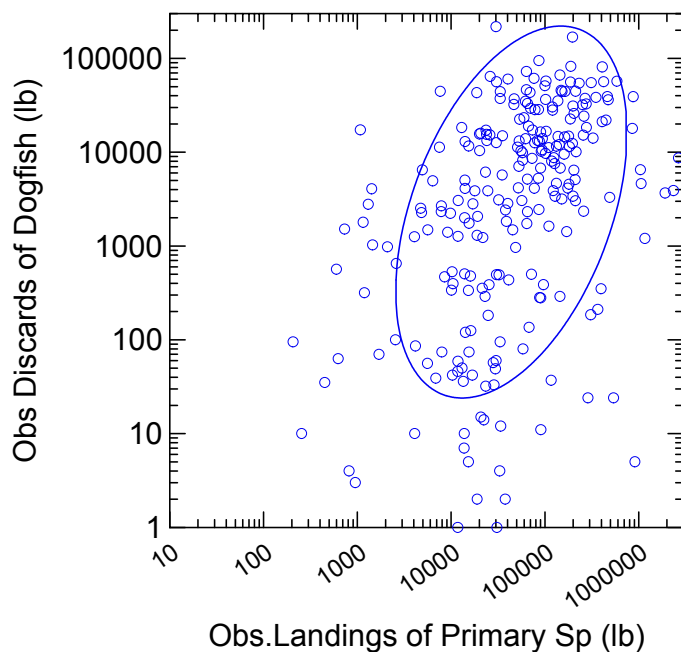


Fig. B4.10 Relationship between total dogfish discards and total landings of primary species group on commercial vessels with at sea observers on board. Each point represents an individual trip, 1989-2002. All gears and species groups combined. Confidence ellipse represents 0.68 probability level.

## Trawl Gear and Sp.Grps: Dog discard vs primary sp landed



## Gill Net Gear and Sp.Grps: Dog discard vs primary sp landed

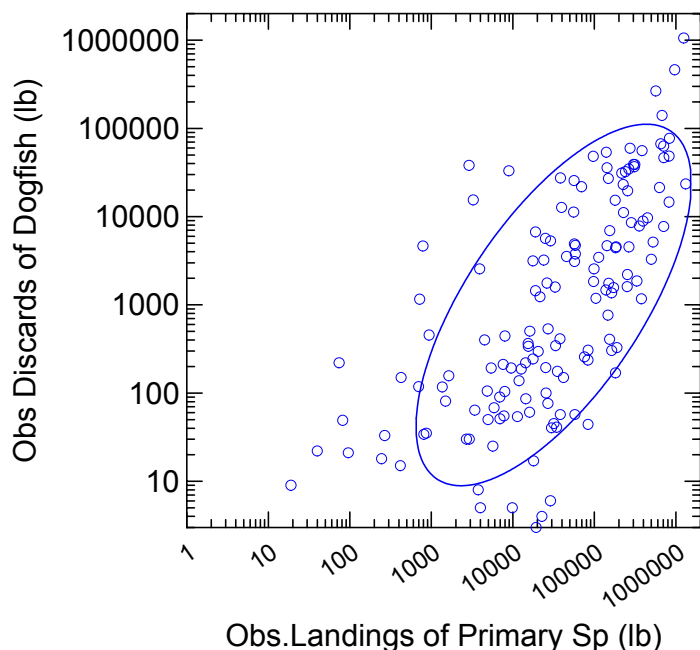
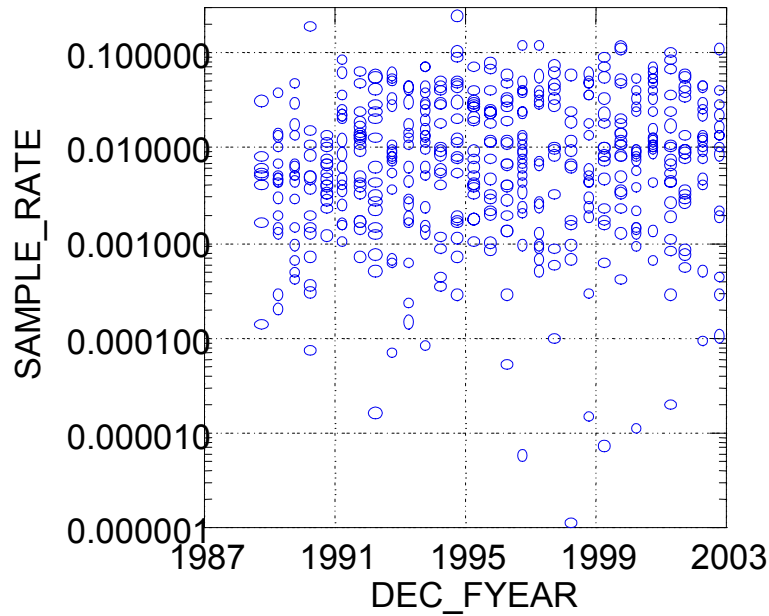


Fig. B4.11 Relationship between total dogfish discards and total landings of primary species group on commercial vessels with at sea observers on board. Each point represents an individual trip, 1989-2002. All species groups combined. Trawl gear (top panel); gill net gear (bottom panel). Confidence ellipse represents 0.68 probability level.

### All Gears and Sp.Grp: Sample Rate vs Fishing Period



### All Gears and Sp Grp: Obs Landings(lb) vs Total Landings (mt)

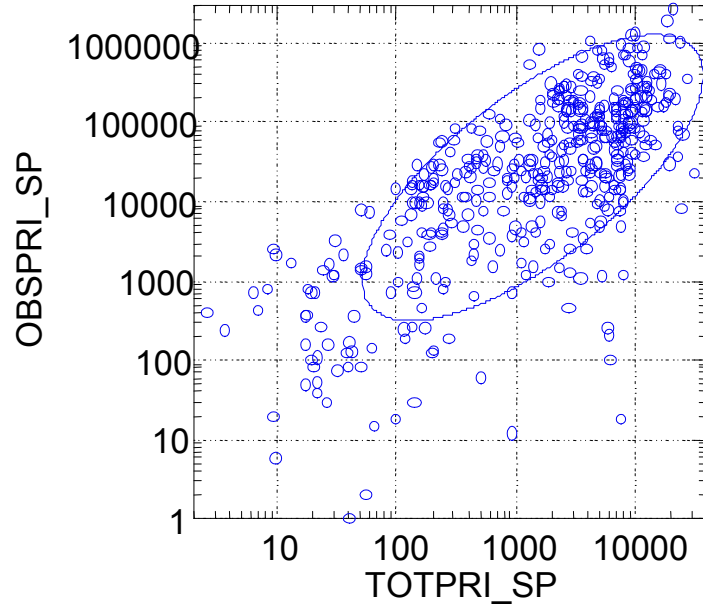
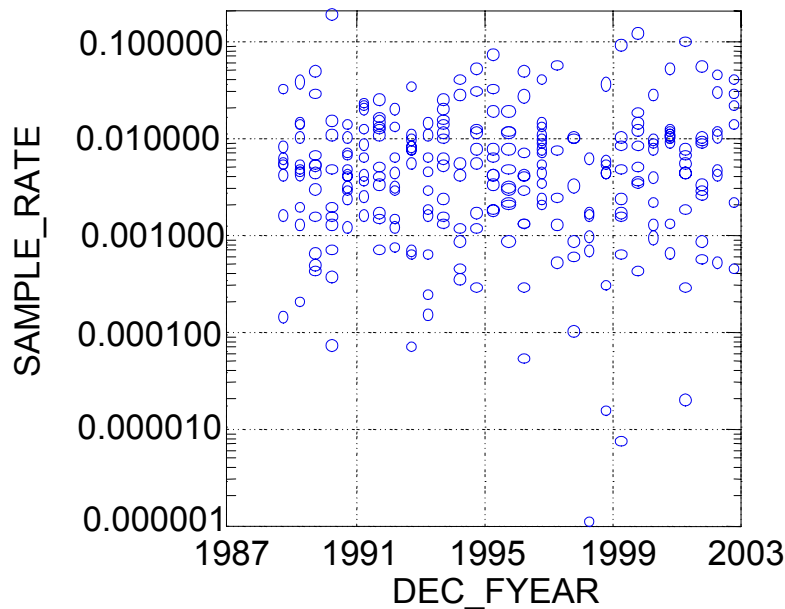


Fig. B4.12 Estimated sampling rate by month (denoted as decimal year) for each species group (top). Bottom panel illustrates relationship between total observed landings of primary species groups and gear groups and total landings those groups in commercial dealer database. Landings on X axis are in mt. Observed landings on Y axis are in pounds. Confidence ellipse represents 0.68 probability level.

### Trawl Gear and Sp.Grp: Sample Rate vs Fishing Period



### Trawl Gear and Sp Grp: Obs Landings(lb) vs Total Landings (mt)

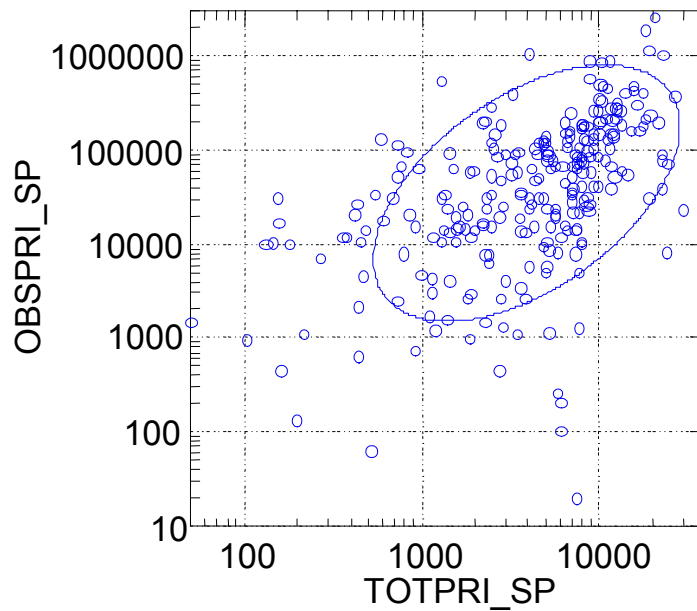
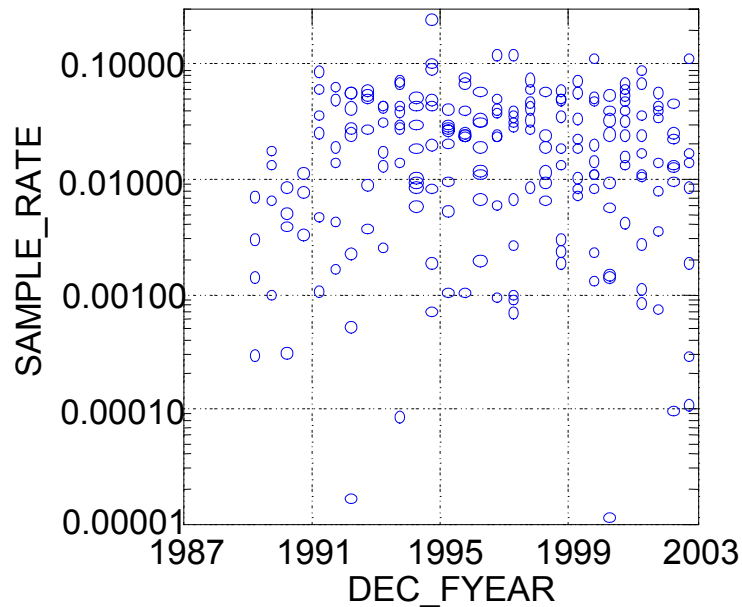


Fig. B4.13 Estimated sampling rate by month (denoted as decimal year) for each species group (top). Bottom panel illustrates relationship between total observed landings of primary species groups and total landings those groups in commercial dealer database. Landings on X axis are in mt. Observed landings on Y axis are in pounds. Only trawl gear. Confidence ellipse represents 0.68 probability level.

## Gill Net Gear and Sp.Grp: Sample Rate vs Fishing Period



## Gill Net Gear and Sp Grp: Obs Landings(lb) vs Total Landings (mt)

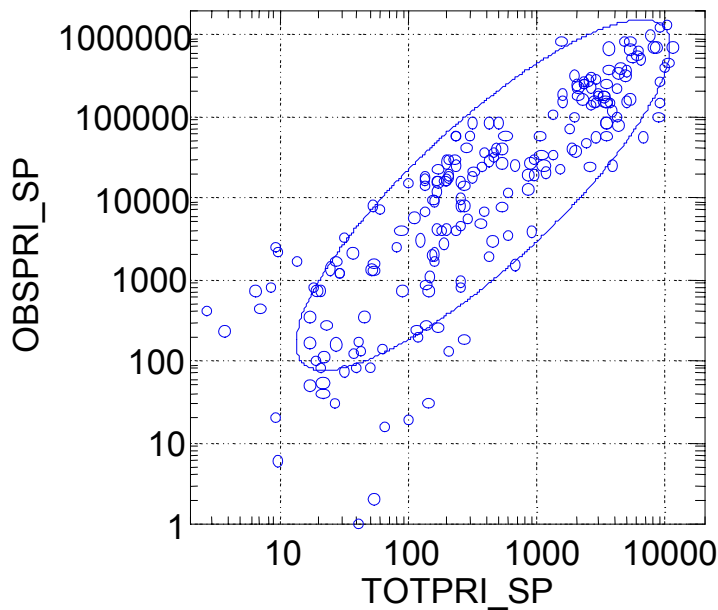


Fig. B4.14 Estimated sampling rate by month (denoted as decimal year) for each species group (top). Bottom panel illustrates relationship between total observed landings of primary species groups and total landings those groups in commercial dealer database. Landings on X axis are in mt. Observed landings on Y axis are in pounds. Only gill net gear. Confidence ellipse represents 0.68 probability level.



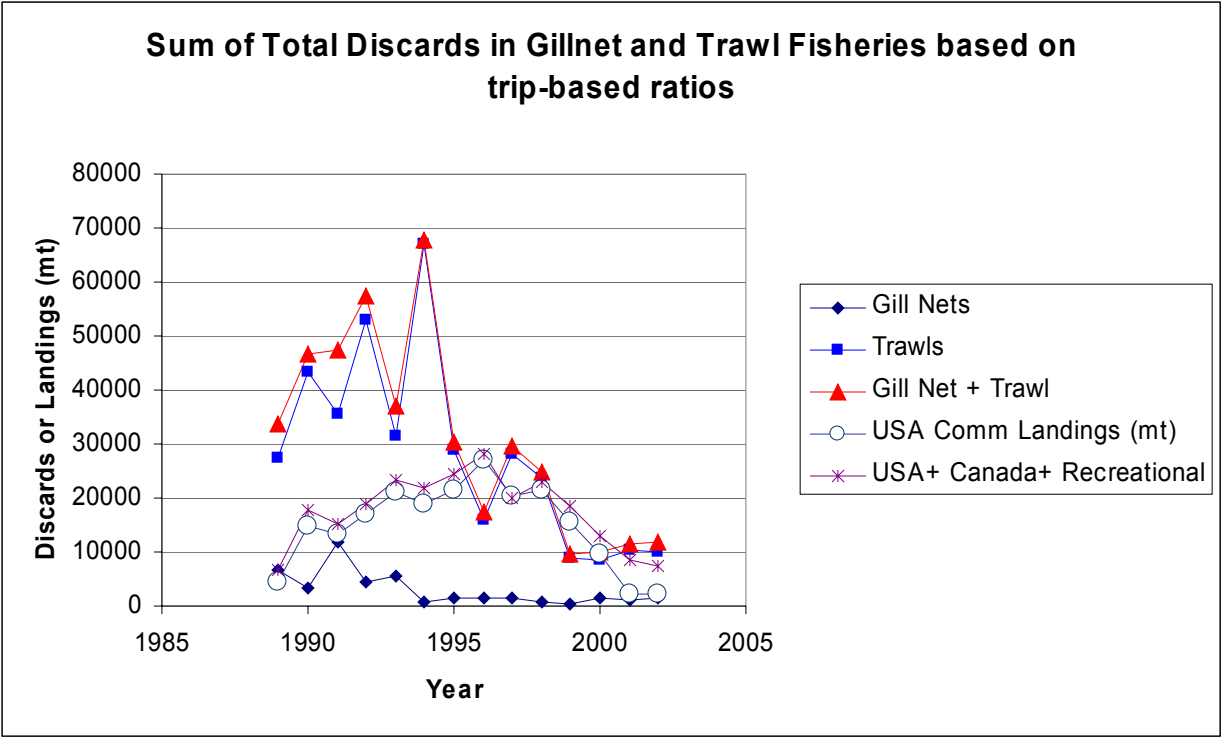
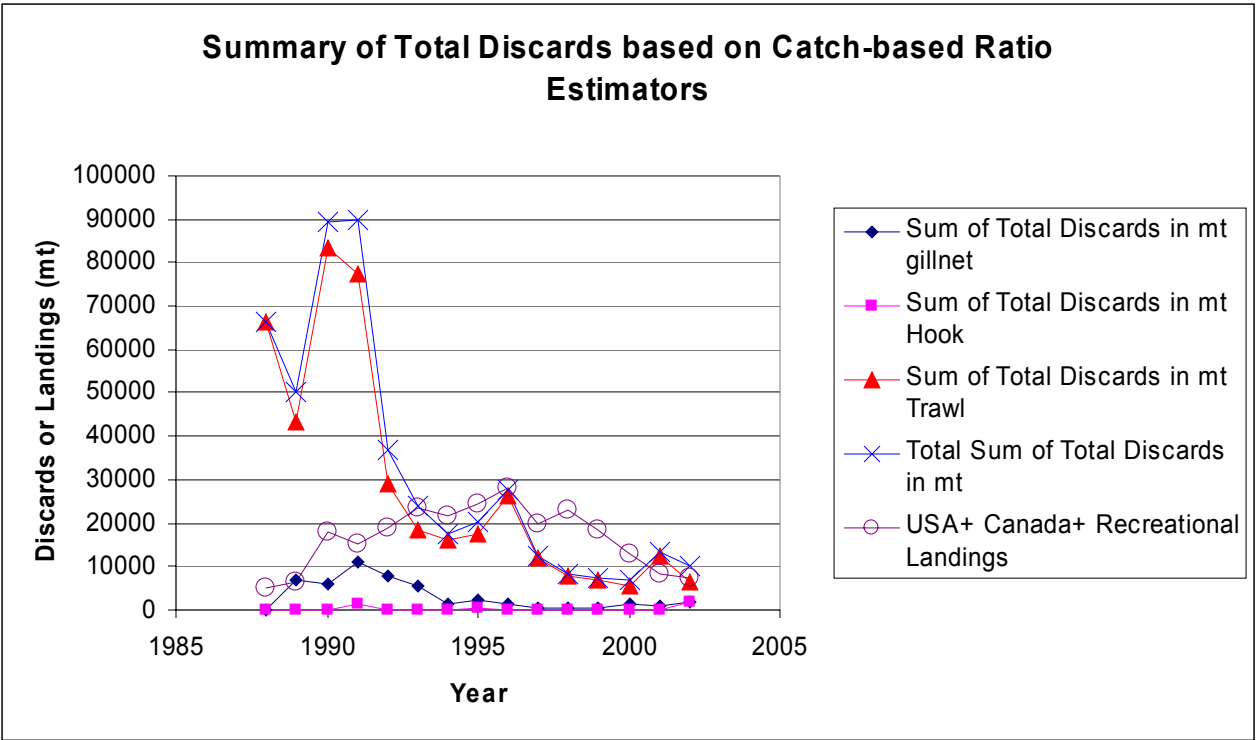
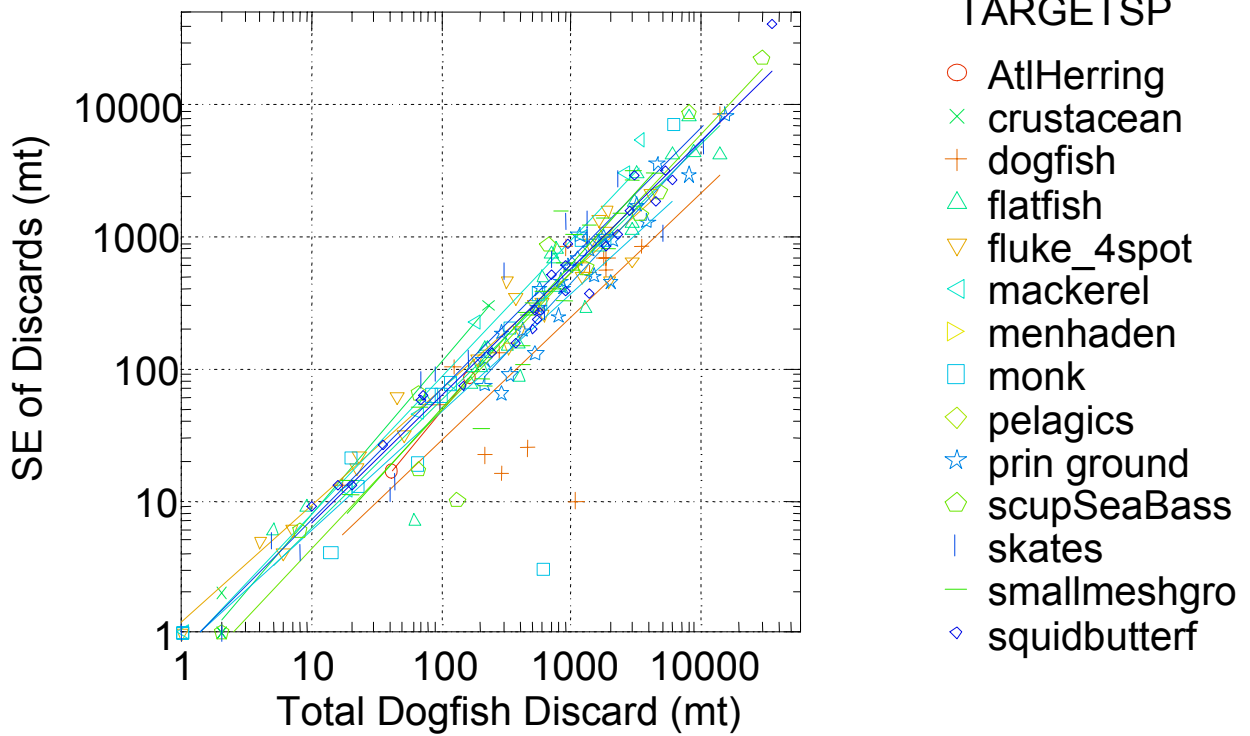


Fig. B4.15 Summary of total discard estimates based on catch ratio method (top) and comparisons with total landings in US, Canada and recreational fisheries, 1988-2002 fishing years. Bottom panel represents comparable estimates based on trip ratio estimator.

## Trawl Gear: SE discard vs Total discards



## Gill Net Gear: SE discard vs Total discards

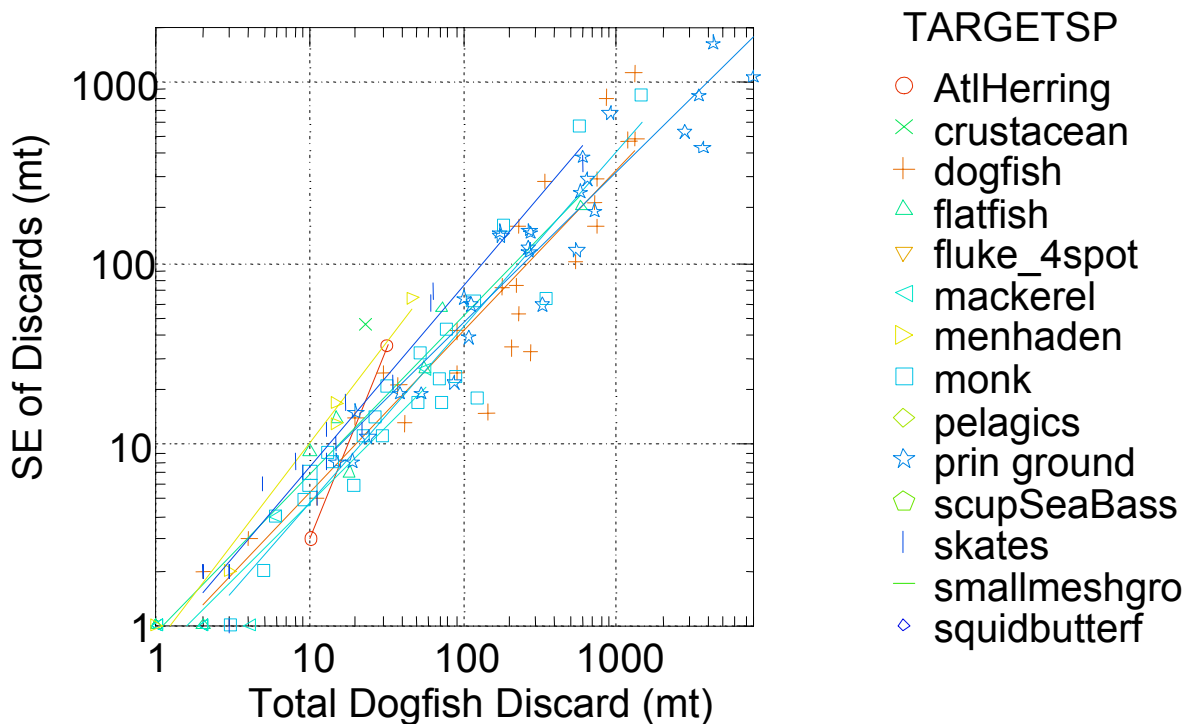


Fig. B4.16 Relationship between standard error of discard estimate and total discards by species group for trawl (top) and gill net (bottom) fisheries. All years combined.

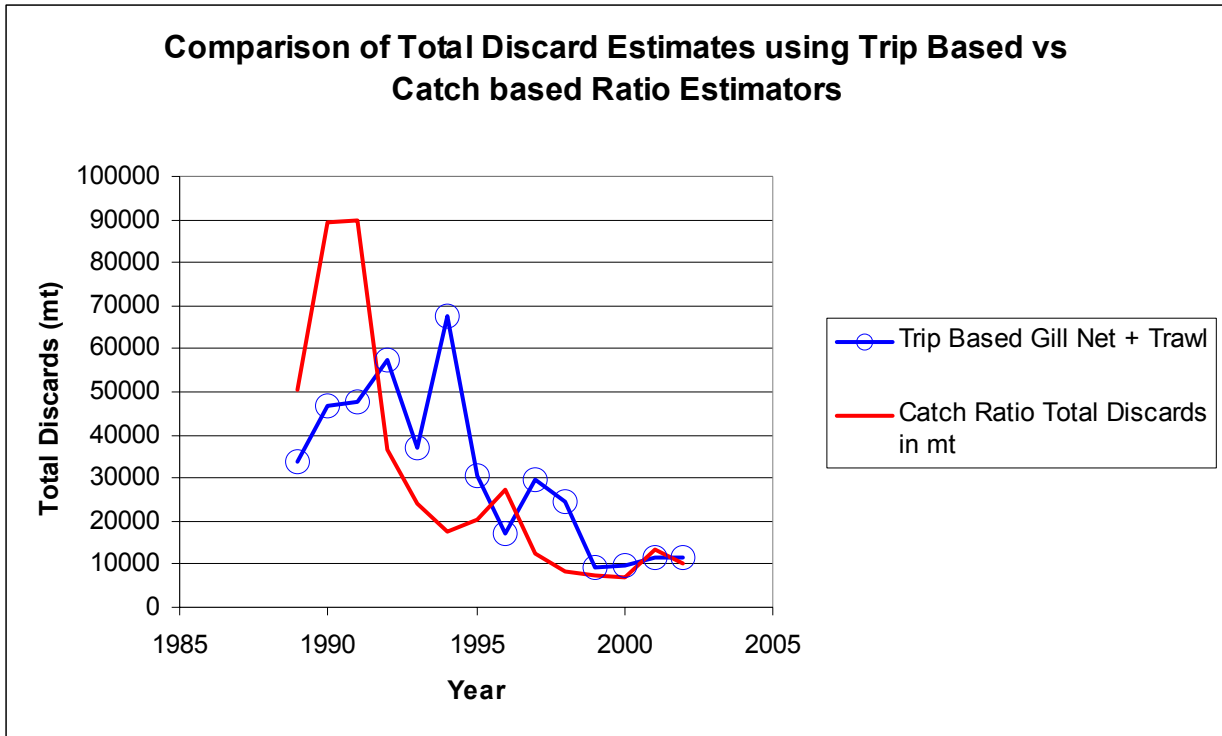


Fig. B4.17 Comparison of total discard estimates using catch ratio method with discard estimates using the trip-ratio method. Trip-based ratio estimator includes only gill net and trawl gear.

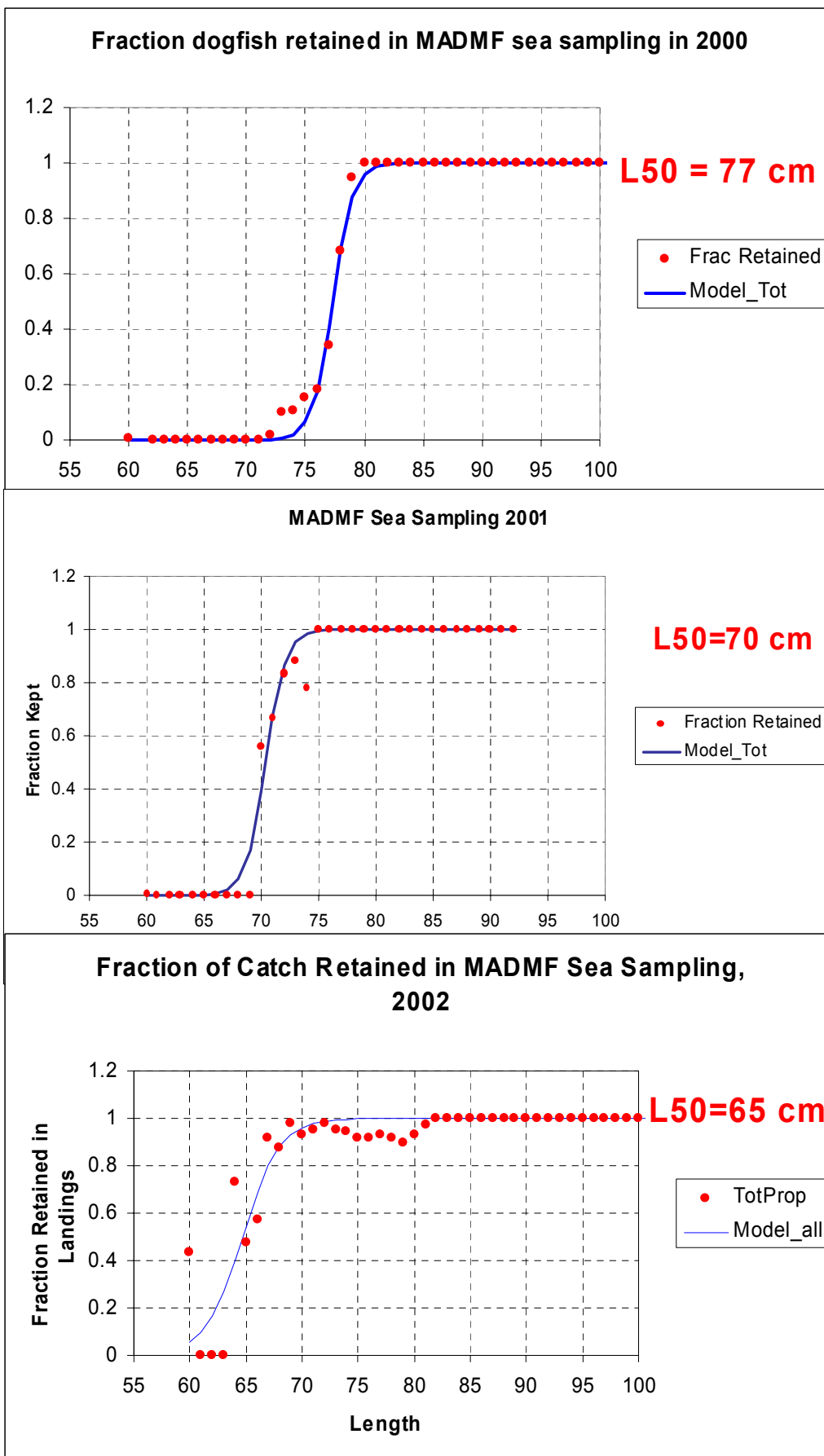


Fig. B4.18. Results of MADMf sea sampling data, 2000-02. Functions represent fits of logistic model to fraction retained by size class.

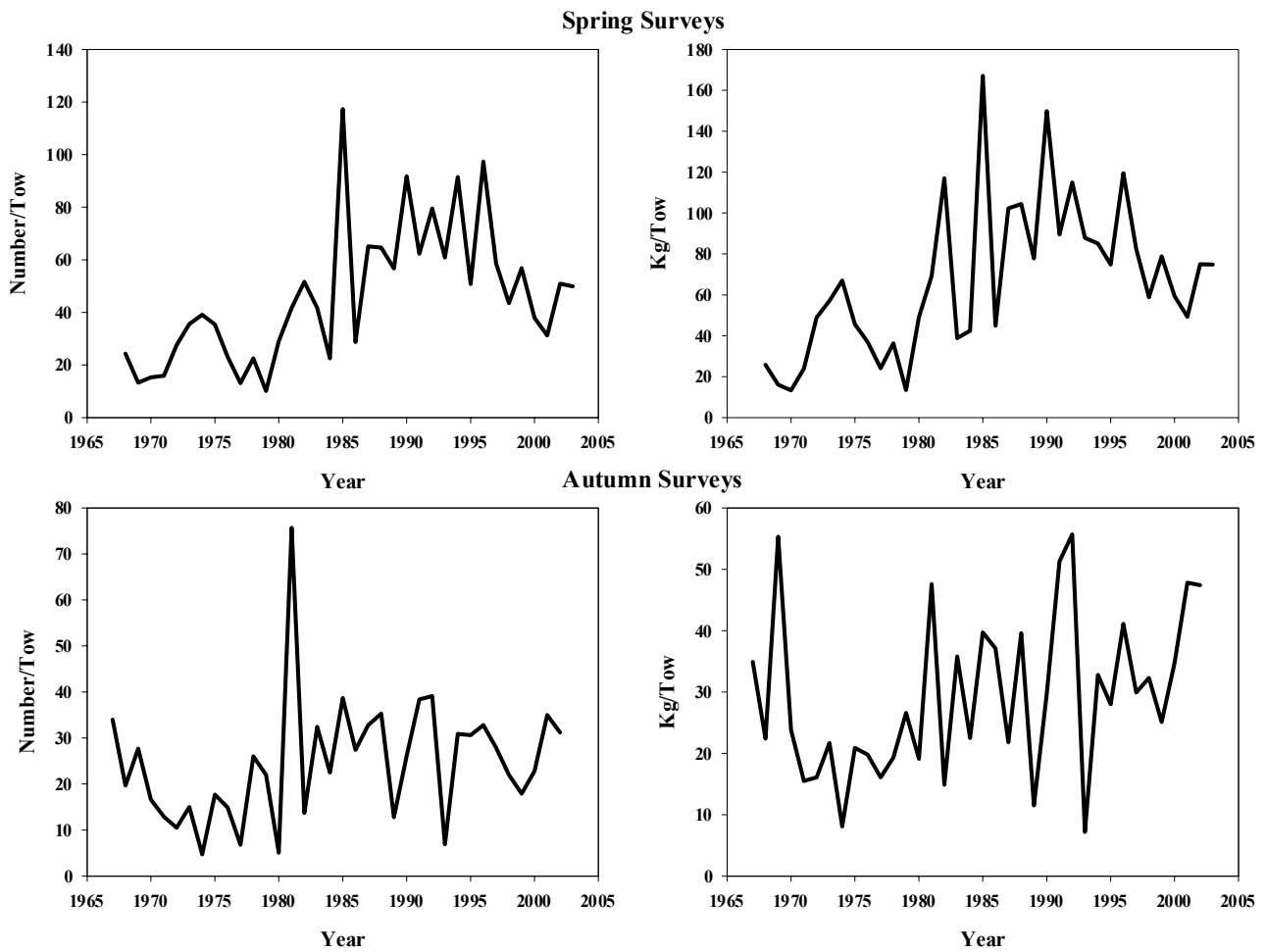


Figure B5.1. Abundance (stratified mean catch per tow in numbers) and biomass (stratified mean catch per tow in kilograms) indices of spiny dogfish from the NEFSC spring survey, 1968-2003, and autumn survey, 1967-2002 (Offshore strata 1-30, 33-40, 61-76).

## Spiny Dogfish, Numbers per Tow

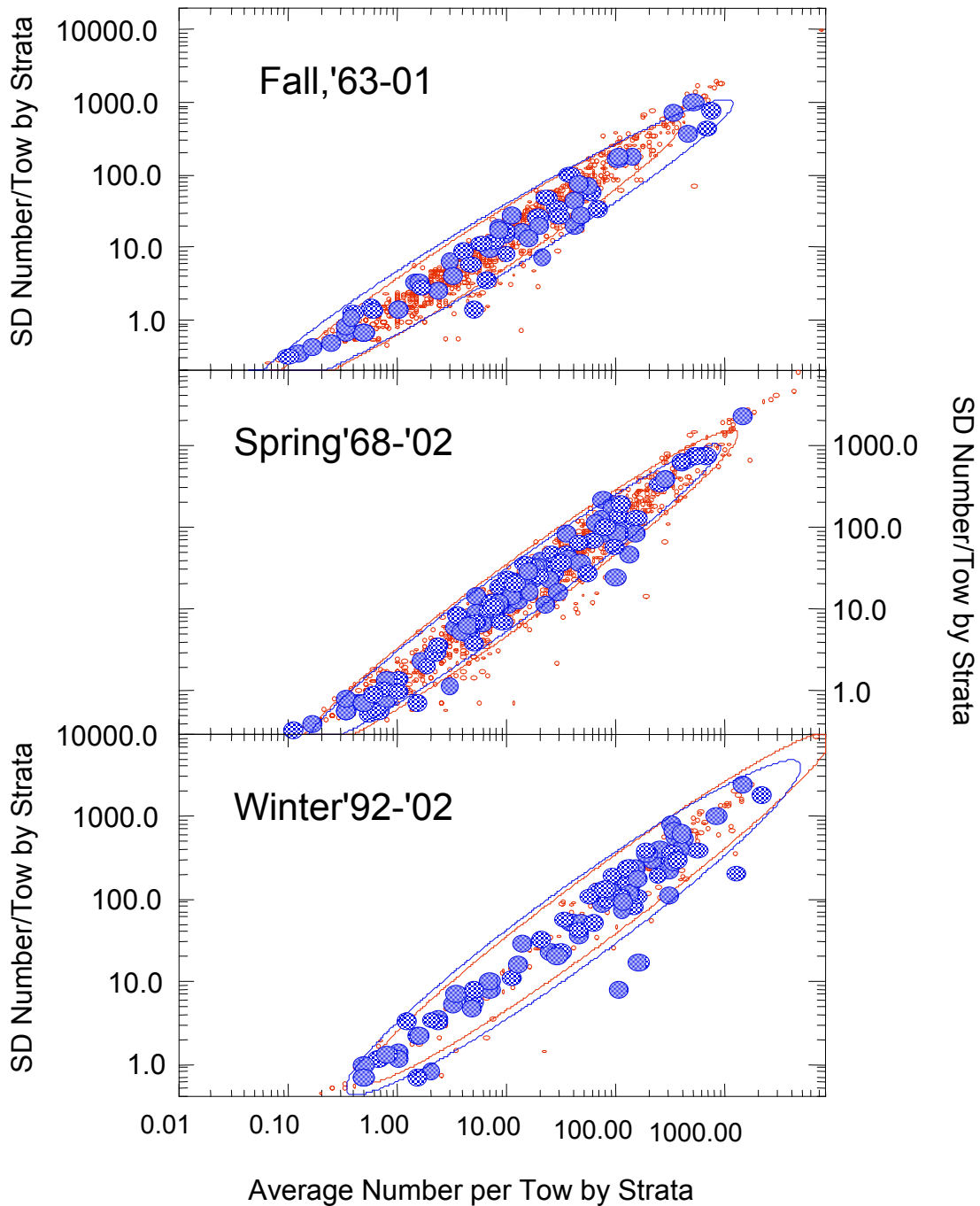


Figure B5.2. Standard deviation of catch in numbers vs. mean catch (#/tow) for Spiny Dogfish in NEFSC fall, spring and winter trawl surveys. Each dot represents a stratum. Small open dots represent data from 1999 and earlier, large solid circles represent data from 2000-02. Confidence ellipses (95%) are drawn for pre and post warp offset treatment period.

Spiny Dogfish  
Spring Survey Biomass Indices  
(Log-Transform vs. Arithmetic)

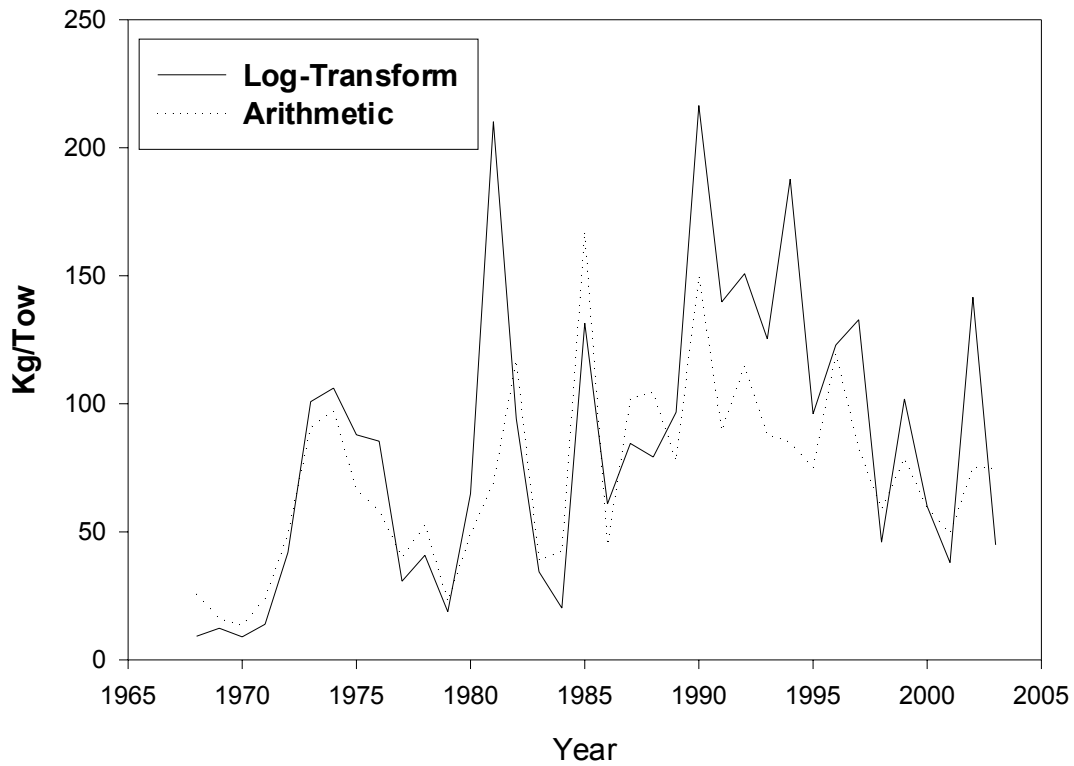


Figure B5.3. Biomass (stratified mean catch per tow in kilograms) indices of spiny dogfish comparing arithmetic and log-transformed means from the NEFSC spring survey, 1968-2003 (Offshore strata 1-30, 33-40, 61-76).

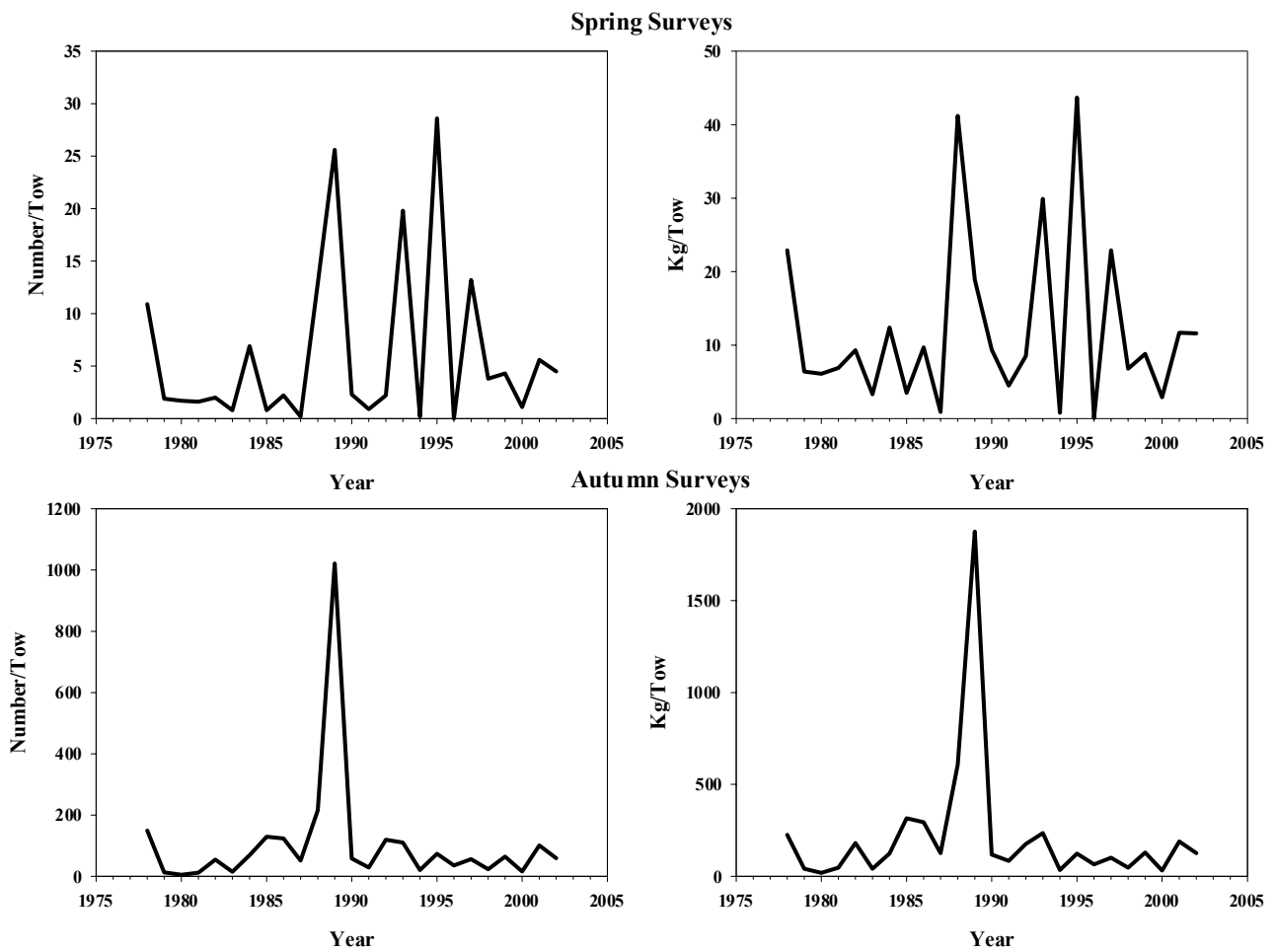
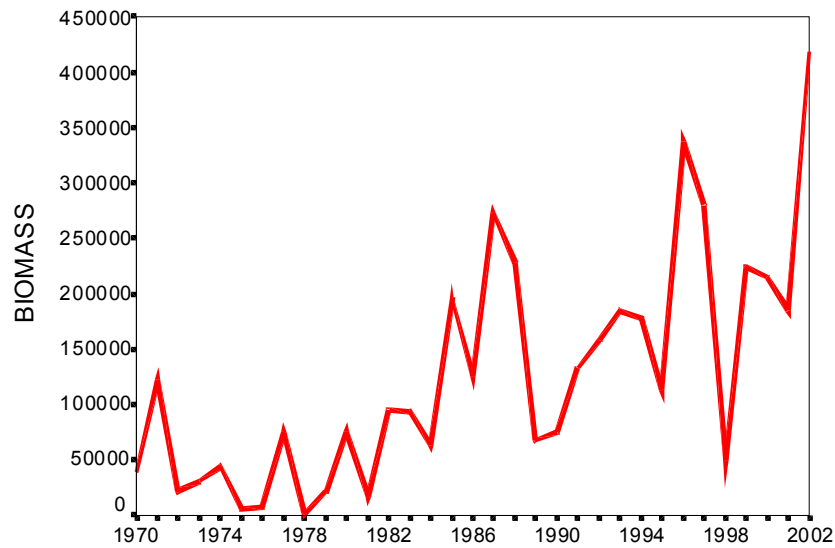


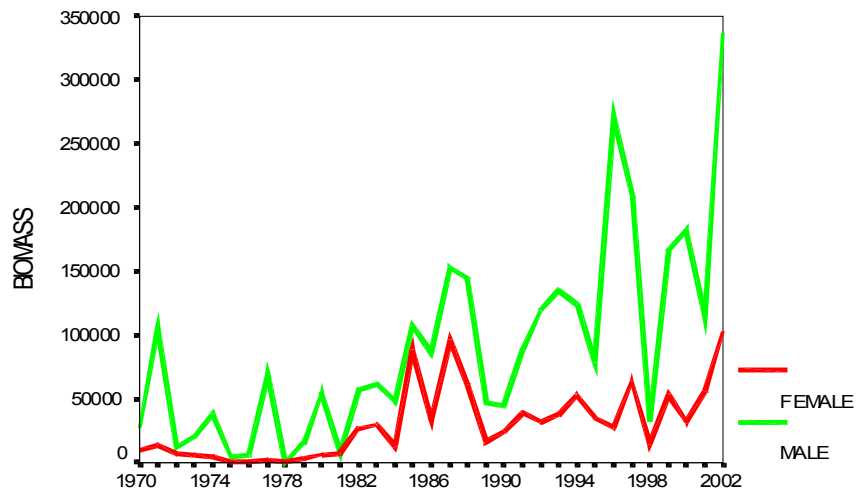
Figure B5.4 Abundance (mean catch per tow in numbers) and biomass (mean catch per tow in kilograms) indices of spiny dogfish from the Massachusetts spring and autumn surveys, 1978-2002.



### Canadian RV Summer Survey 1970 - 2002



### Canadian RV Summer Survey 1970 - 2002



### Canadian RV Summer Survey 1970 - 2002

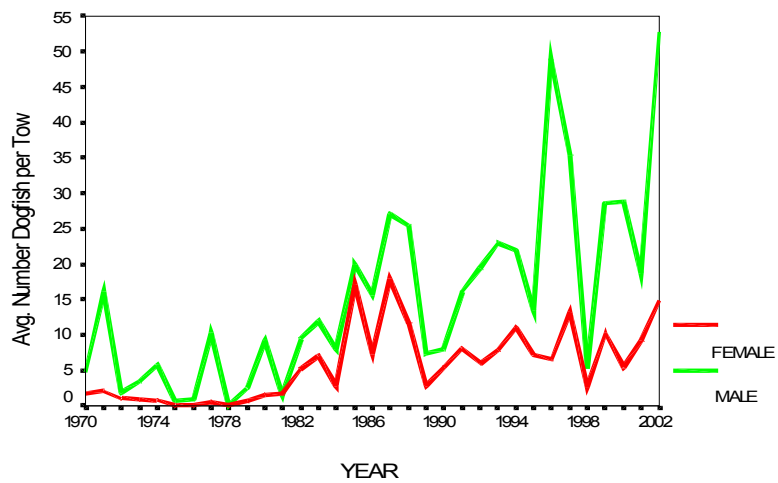


Fig. B5.5 Summary of abundance trends for spiny dogfish captured in Canadian R/V trawl surveys. Data provided courtesy of Steve Campana, DFO, Halifax.

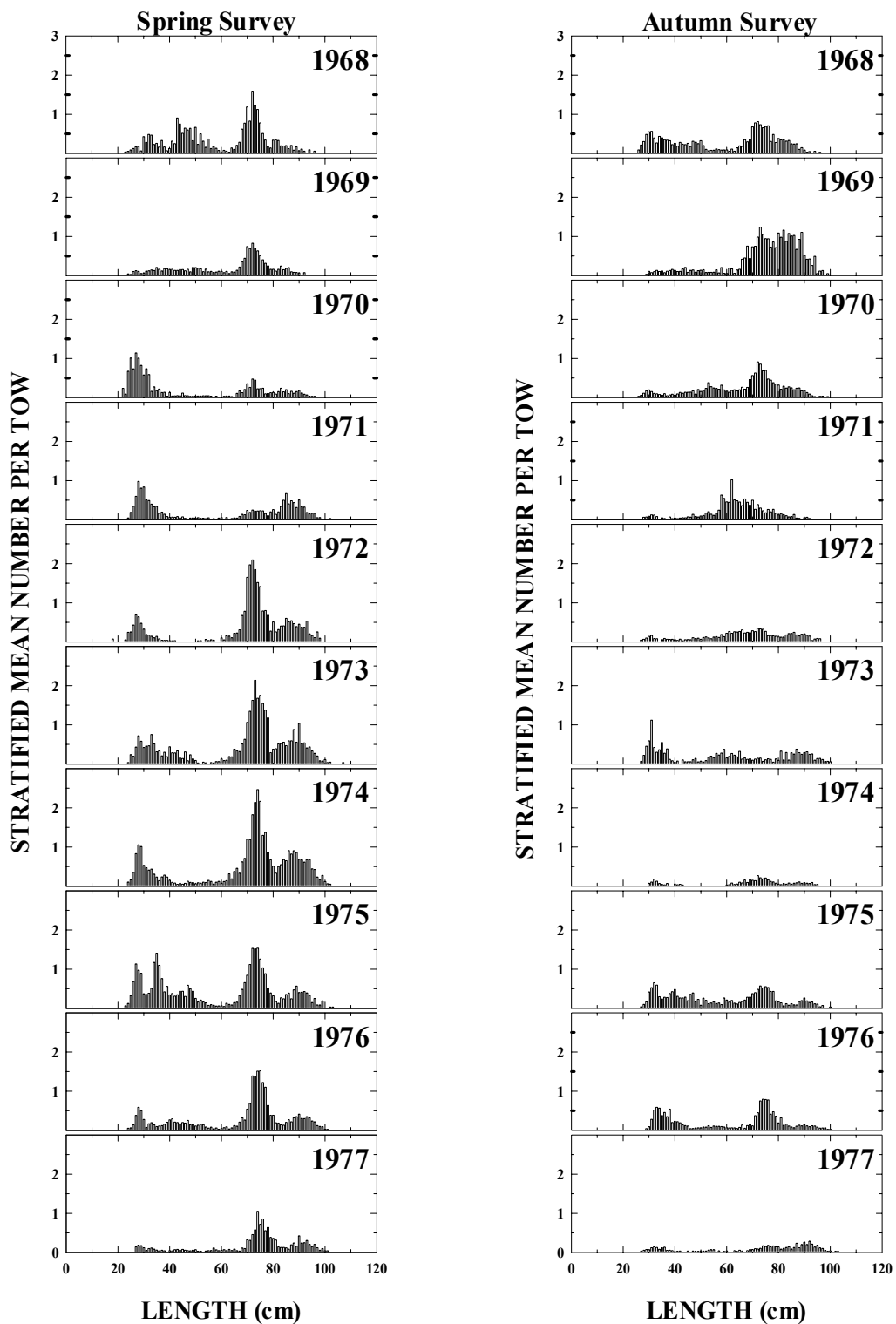


Figure B5.6.a. Length composition of spiny dogfish from the NEFSC spring and autumn bottom trawl survey, 1968-1977 (Offshore strata 1-30, 33-40, 61-76).

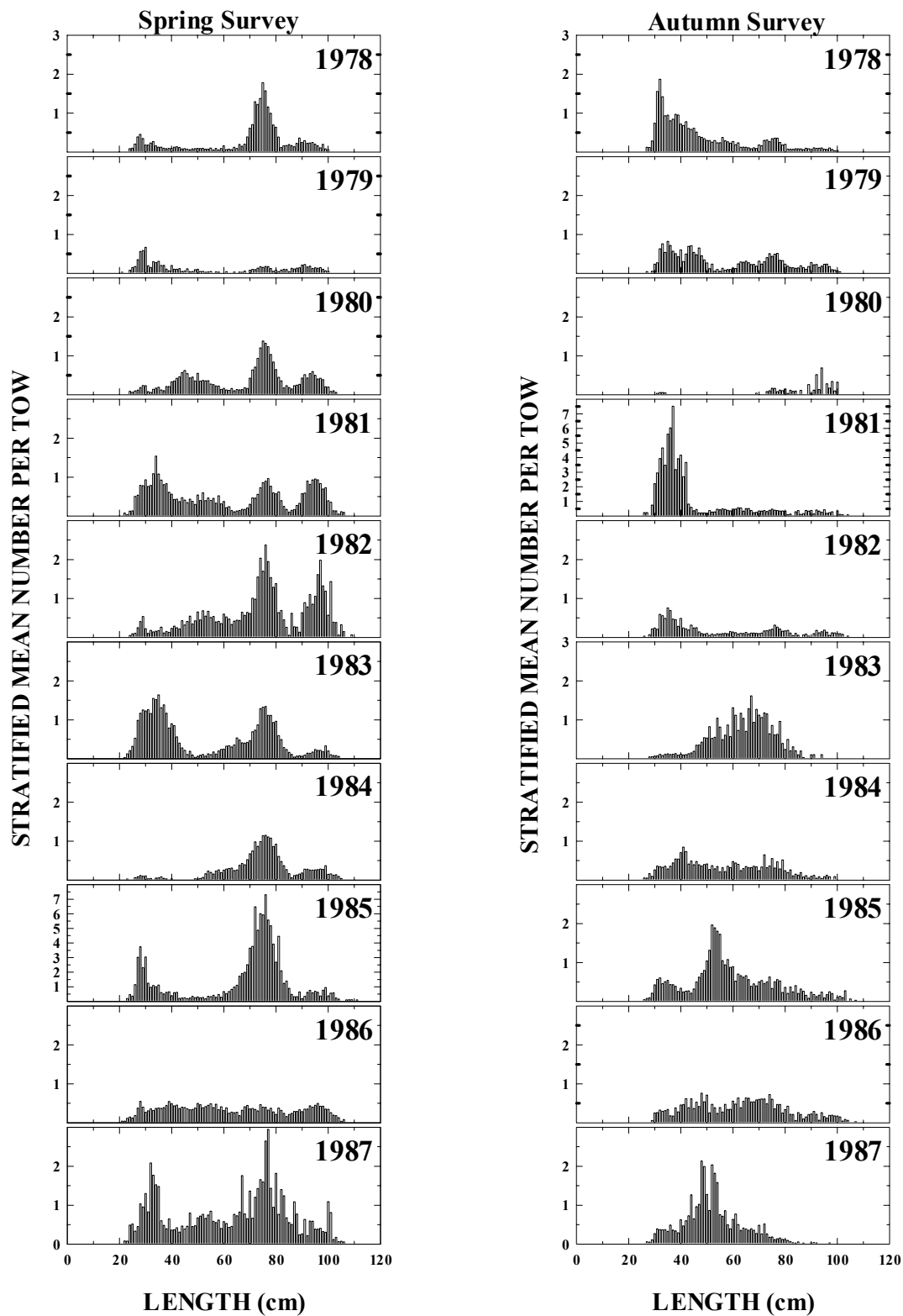


Figure B5.6 b. Length composition of spiny dogfish from the NEFSC spring and autumn bottom trawl survey, 1978-1987 (Offshore strata 1-30, 33-40, 61-76). Note the scales for spring 1985 and autumn 1981 are higher.

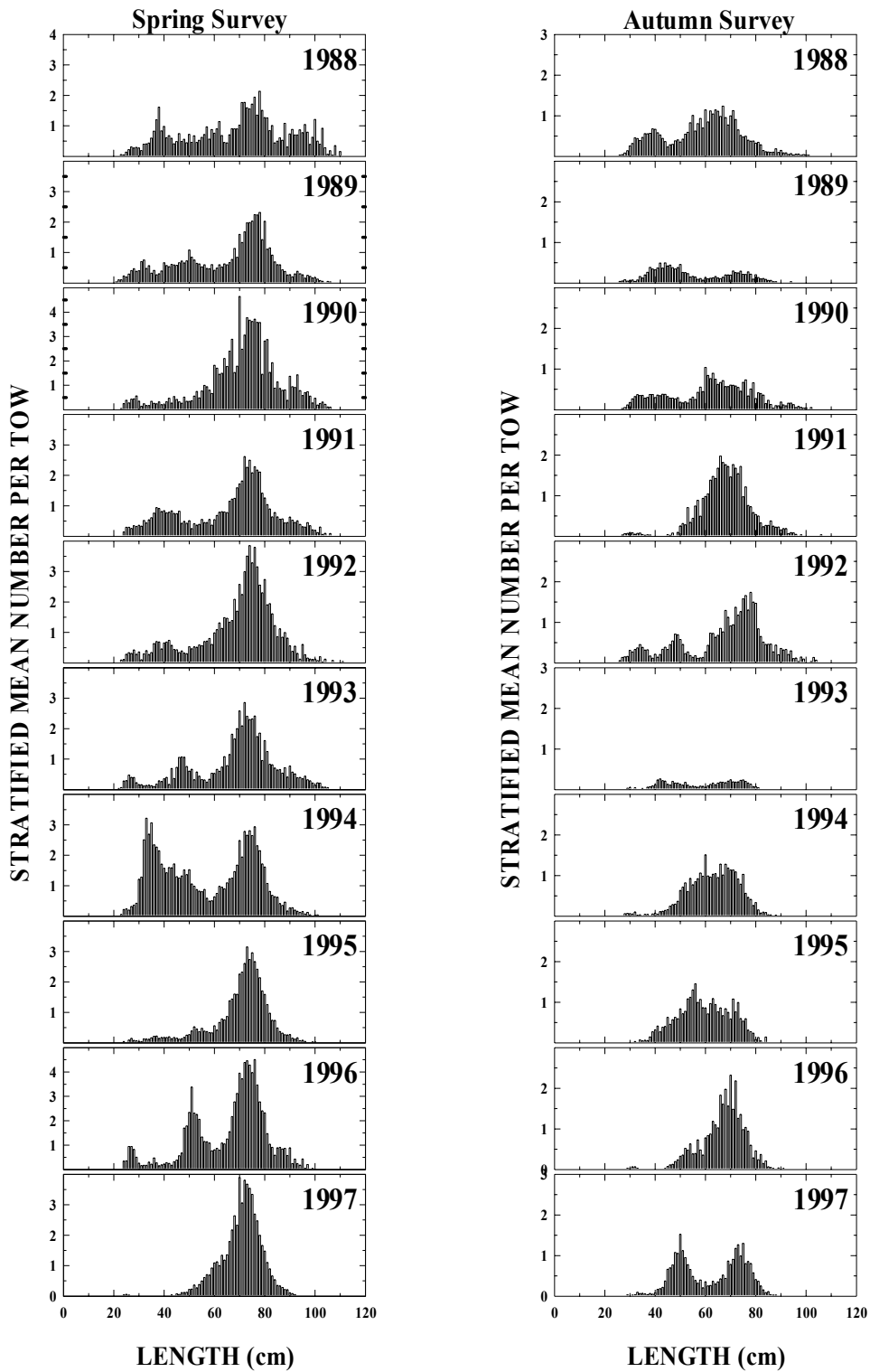


Figure B5.6 c. Length composition of spiny dogfish from the NEFSC spring and autumn bottom trawl survey, 1988-1997 (Offshore strata 1-30, 33-40, 61-76). Note the scales for spring and autumn differ and spring 1990 and 1996 are also different.

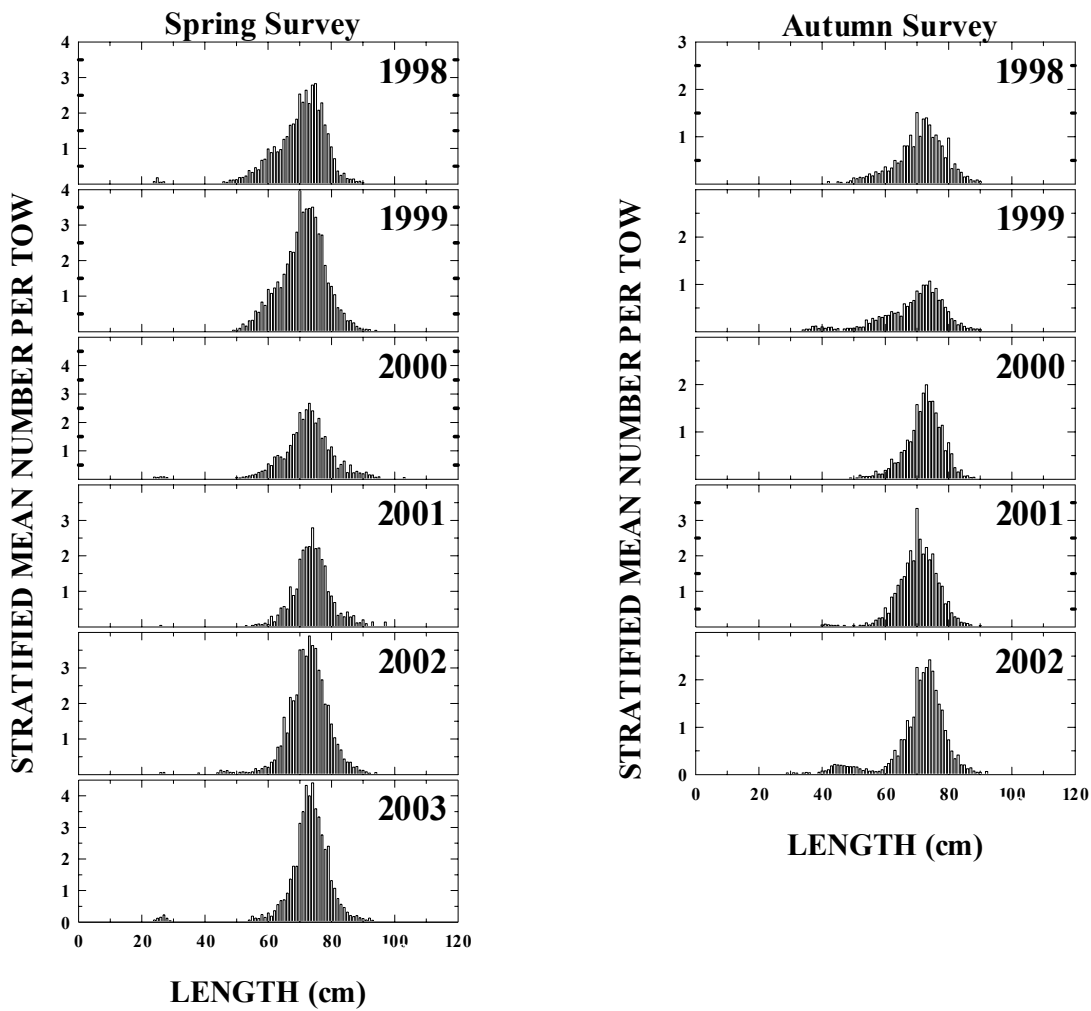


Figure B5.6d. Length composition of spiny dogfish from the NEFSC spring and autumn bottom trawl survey, 1998-2003 (Offshore strata 1-30, 33-40, 61-76). Note the scales for spring and autumn differ and spring 2002 and autumn 2001 are also different.

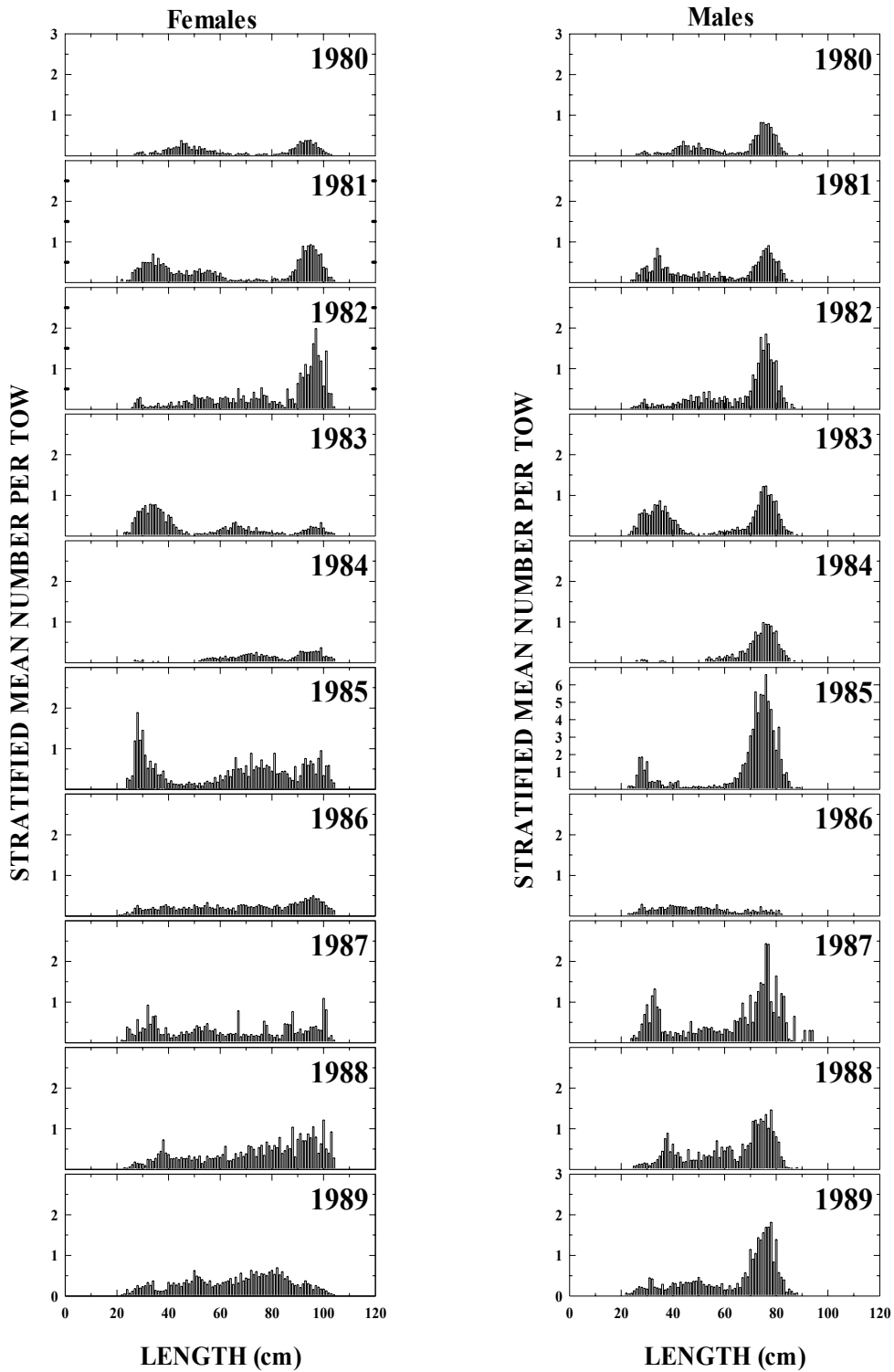


Figure B5.7 a. Length composition of male and female spiny dogfish from the NEFSC spring bottom trawl surveys, 1980-1989 (Offshore strata 1-30, 33-40, 61-76). Note the scale for males in 1985 is larger.

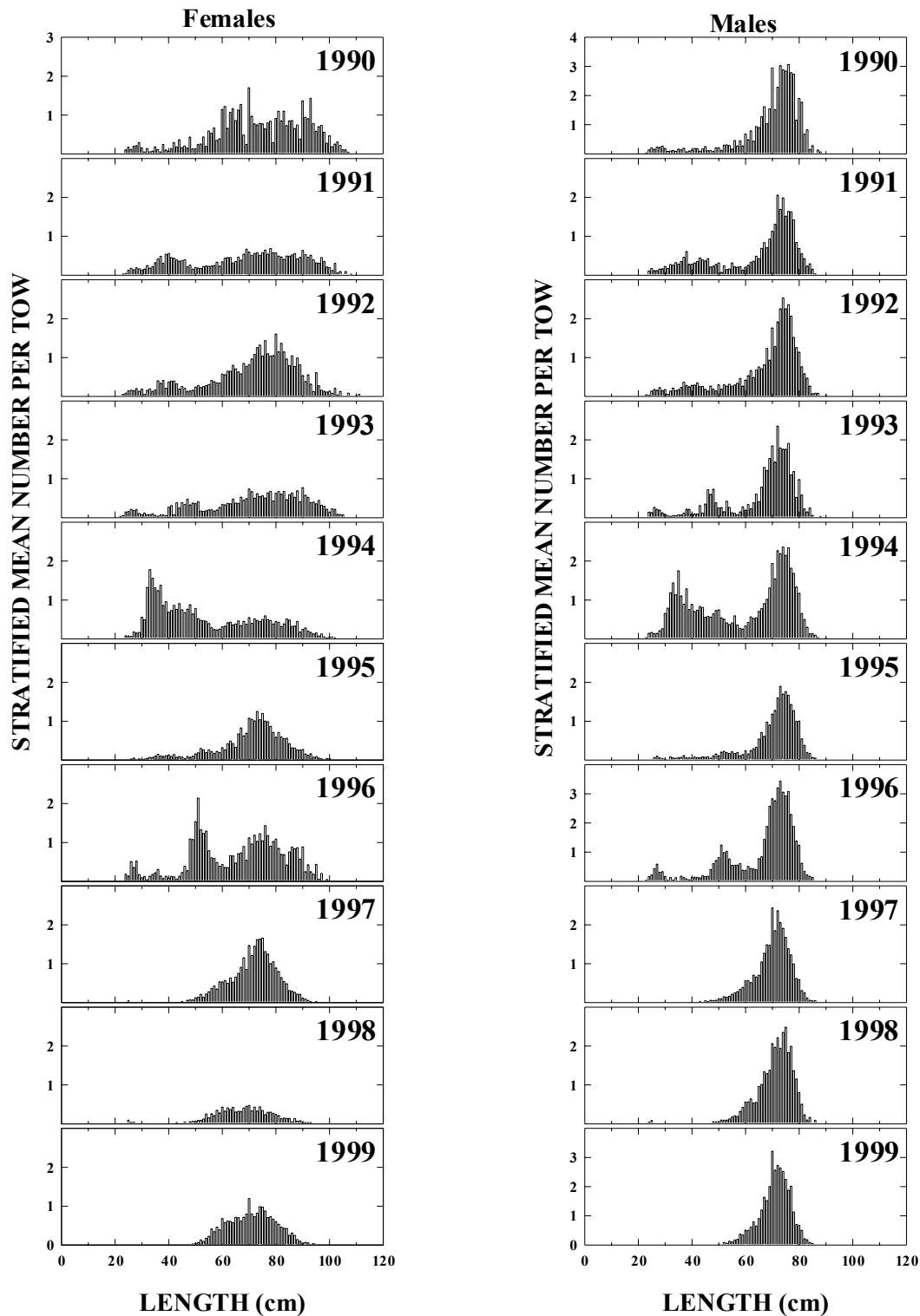


Figure B5.7 b. Length composition of male and female spiny dogfish from the NEFSC spring bottom trawl surveys, 1989-1999 (Offshore strata 1-30, 33-40, 61-76). Note the scales for males in 1990, 1996, and 1999 are larger.

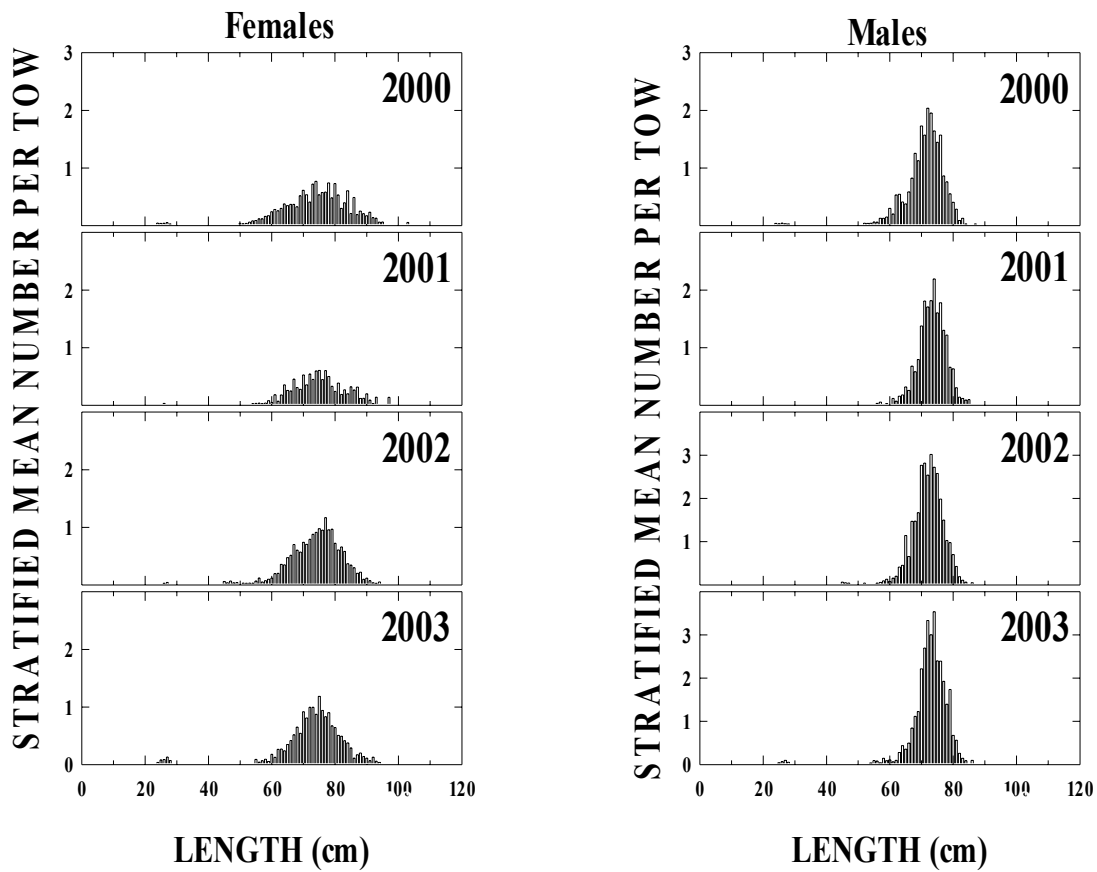


Figure B5.7 c. Length composition of male and female spiny dogfish from the NEFSC spring bottom trawl surveys, 2000-2003 (Offshore strata 1-30, 33-40, 61-76). Note the scale for males in 2002 is different.



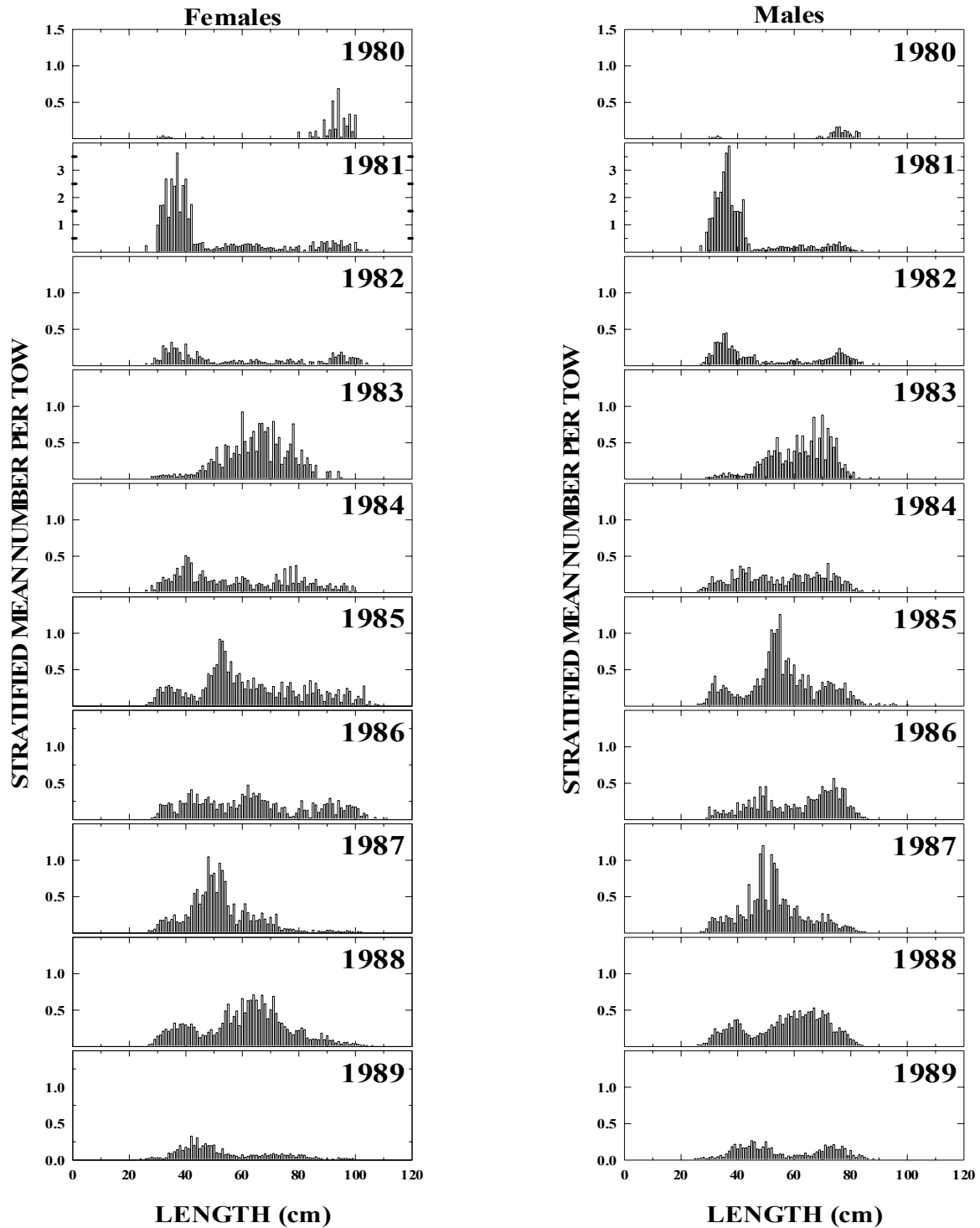


Figure B5.8 a. Length composition of male and female spiny dogfish from the NEFSC autumn bottom trawl surveys, 1980-1989 (Offshore strata 1-30, 33-40, 61-76). Note the scale for males in 1981 is larger.

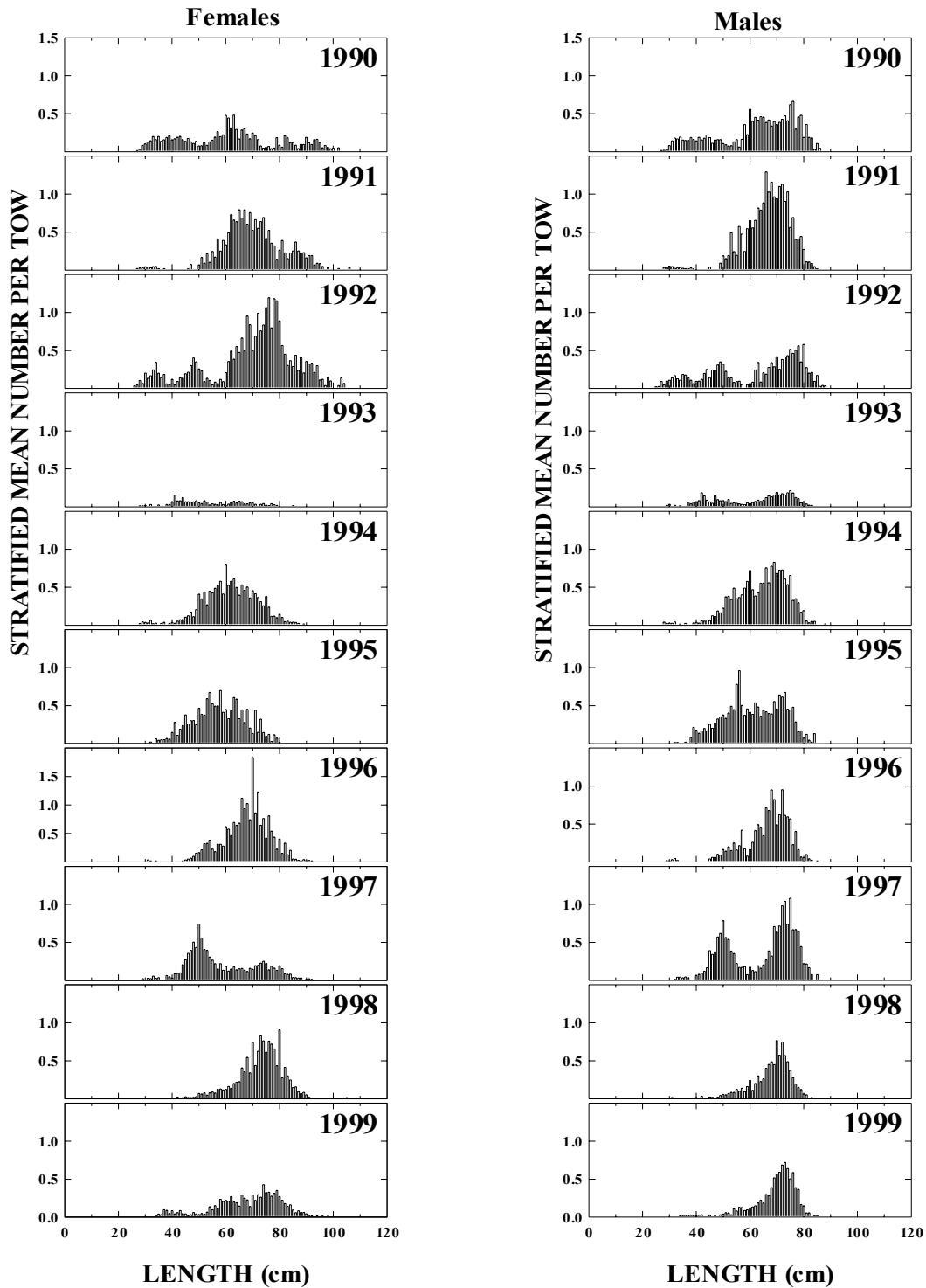


Figure B5.8 b. Length composition of male and female spiny dogfish from the NEFSC autumn bottom trawl surveys, 1990-1999 (Offshore strata 1-30, 33-40, 61-76). Note the scale for females in 1996 is larger.

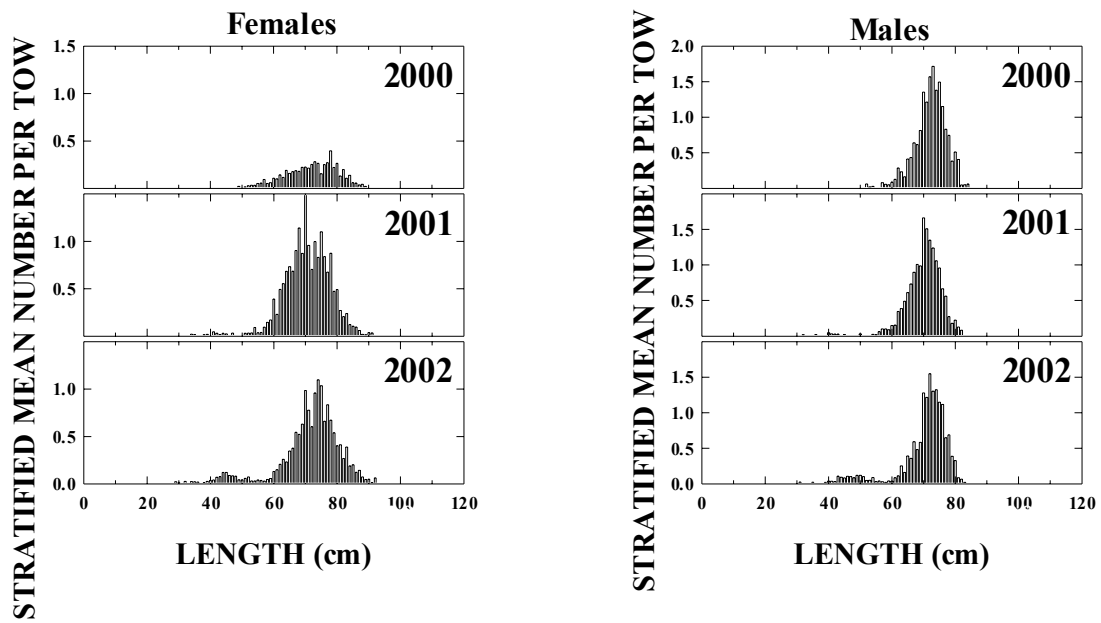


Figure B5.8c. Length composition of male and female spiny dogfish from the NEFSC autumn bottom trawl surveys, 2000-2002 (Offshore strata 1-30, 33-40, 61-76). Note the scale for males is different from previous figures.

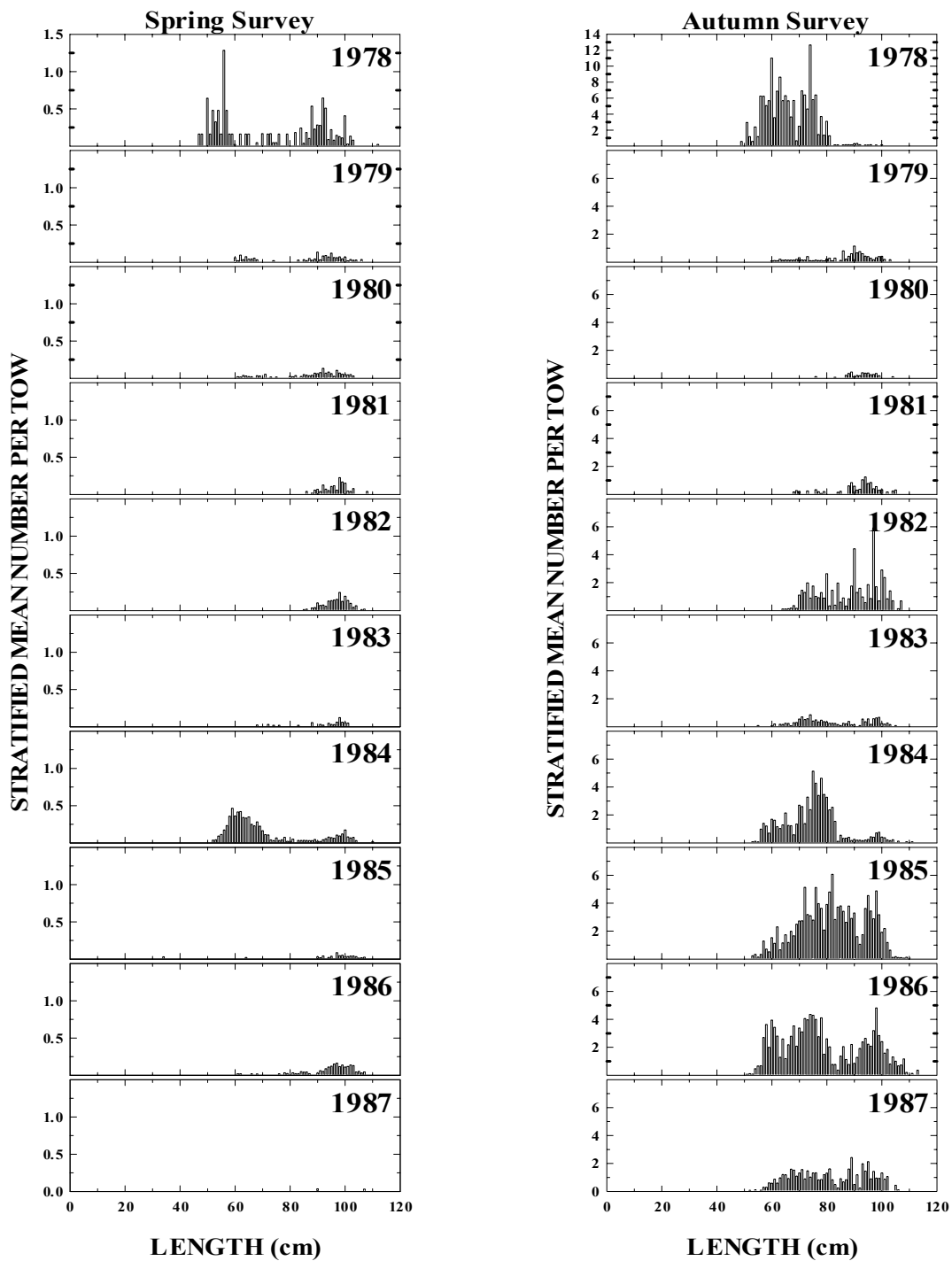


Figure B5.9 a. Length composition of spiny dogfish from the Massachusetts spring and autumn bottom trawl surveys, 1978-1987. Note the scales for spring and autumn differ and autumn 1978 is higher.

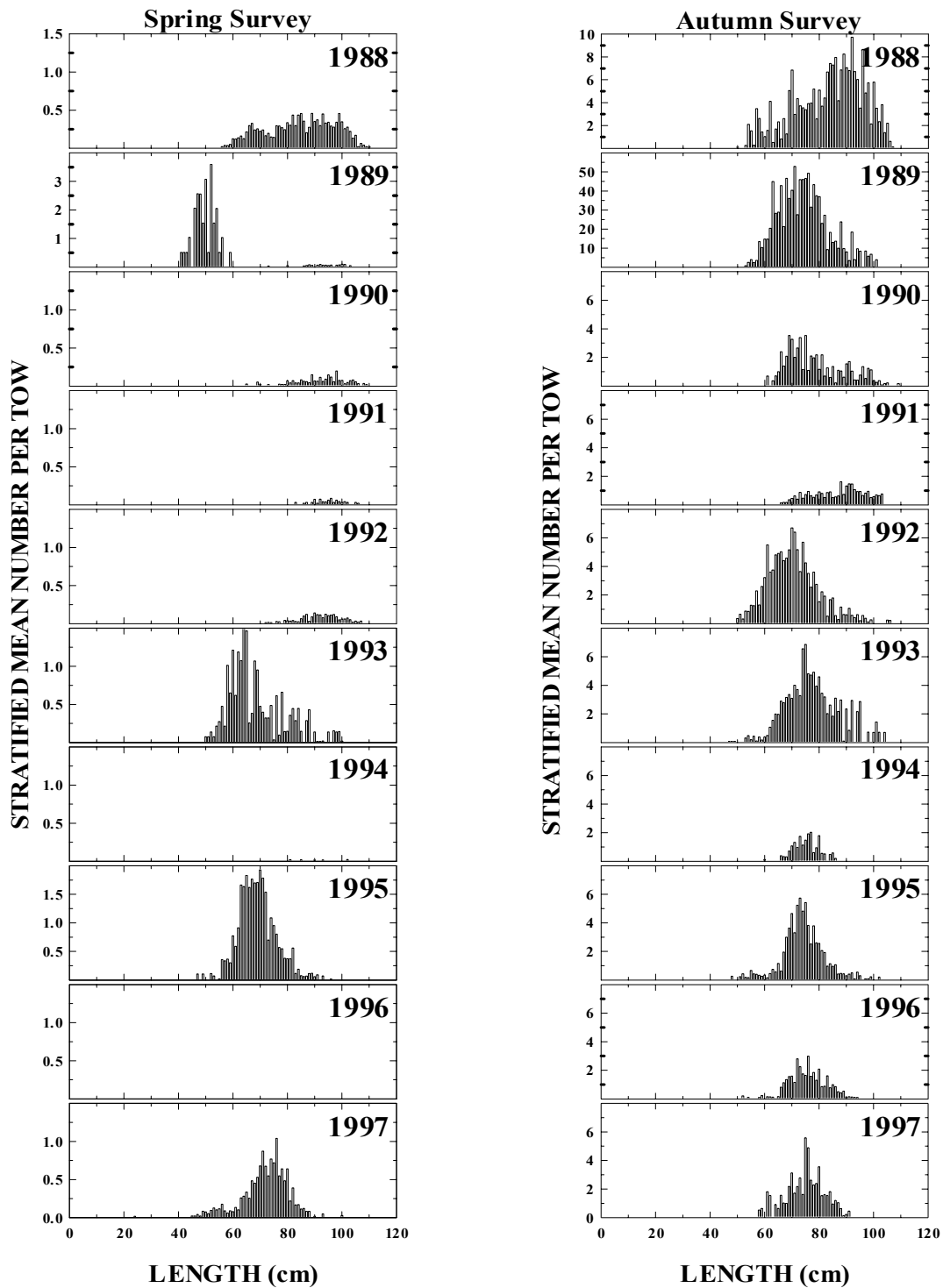


Figure B5.9 b. Length composition of spiny dogfish from the Massachusetts spring and autumn bottom trawl surveys, 1988-1997. Note the scales for spring and autumn differ and spring (1989,1995) autumn (1988,1989) are also different.

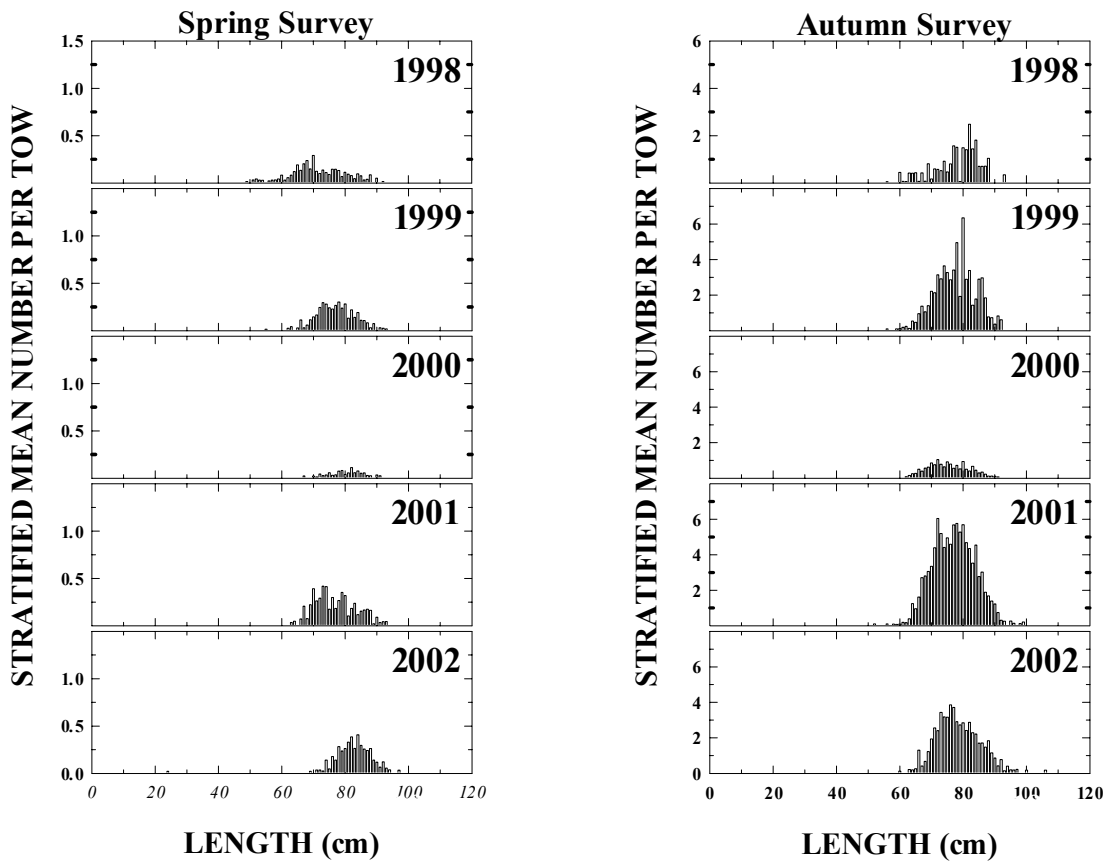


Figure B5.9c. Length composition of spiny dogfish from the Massachusetts spring and autumn bottom trawl surveys, 1998-2002.

# Swept Area Biomass: All Sizes

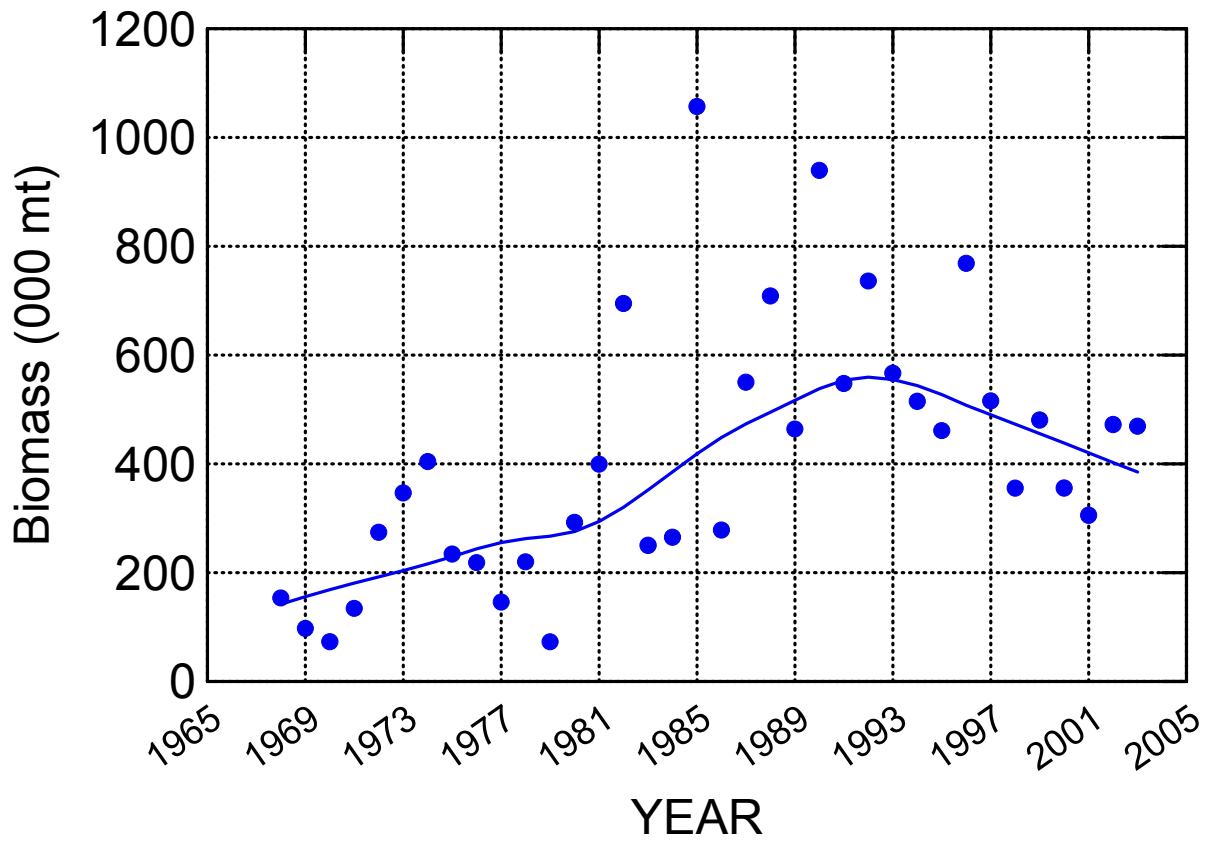
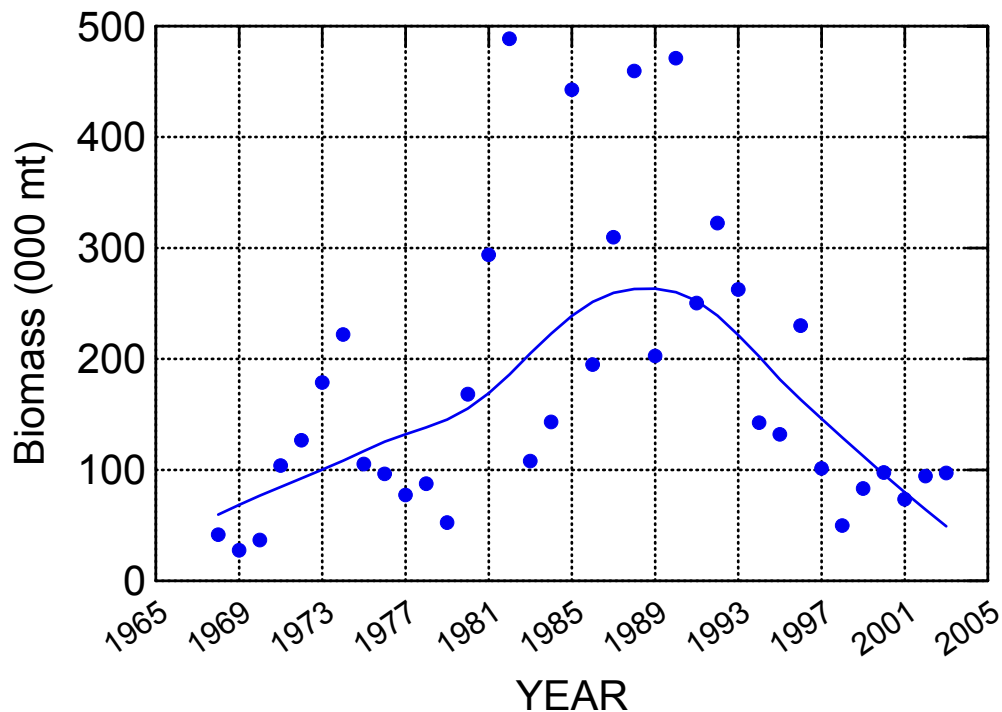


Fig. 6.1 Swept area estimate of total dogfish biomass (000 mt) in spring R/V trawl survey, 1968-2003. Line represents Lowess smooth with tension factor = 0.5.

### Swept Area Biomass: All $\geq 80$ cm



### Swept Area Biomass: All 36-79cm

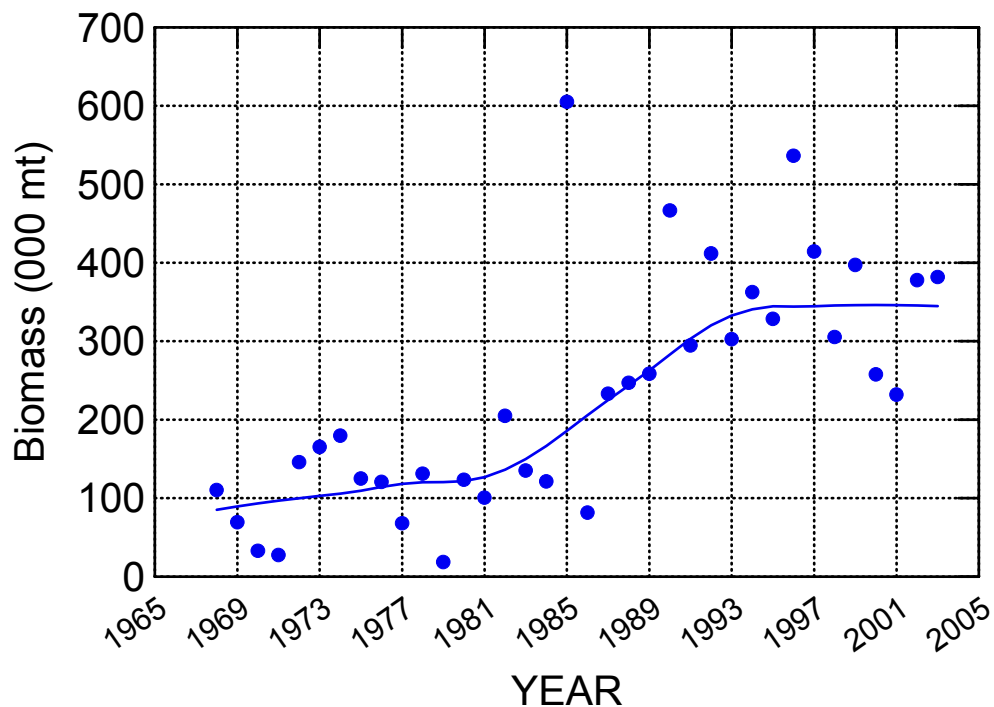
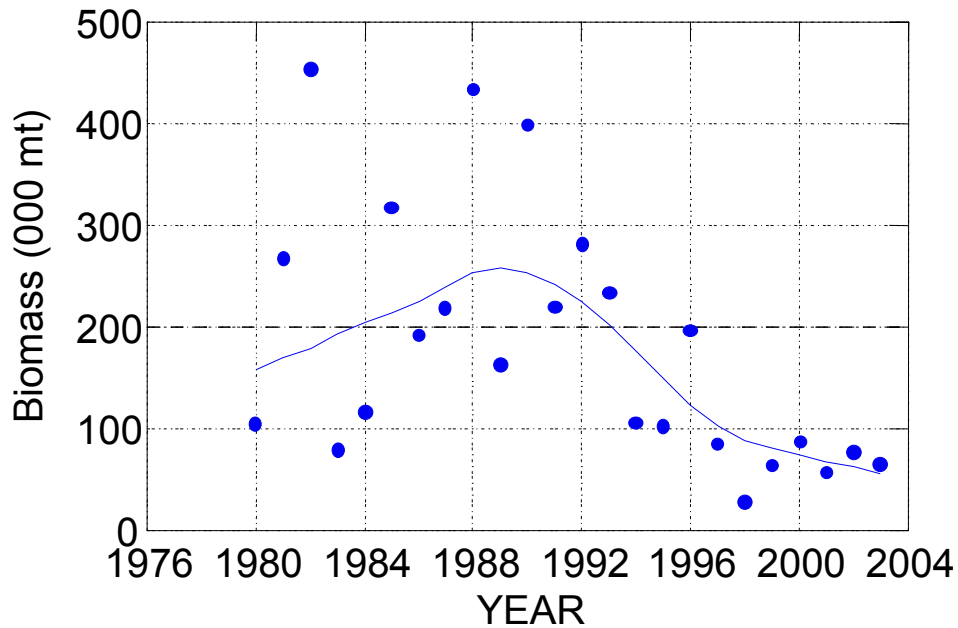


Fig. 6.2 Swept area estimate of dogfish biomass (000 mt) in spring R/V trawl survey, 1968-2003 for dogfish greater than 80 cm (top) and 36-79 cm (bottom). Both sexes combined. Line represents Lowess smooth with tension factor = 0.5.



## Swept Area Biomass: Females $\geq 80$ cm



## Swept Area Biomass: Males $\geq 80$ cm

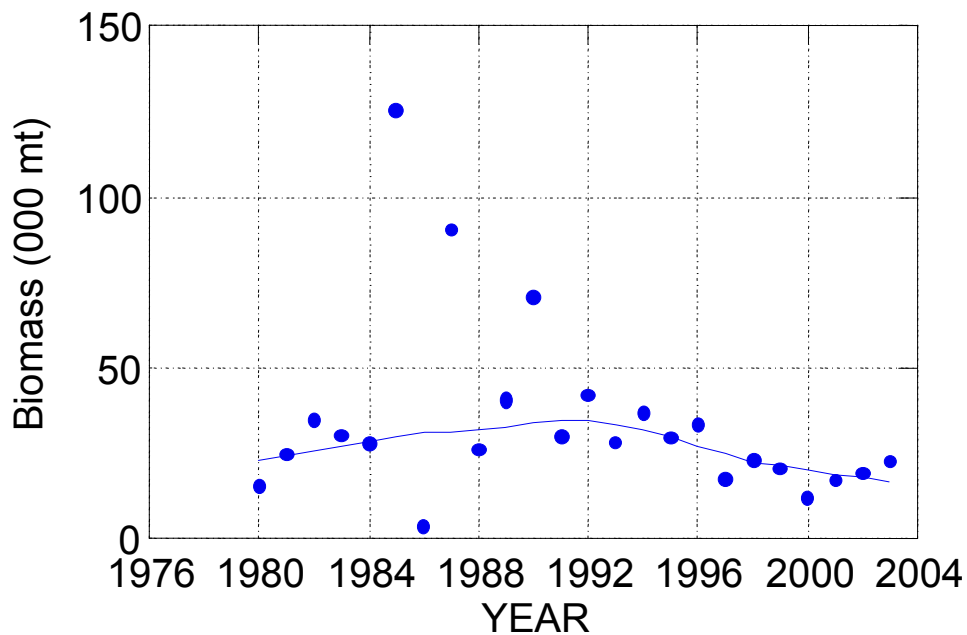
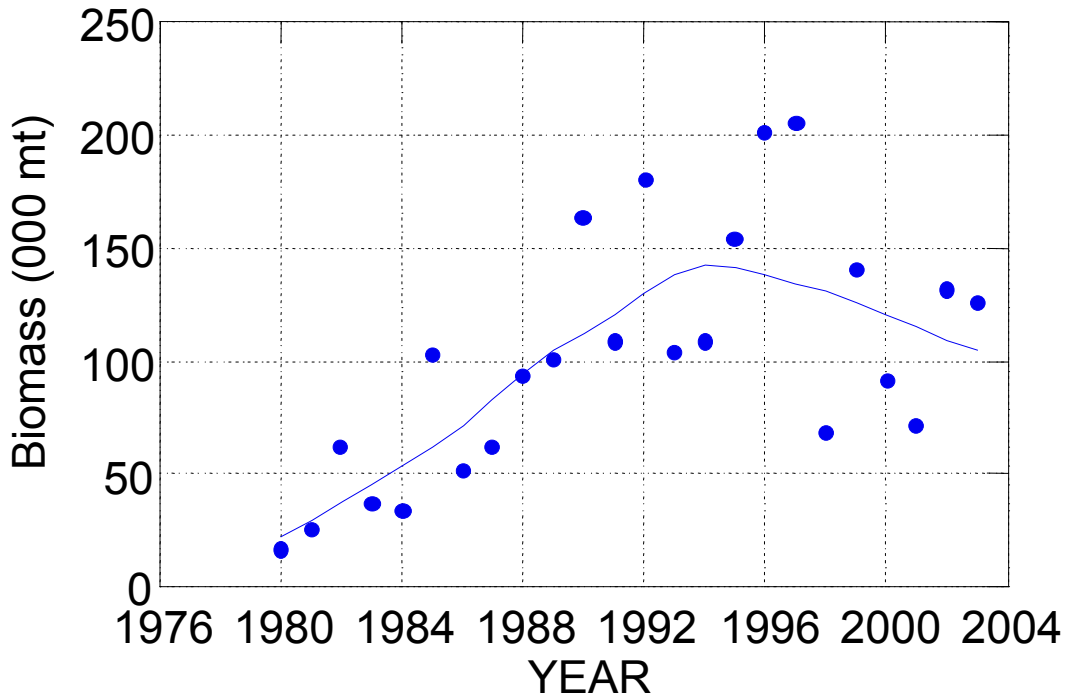


Fig. B6.3 Swept area estimate of dogfish biomass (000 mt) by sex in spring R/V trawl survey, 1980-2003 for dogfish greater than 80 cm, Females (top) and males (bottom). Line represents Lowess smooth with tension factor = 0.5.

## Swept Area Biomass: Females 36-79cm



## Swept Area Biomass: Males 36-79cm

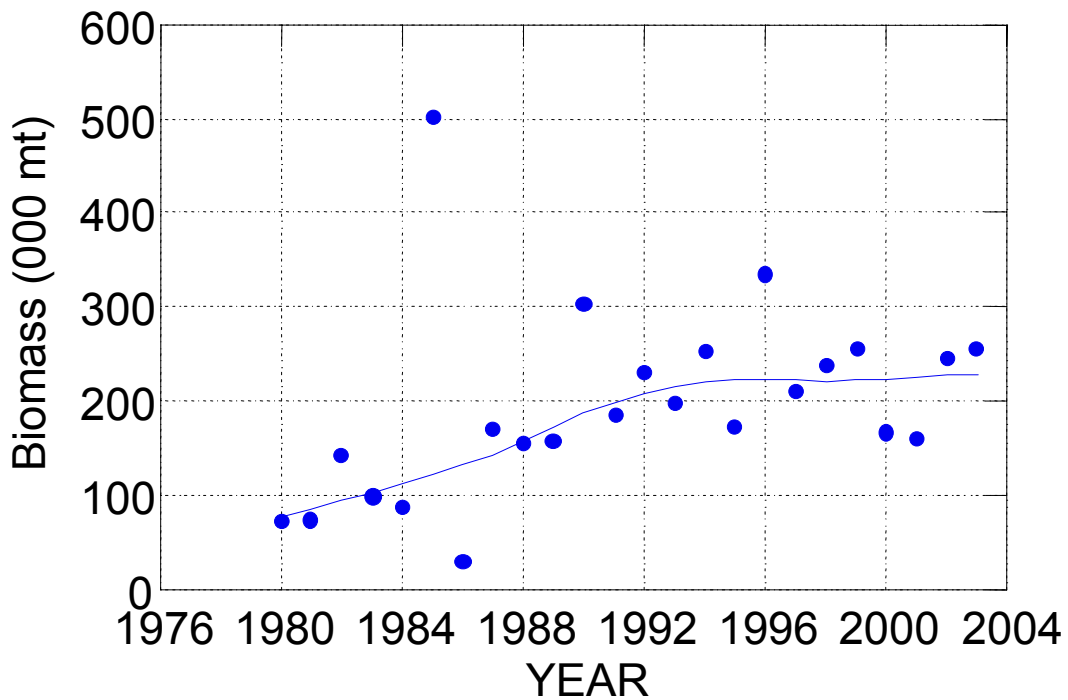


Fig. B6.4 Swept area estimate of dogfish biomass (000 mt) by sex in spring R/V trawl survey, 1980-2003 for dogfish between 36-79 cm, Females (top) and males (bottom). Line represents Lowess smooth with tension factor = 0.5.

# Swept Area Biomass, Pups, Nominal Footprint

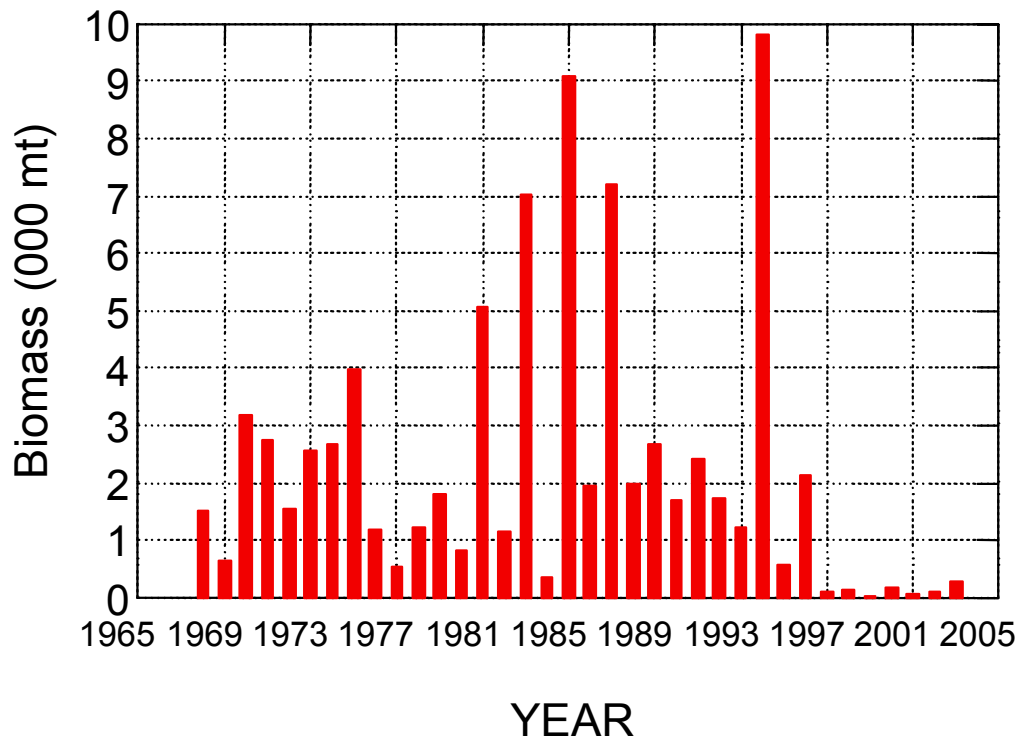


Fig. B6.5 Swept area estimate of dogfish biomass (000 mt) recruits in spring R/V trawl survey, 1968-2003. Recruits defined as individuals less than 36 cm.

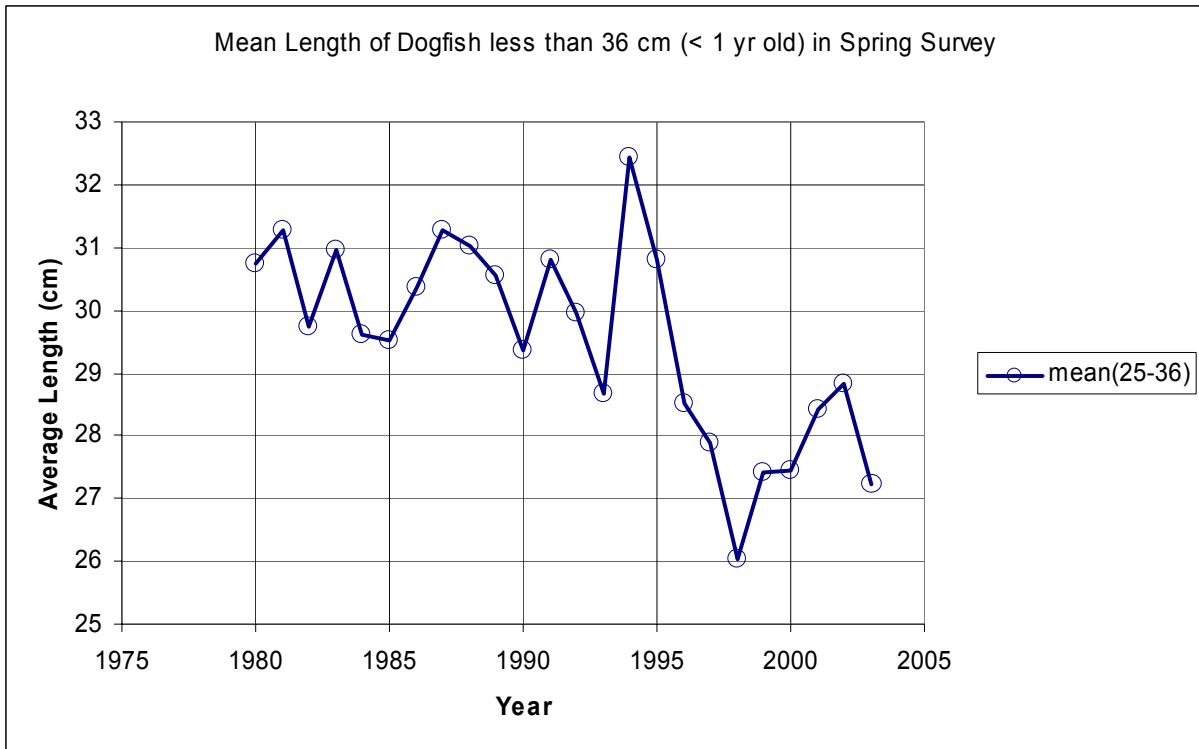
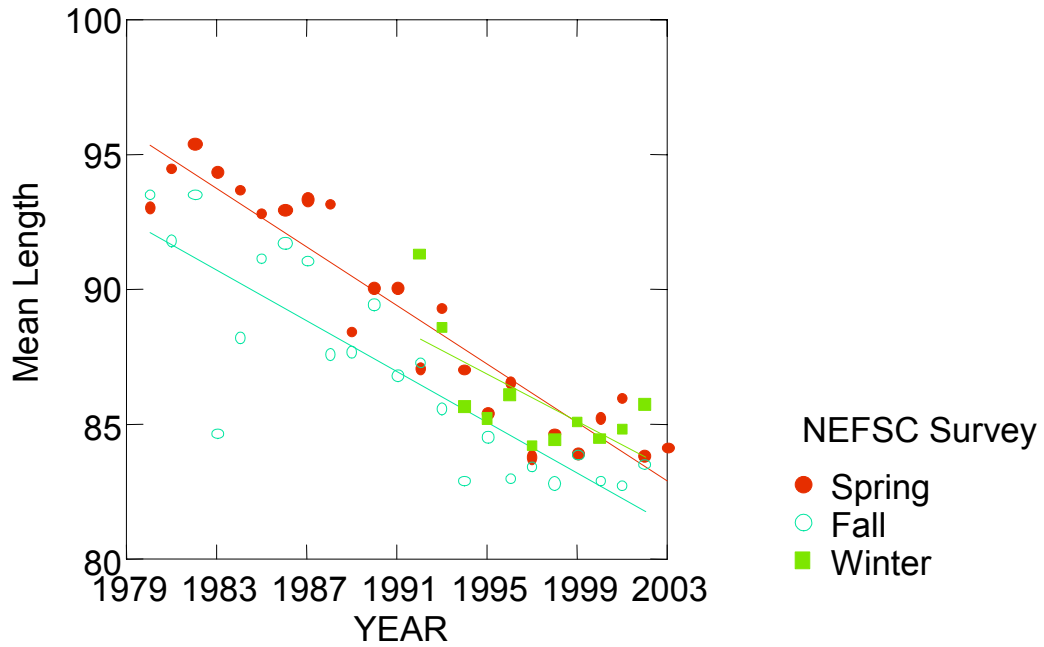


Fig. B6.6 Trend in average size of dogfish recruits, 1980-2003. Recruits defined as individuals less than 36 cm.

## Female Dogfish >80 cm, NEFSC surveys



## Female Dogfish >80 cm, MADMF Surveys

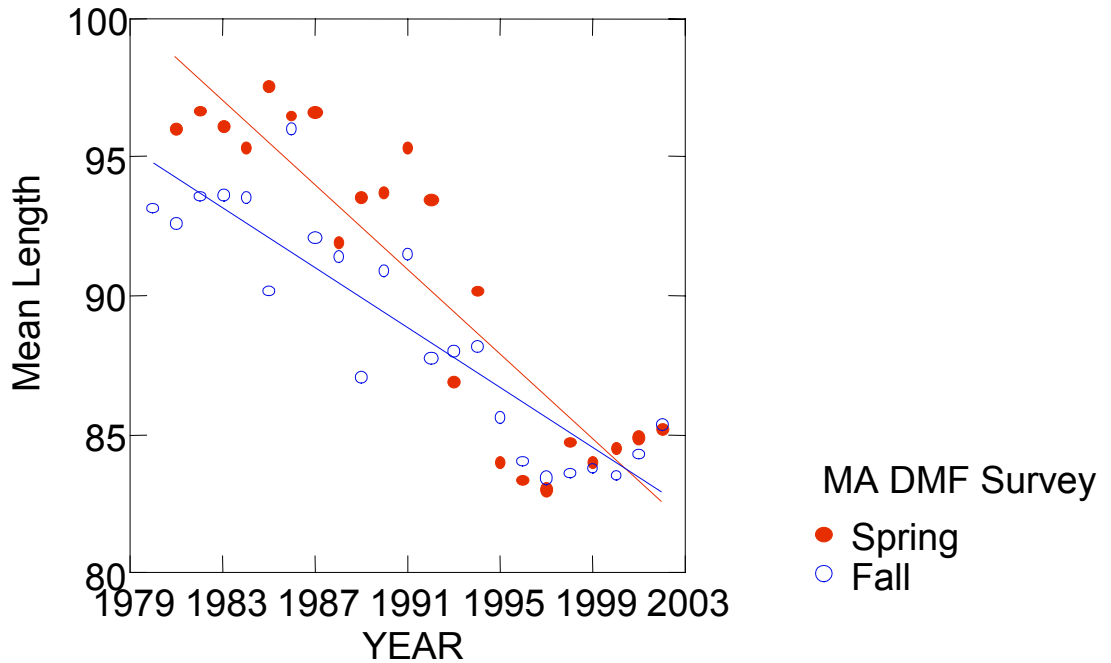


Fig. B6.7 Average size of mature female dogfish (>80cm) in NMFS R/V surveys, 1980-2003, (top) and MADMF R/V surveys (bottom), 1980-2002.

## Female Dogfish >80 cm, All Surveys

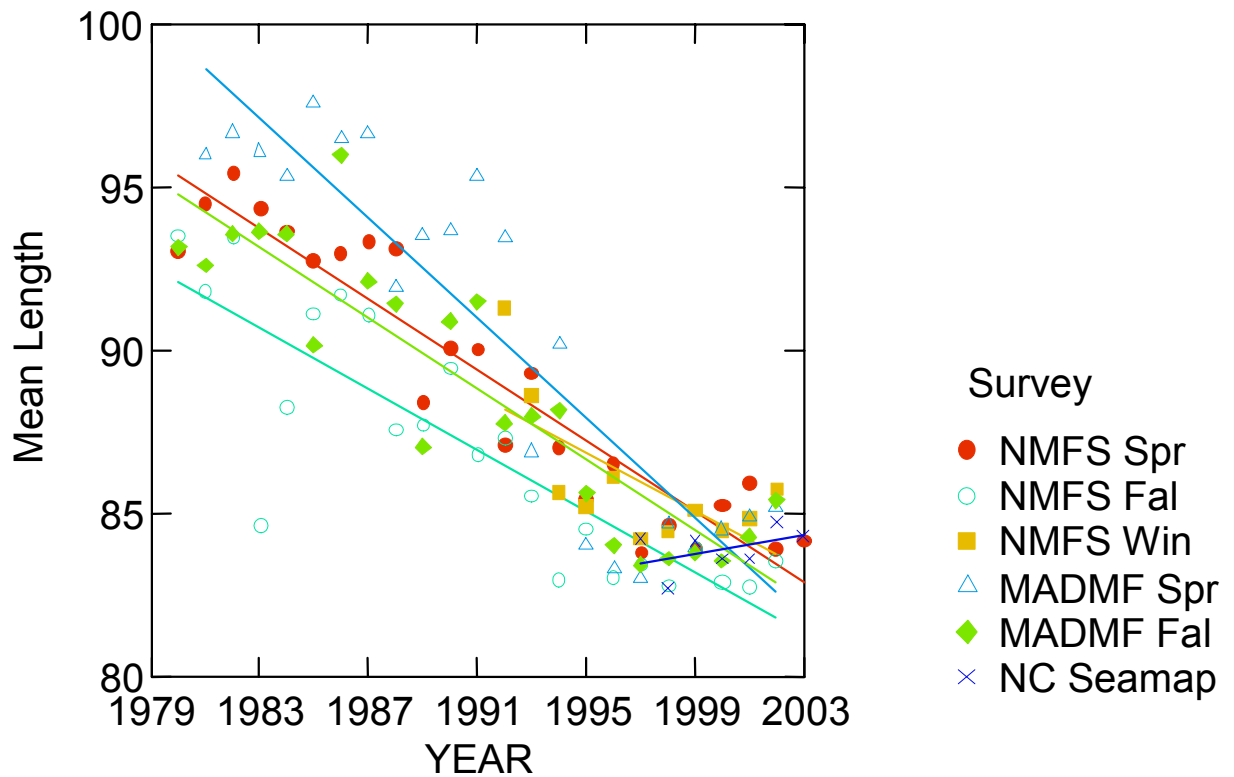
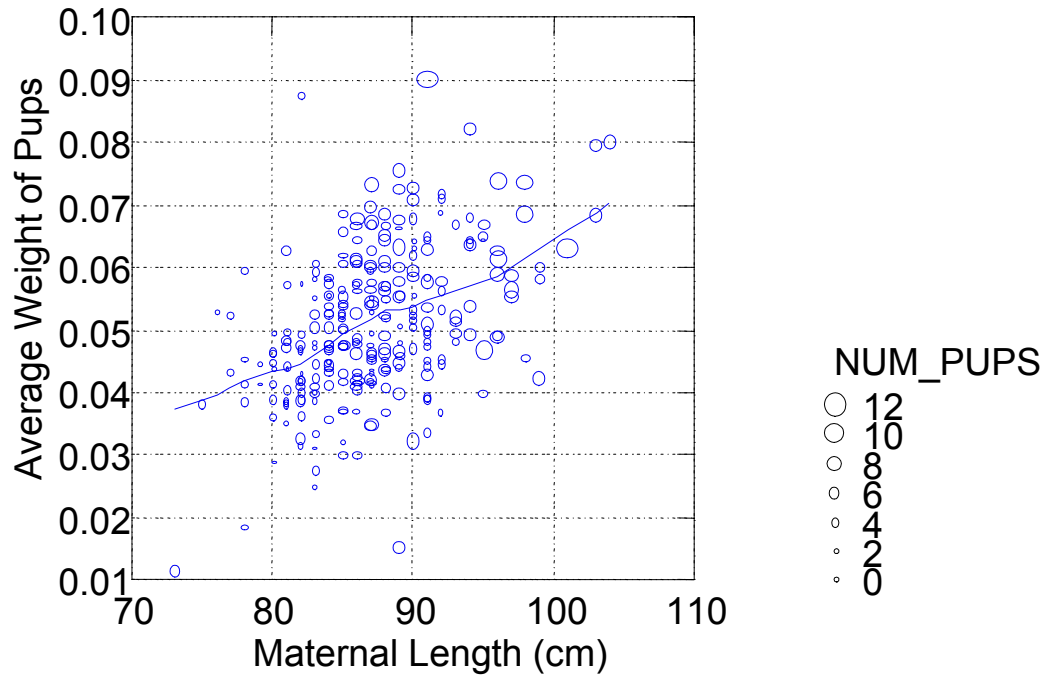


Fig. B6.8 Average size of mature female dogfish (>80cm) in all surveys: NMFS R/V surveys, 1980-2003, and MADMF R/V surveys, 1980-2002, and NC SeaMap survey.

## Pup Weight (kg) vs Maternal Length (cm)



## Pup Length (cm) vs Maternal Length (cm)

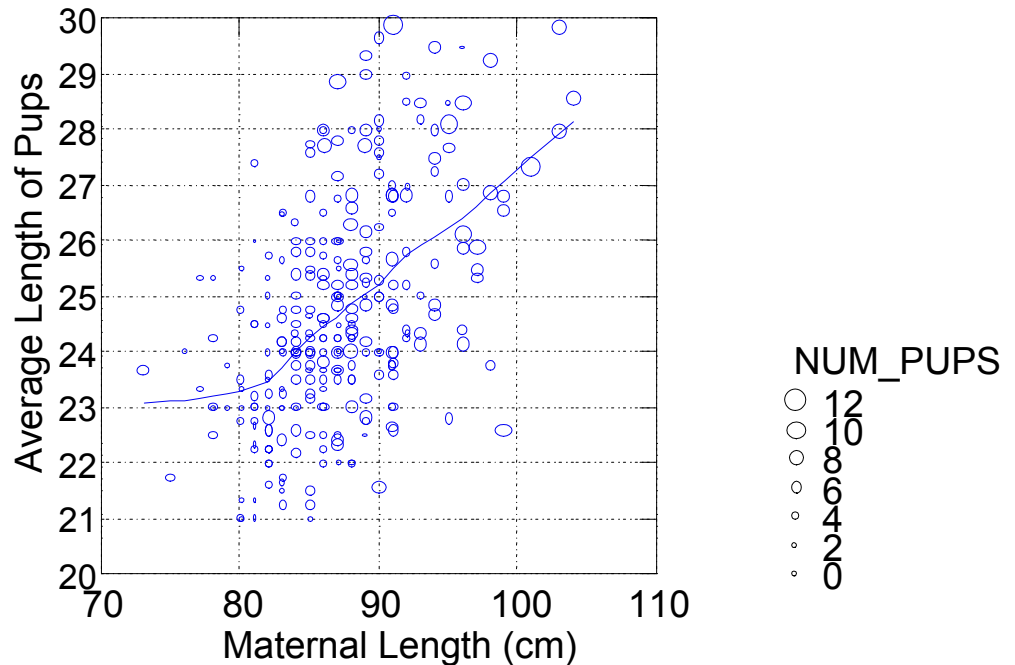


Fig. B6.9 Relationship between average weight (kg) of near-term pups (top) and average length (cm) of pups (bottom) with maternal length (cm). Circle size is proportional to number of pups in brood. Line represents Lowess smooth with tension =0.5.

## Number of Pups vs Maternal Length (cm)

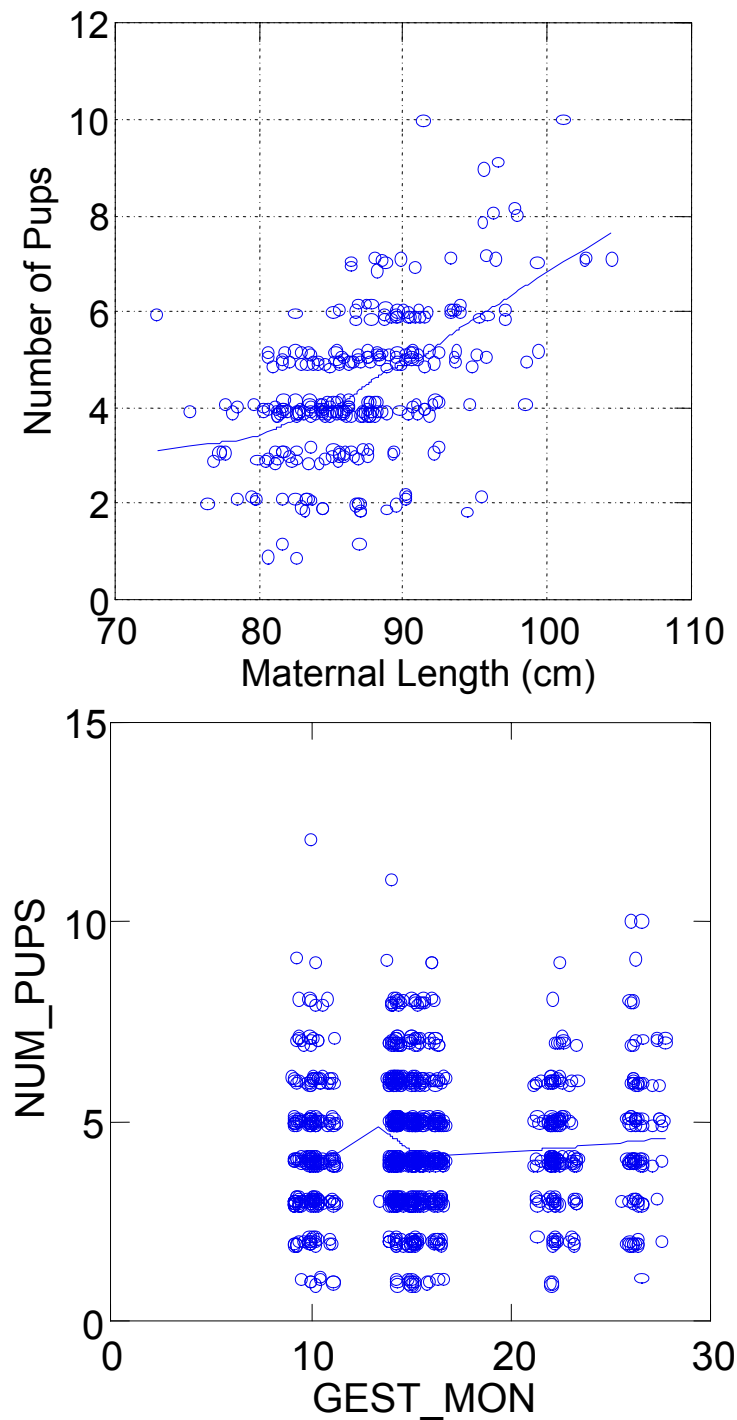


Fig. B6.10 Relationship between number of near-term pups per brood (top) and maternal length (cm). Bottom panel shows relationship between gestational month and number of pups present in brood. Lines represents Lowess smooth with tension =0.5.



## Average Pup Size vs Litter Size

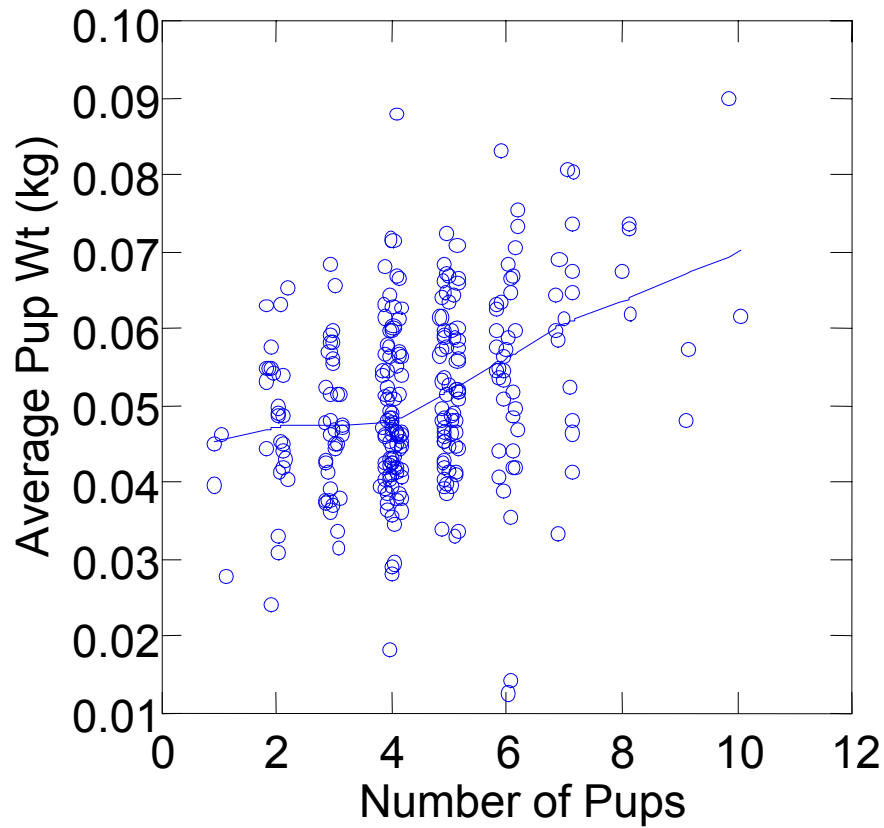


Fig. B6.11 Relationship between average size of near term free embryos and number of pups present in brood, based on 1998-2002 samples. Data points are jittered to show number of points within integer number of pups within brood. Line represent Lowess smooth with tension =0.5.

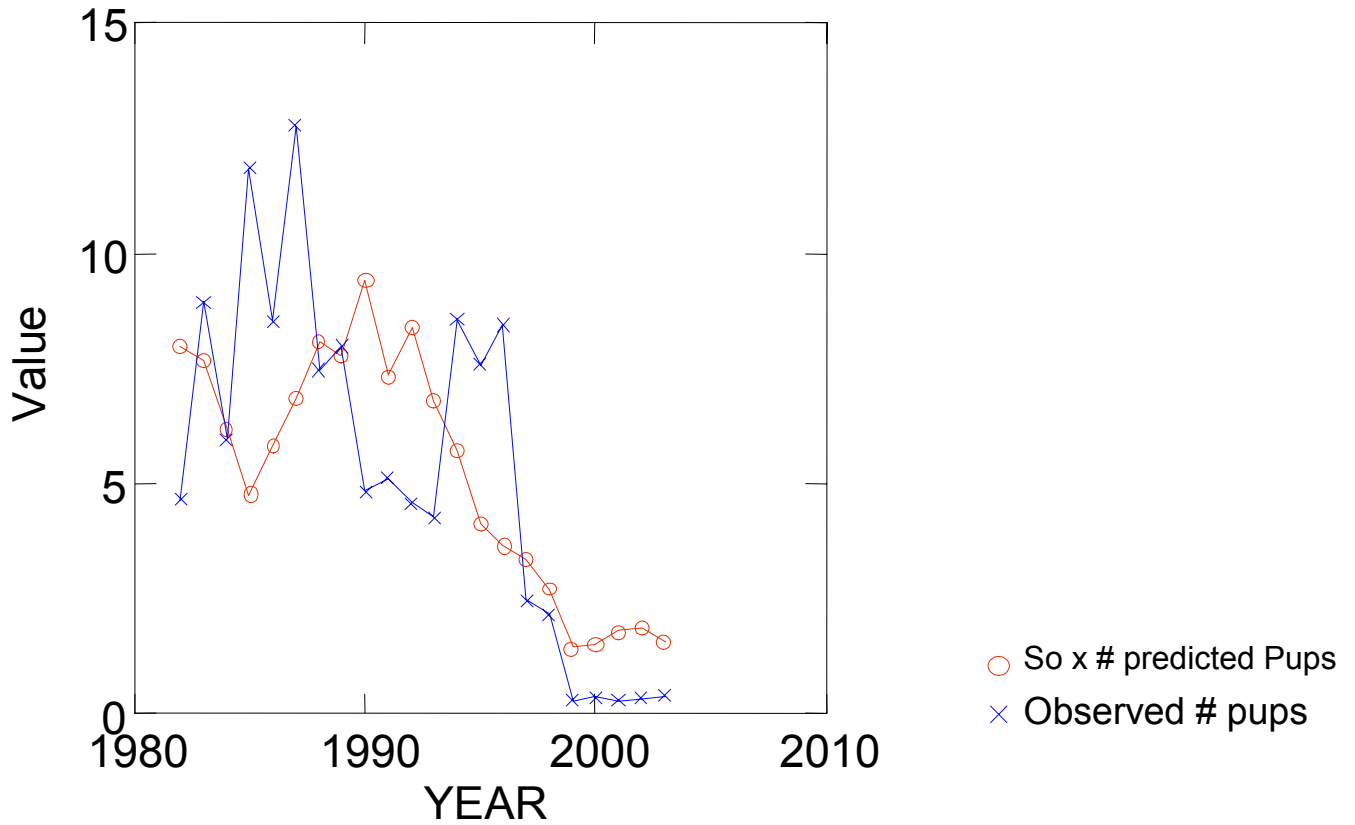


Fig. B6.12 Comparison of observed and predicted number of pups based on a 3 yr moving average. Predicted pups estimated as sum product of abundance and number per tow, multiplied by first year survival rate estimated from life history model. Observed number of pups is total number per tow in the <36 cm range. No adjustments for scale have been made.

# Num Spawners/Tow (lf) and Maternal Size (rt) vs year

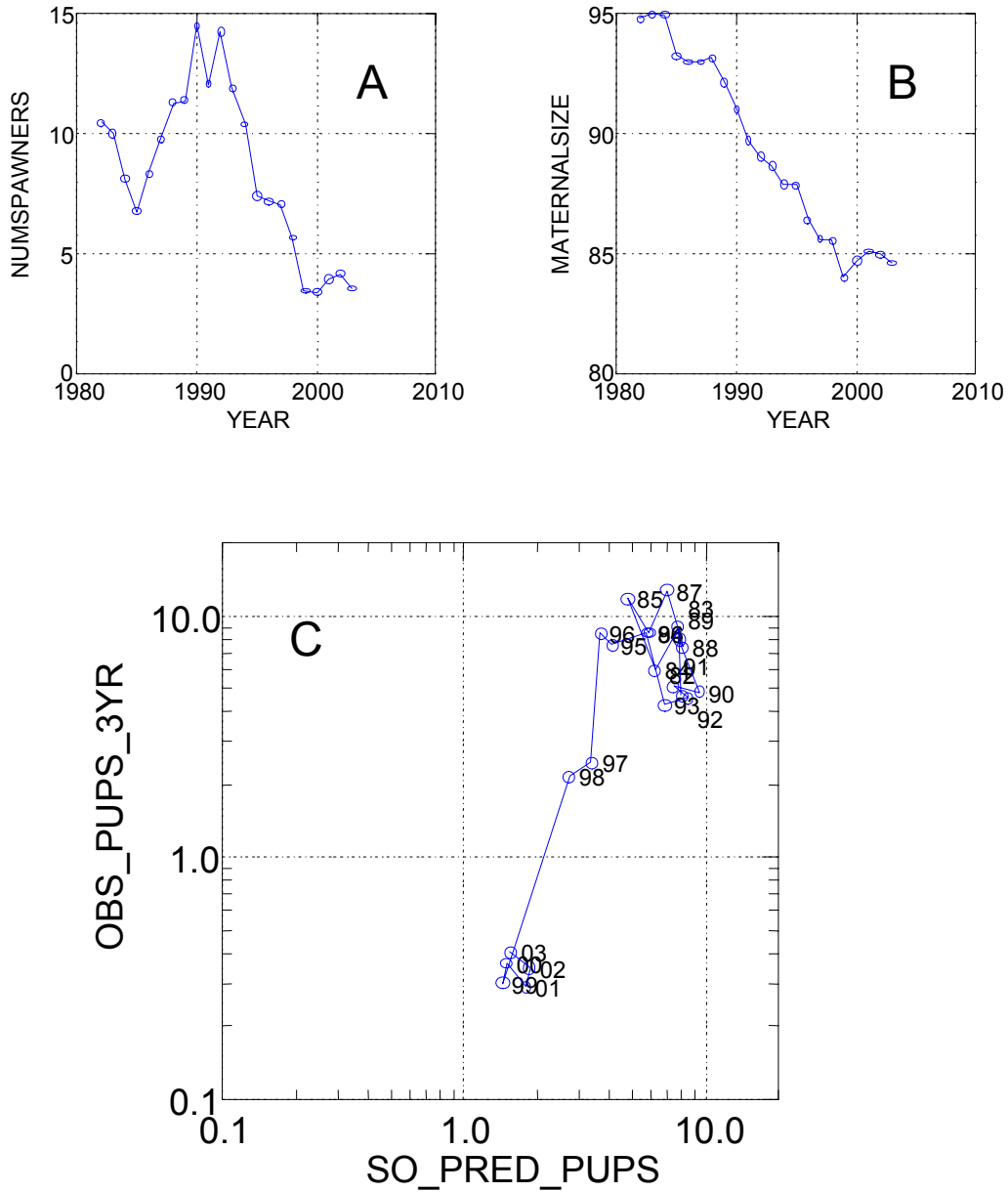


Fig. B6.13. Summary of trends in total number of mature female dogfish (#/tow) (A), average maternal size (cm) (B) and relationship between observed and predicted numbers of pups C.

Exploitable\_\_\_ and Total Biomass---, 1990-1996, Min

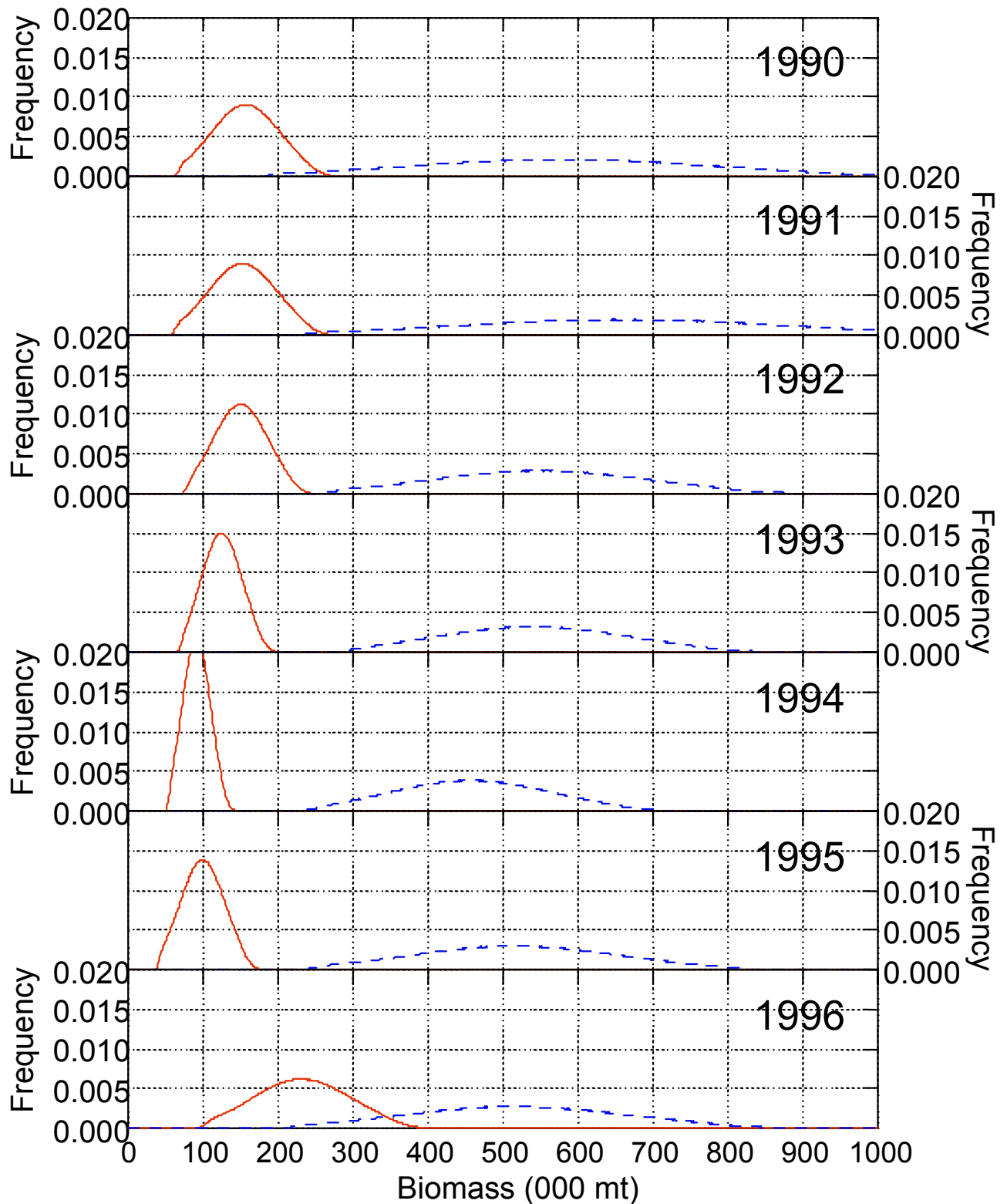


Fig. B7.3 a. Sampling distribution of exploitable(solid line) and total biomass (dashed line) of spiny dogfish, 1990-1996, under the assumption of the minimum trawl footprint.

Exploitable\_\_\_ and Total Biomass---, 1997-2002, Min

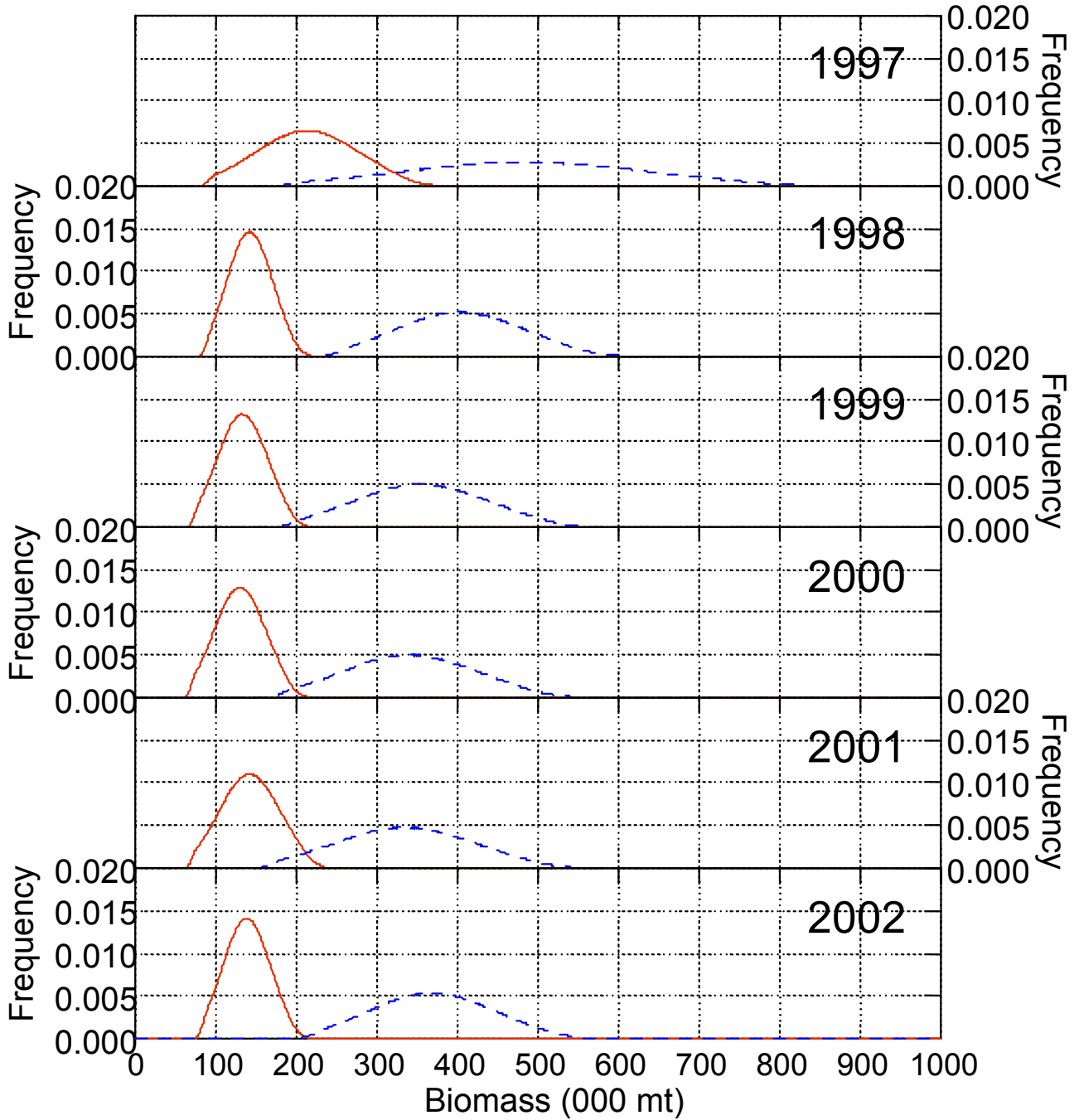


Fig. B7.3 b. Sampling distribution of exploitable(solid line) and total biomass (dashed line) of spiny dogfish, 1997-2002, under the assumption of the maximum trawl footprint.

SSB \_\_\_\_, Female Expl B--- and Male Expl B..., 1990-96, Min

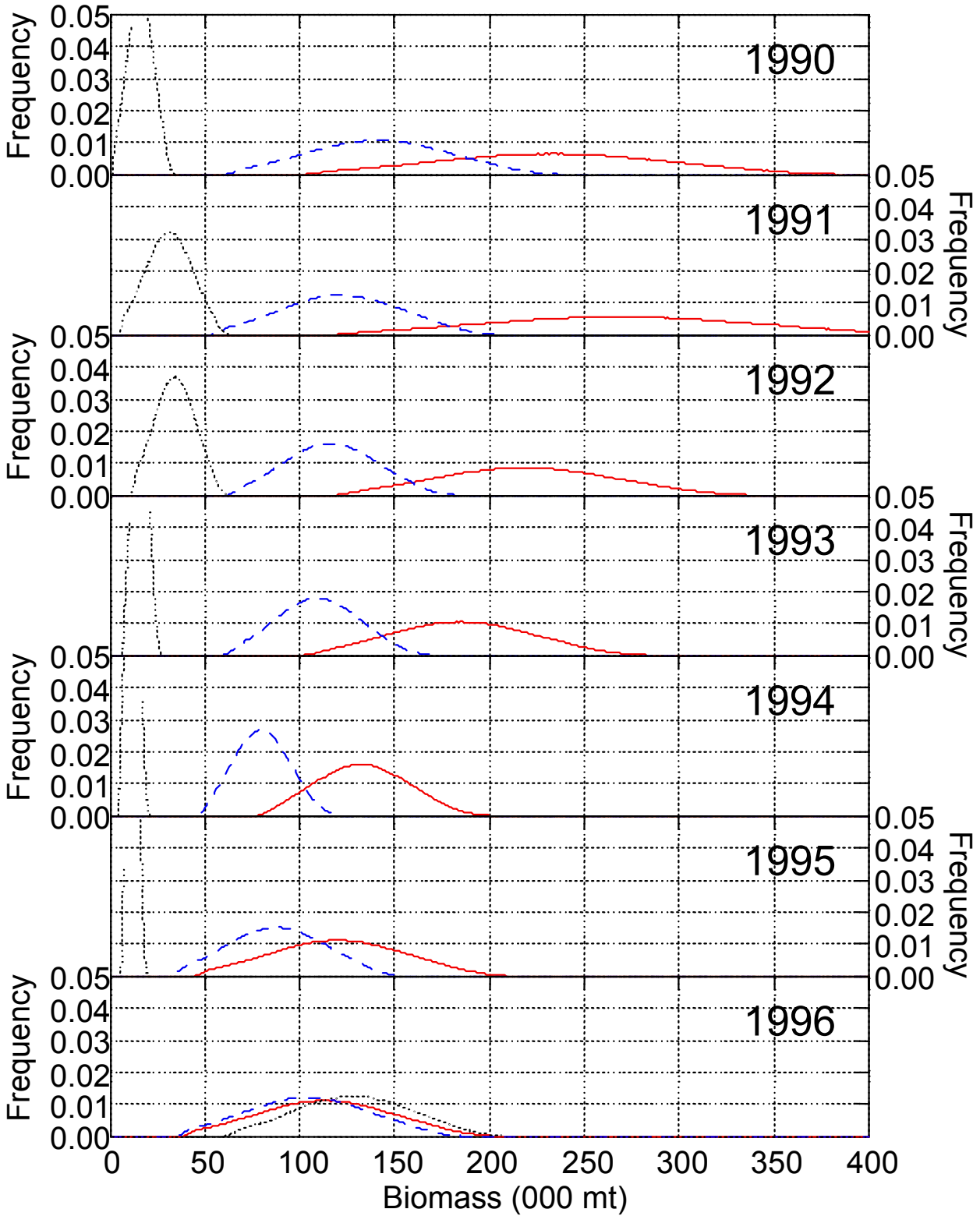


Fig. B7.4 a. Sampling distribution of spawning stock biomass (solid line), female exploitable biomass (dashed) and male exploitable biomass (dashed line) of spiny dogfish, 1990-1996, under the assumption of the minimum trawl footprint.

SSB\_\_\_, Female Expl B--- and Male Expl B..., 1997-02, Min

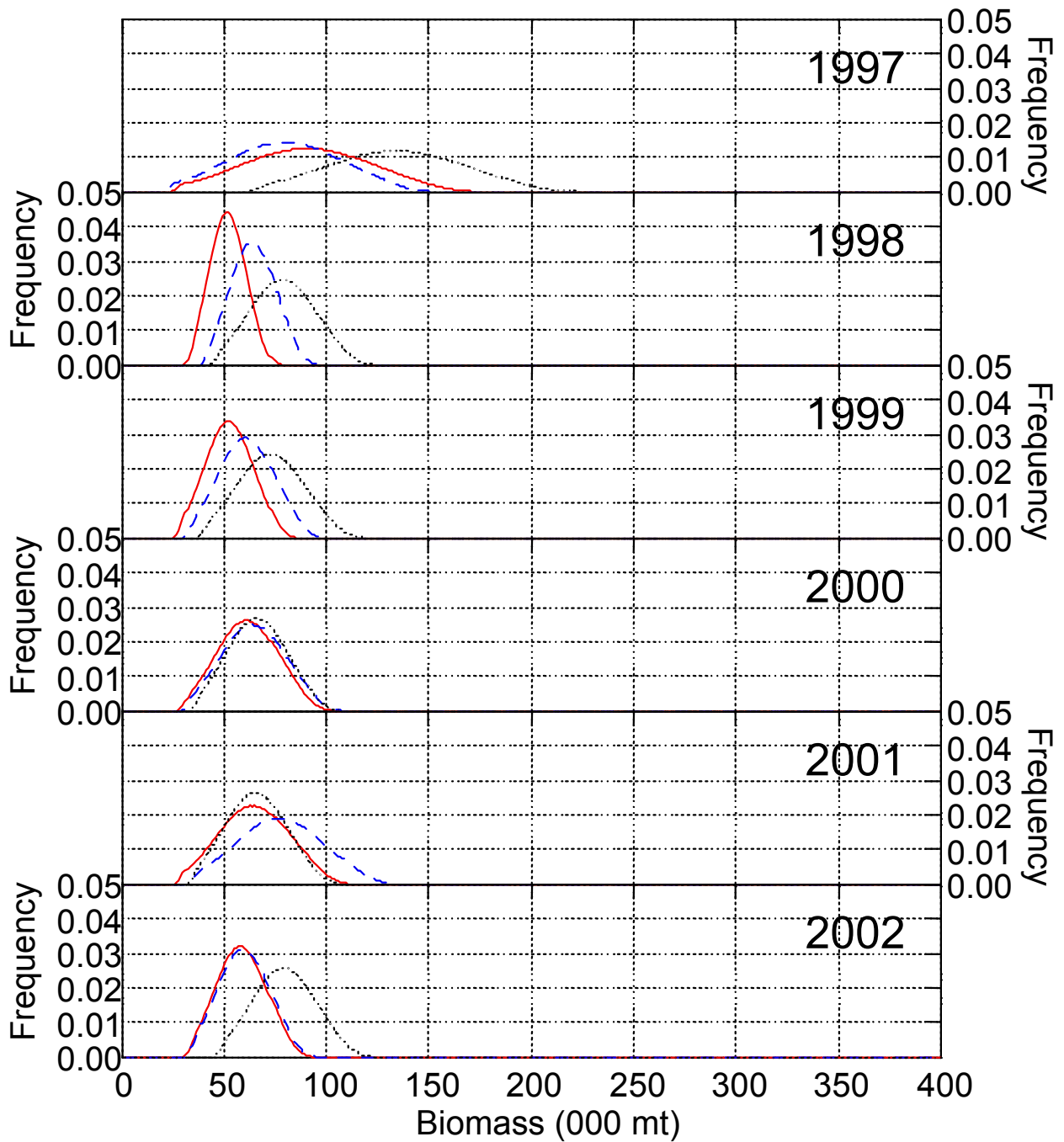


Fig. B7.4 b. Sampling distribution of spawning stock biomass (solid line), female exploitable biomass (dashed) and male exploitable biomass (dashed line) of spiny dogfish, 1997-2002, under the assumption of the minimum trawl footprint.

Exploitable\_\_\_ and Total Biomass---, 1990-1996, Max.

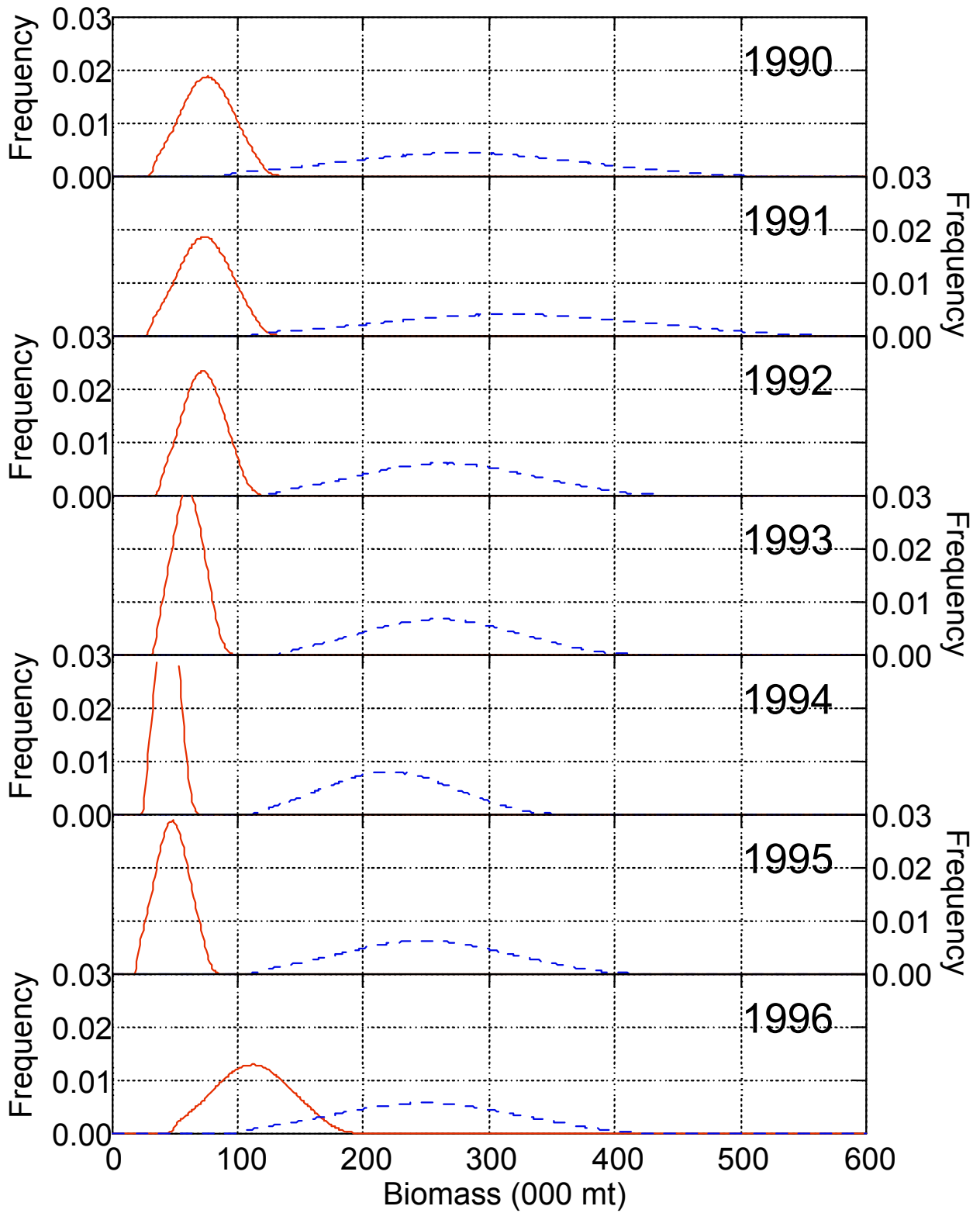


Fig. B7.5 a. Sampling distribution of exploitable(solid line) and total biomass (dashed line) of spiny dogfish, 1990-1996, under the assumption of the maximum trawl footprint.



### Exploitable\_\_\_ and Total Biomass---, 1997-2002, Max

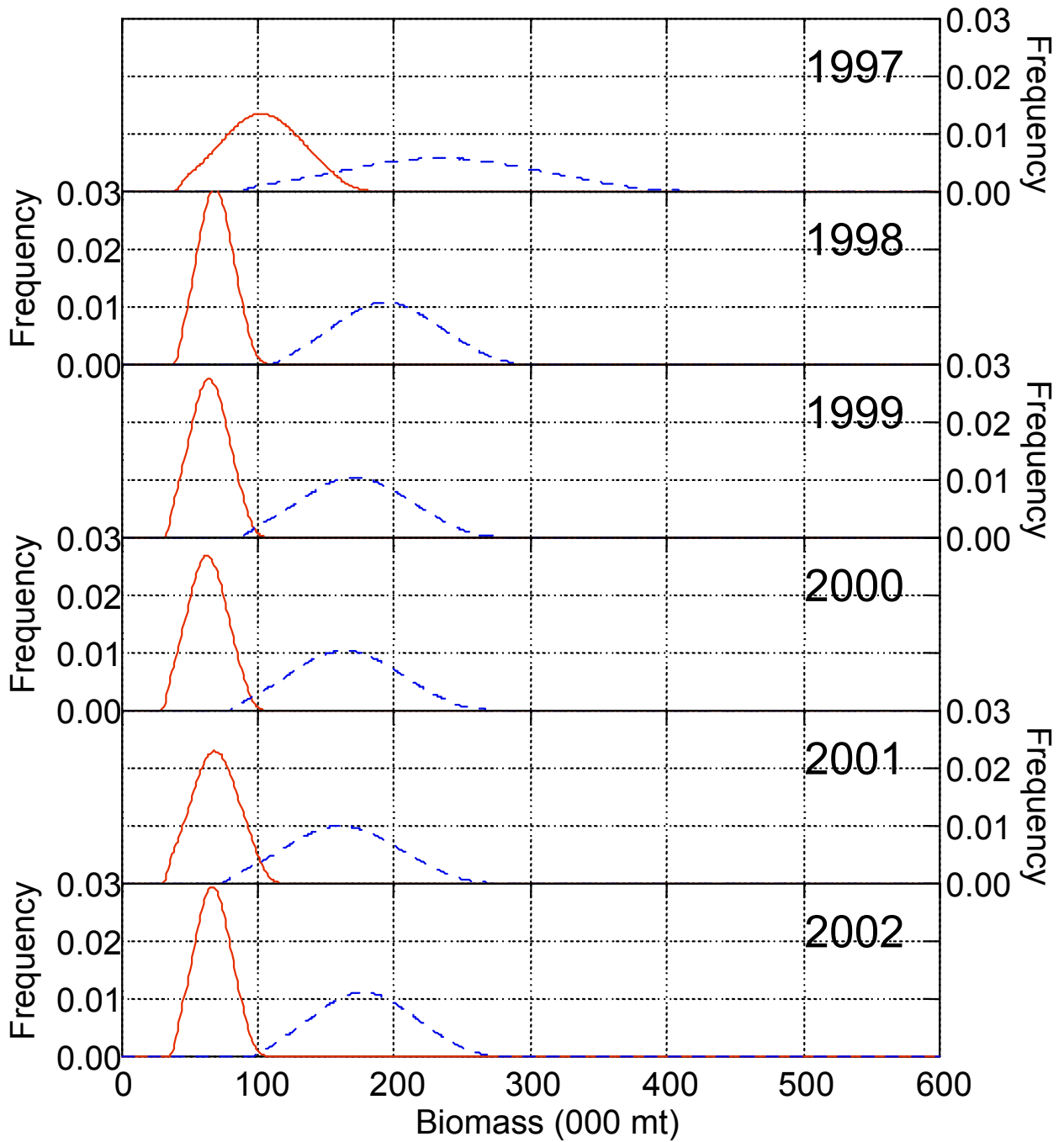


Fig. B7.5 b. Sampling distribution of exploitable(solid line) and total biomass (dashed line) of spiny dogfish, 1997-2002, under the assumption of the maximum trawl footprint.

SSB \_\_\_\_, Female Expl B--- and Male Expl B..., 1990-96, Max

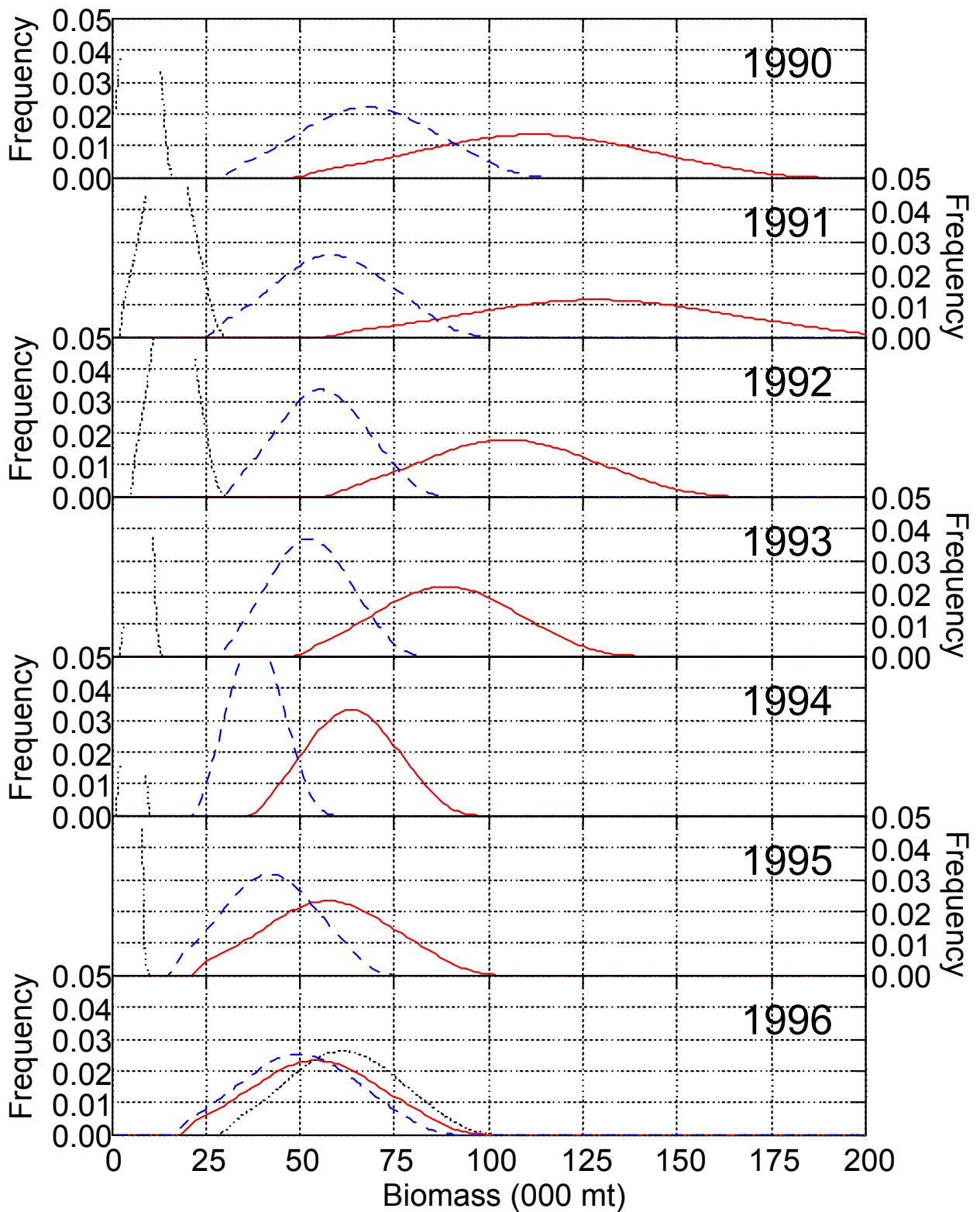


Fig. B7.6 a. Sampling distribution of spawning stock biomass (solid line), female exploitable biomass (dashed) and male exploitable biomass (dashed line) of spiny dogfish, 1990-1996, under the assumption of the maximum trawl footprint.

SSB\_\_\_, Female Expl B--- and Male Expl B..., 1997-02, Max

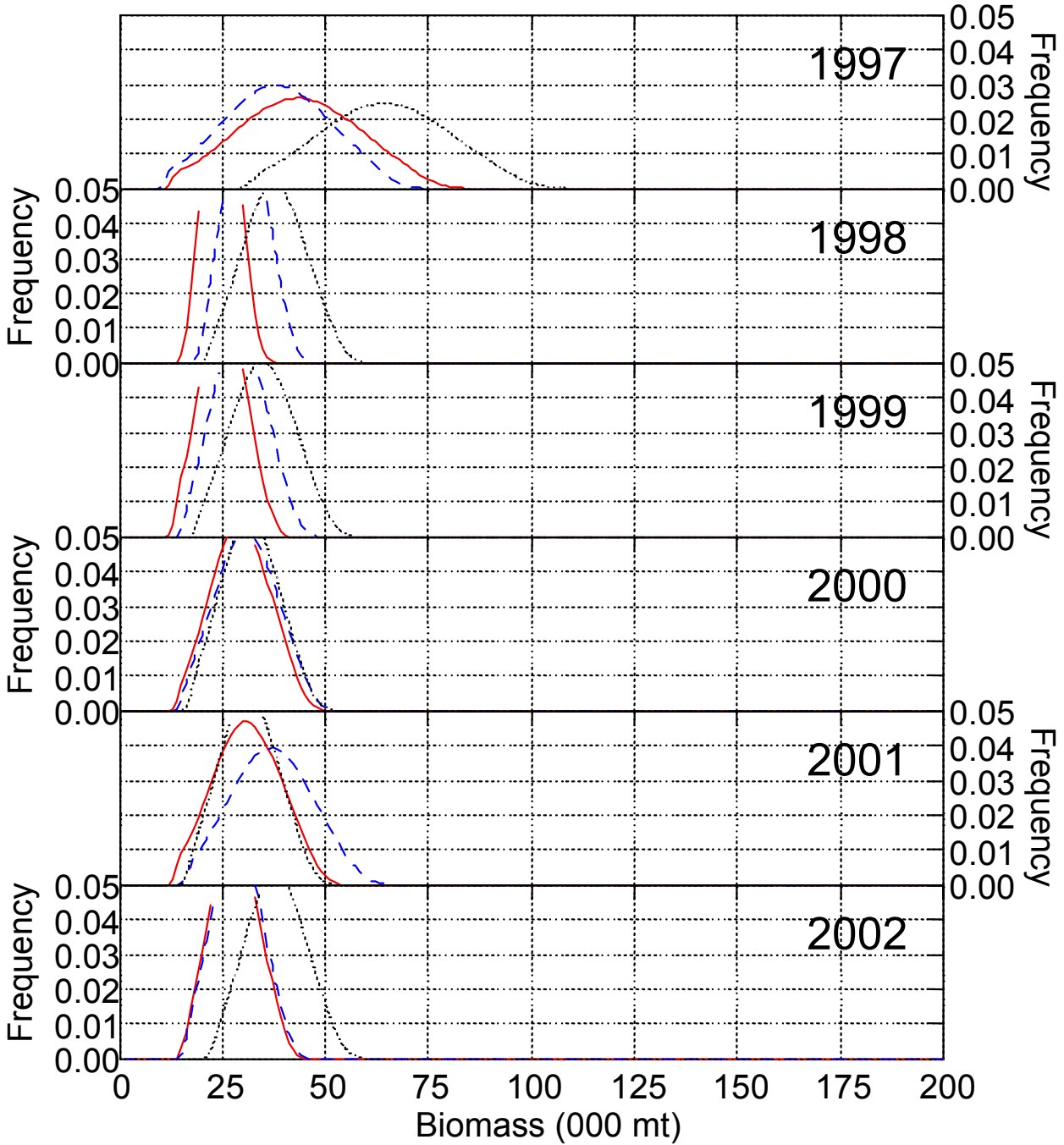


Fig. B7.6b. Sampling distribution of spawning stock biomass (solid line), female exploitable biomass (dashed) and male exploitable biomass (dotted line) of spiny dogfish, 1997-2002, under the assumption of the maximum trawl footprint.

F female \_\_, F expl --, & Discard F..., 1990-1996, Min. Footprint

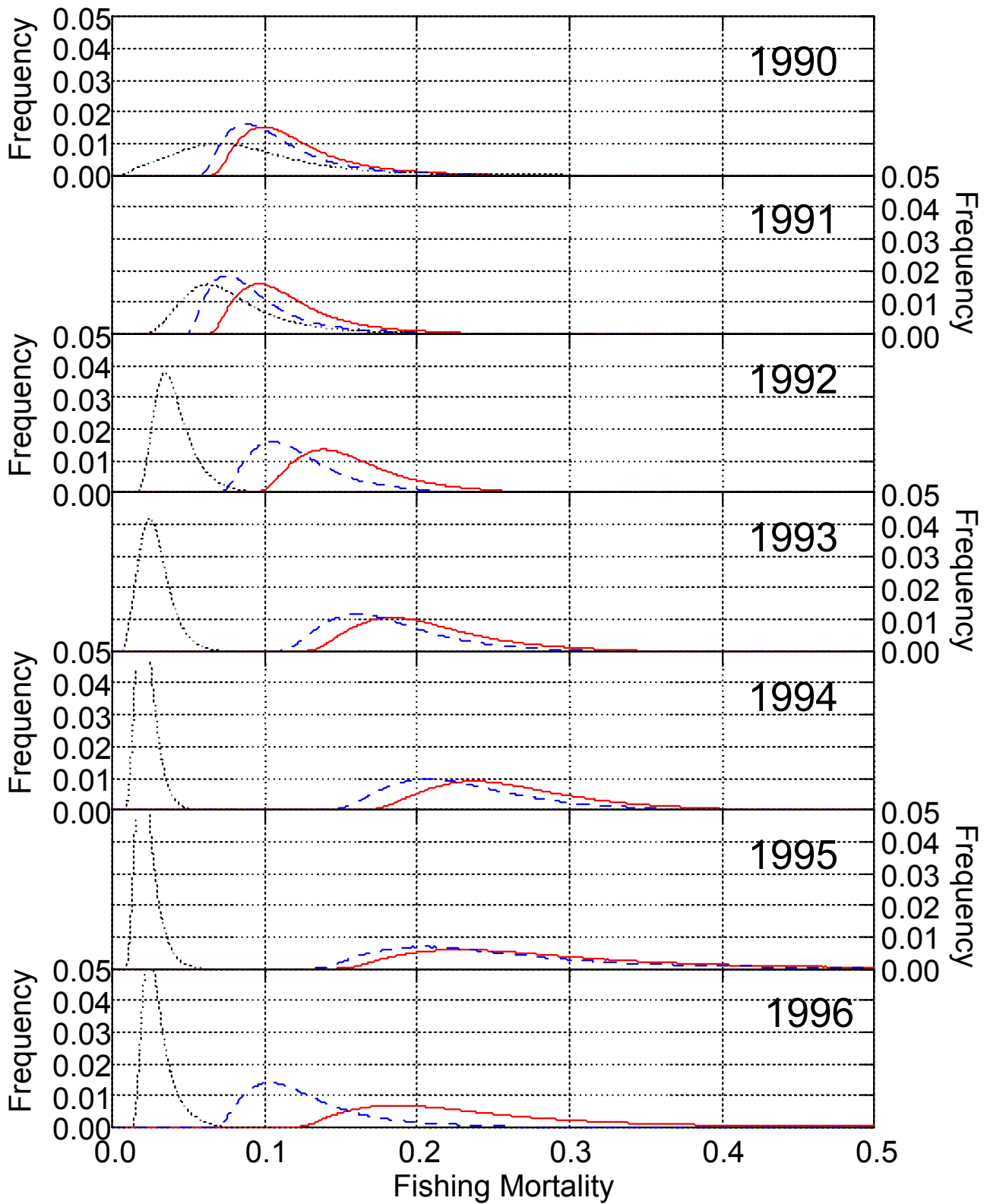


Fig. B7.7 a. Sampling distribution of fishing mortality on female exploitable biomass (solid line), on total exploitable biomass (dashed) and fishing mortality from discards on total biomass (dots) of spiny dogfish, 1990-1996, under the assumption of the minimum trawl footprint.

F female \_\_, F expl --, & Discard F..., 1997-2002, Min. Footprint

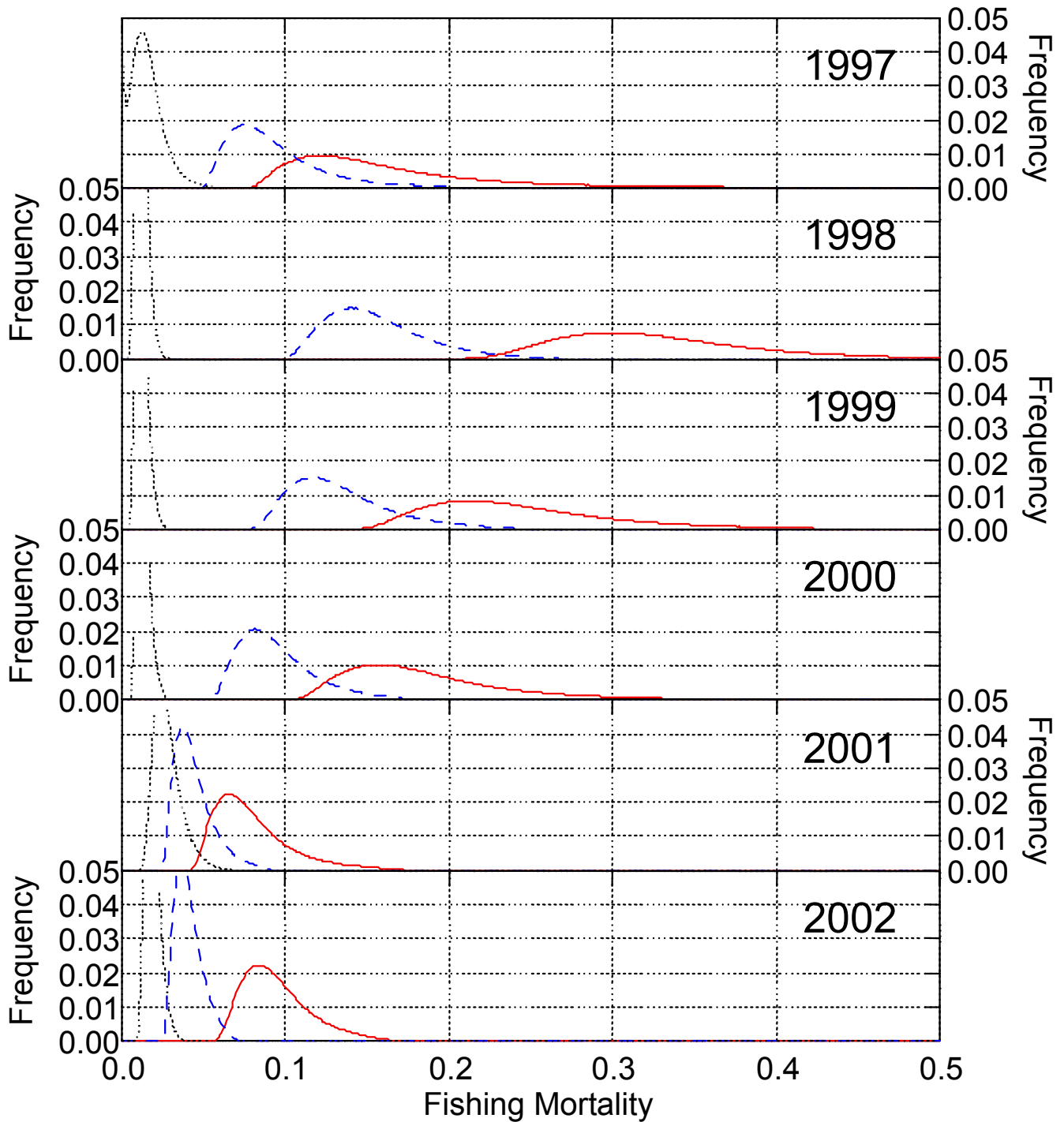


Fig. B7.7 b. Sampling distribution of fishing mortality on female exploitable biomass (solid line), on total exploitable biomass (dashed) and fishing mortality from discards on total biomass (dots) of spiny dogfish, 1997-2002, under the assumption of the minimum trawl footprint.

F female \_\_, F expl --, & Discard F..., 1990-1996, Max. Footprint

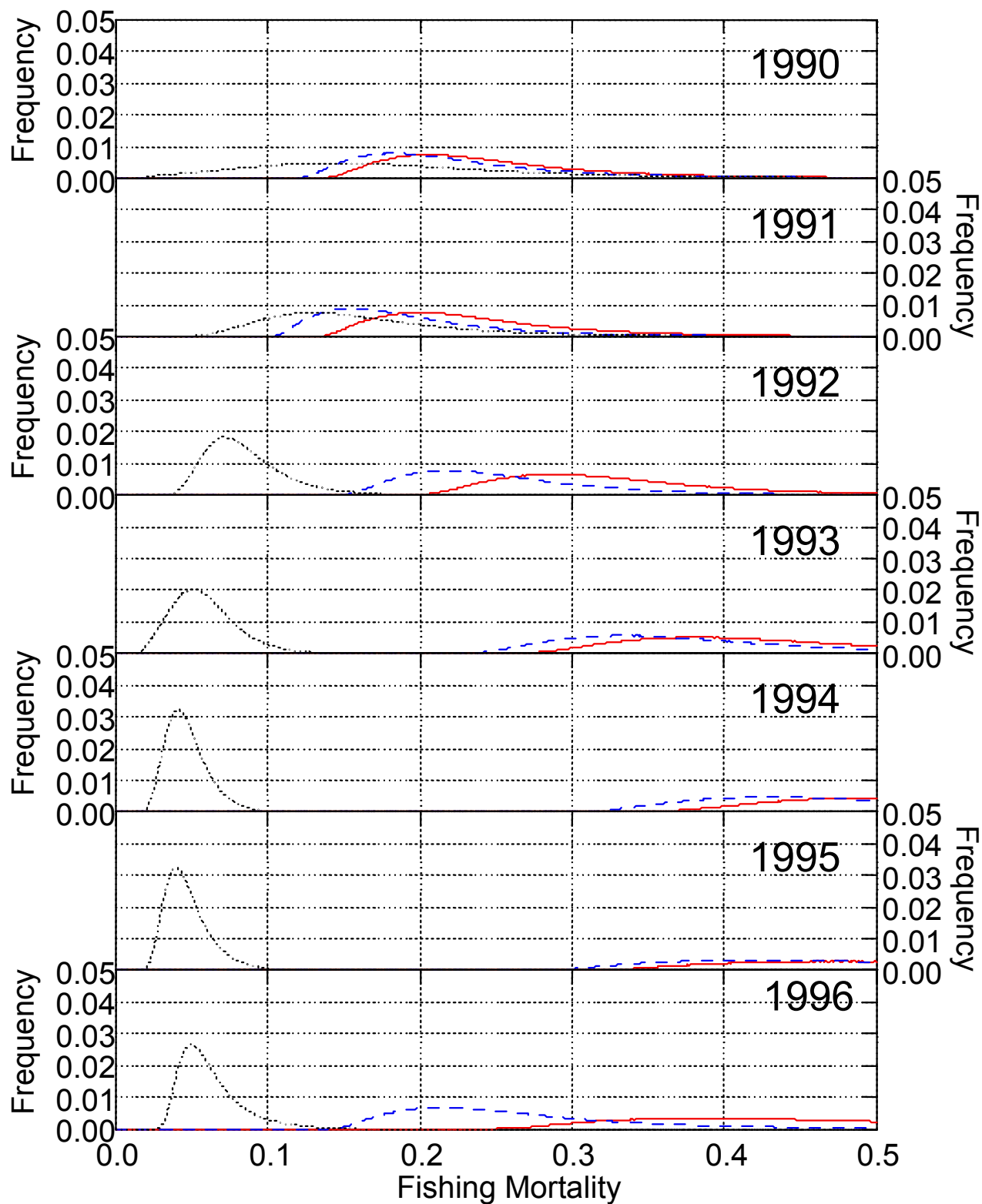


Fig. B7.8 a. Sampling distribution of fishing mortality on female exploitable biomass (solid line), on total exploitable biomass (dashed) and fishing mortality from discards on total biomass (dots) of spiny dogfish, 1990-1996, under the assumption of the maximum trawl footprint.

F female \_\_, F expl --, & Discard F..., 1997-2002, Max. Footprint

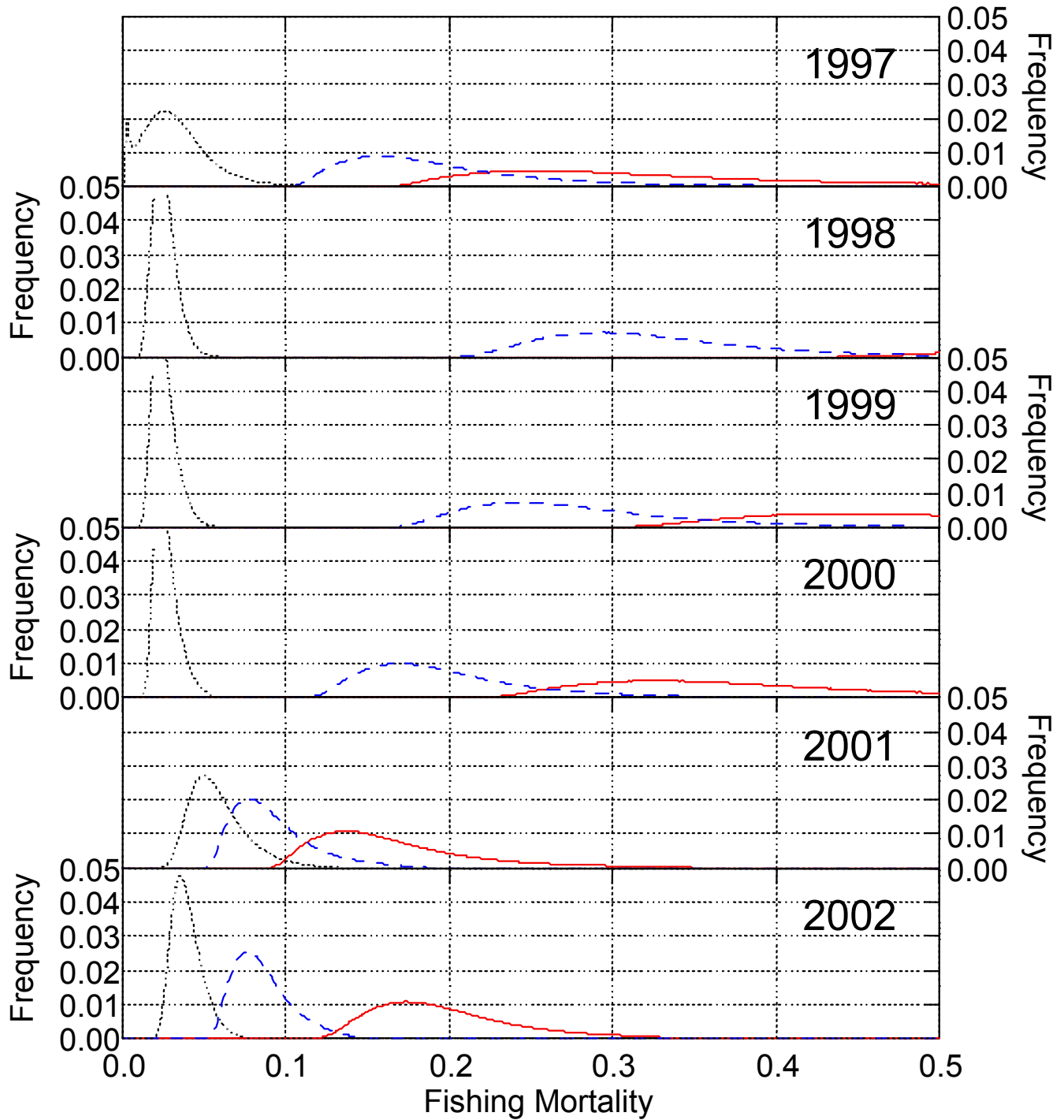


Fig. B7.8 b. Sampling distribution of fishing mortality on female exploitable biomass (solid line), on total exploitable biomass (dashed) and fishing mortality from discards on total biomass (dots) of spiny dogfish, 1997-2002, under the assumption of the maximum trawl footprint.

## 1968-96, 1968-2003 Comparison

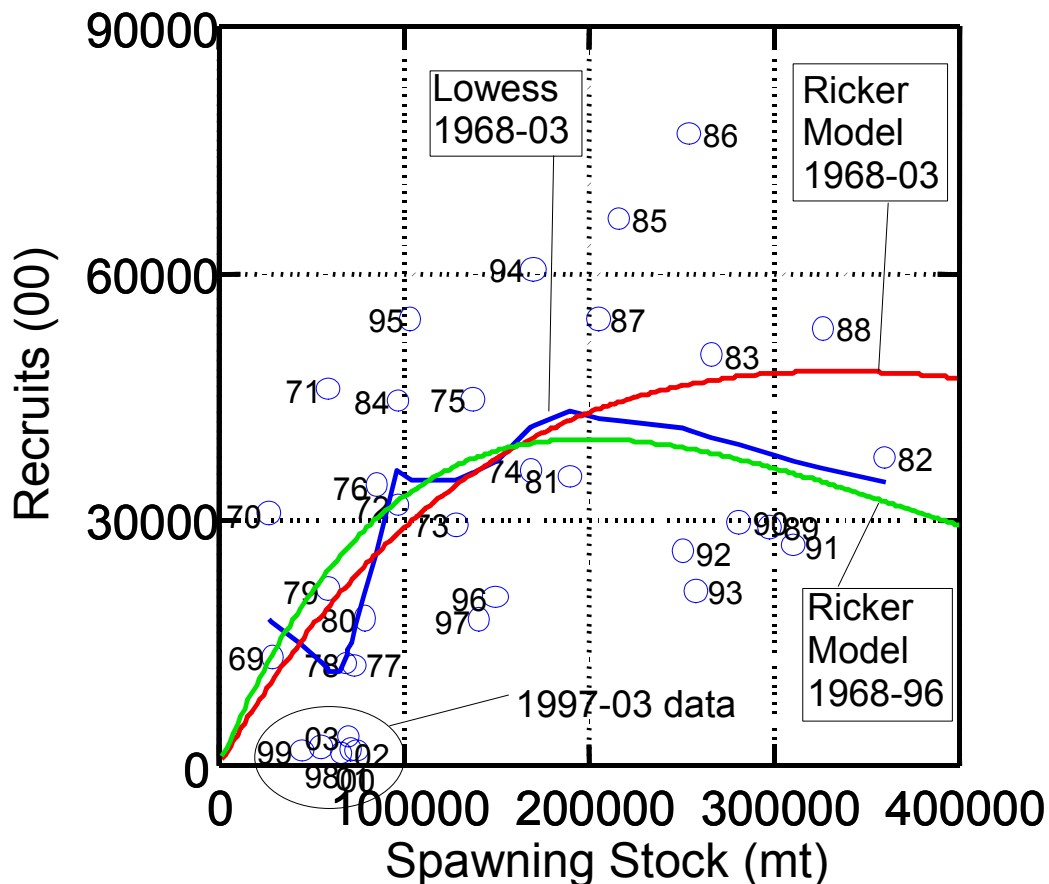
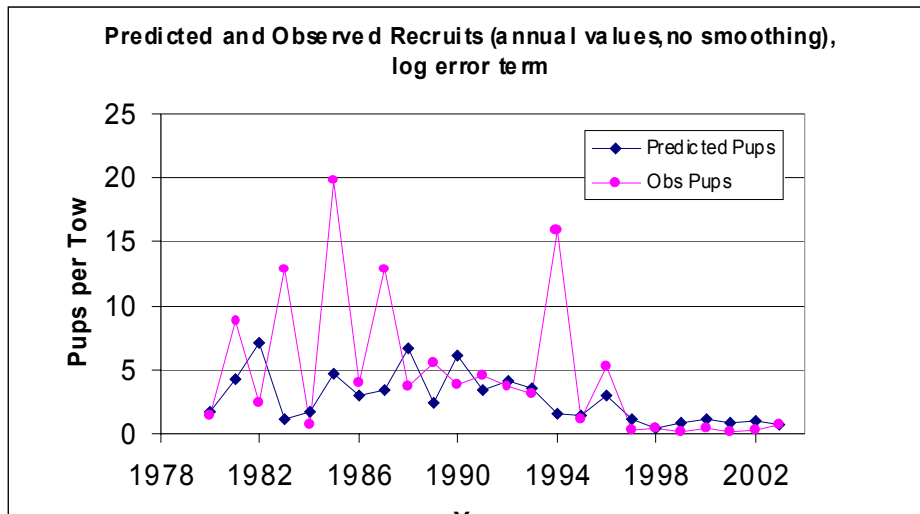


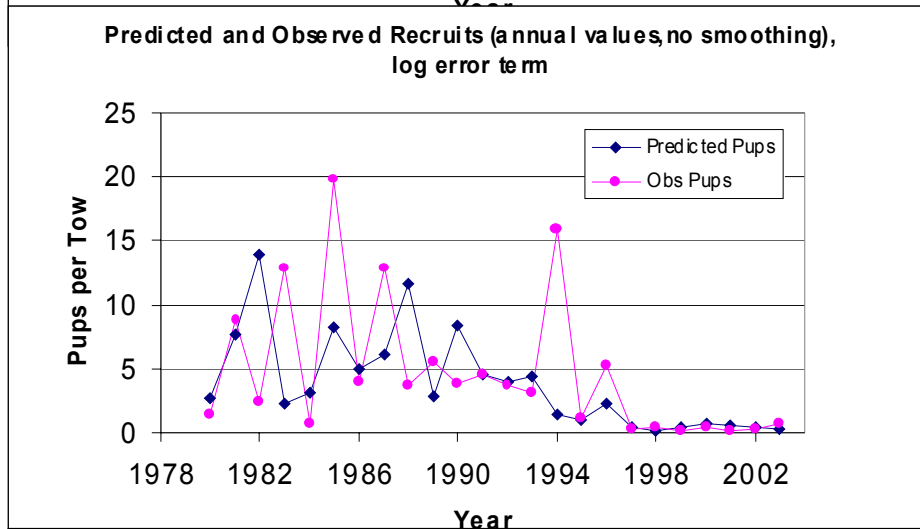
Figure B8.1 Comparison of parametric and nonparametric S-R curves for spiny dogfish for 1968-1996 (top), 1968-2003 (bottom). Point estimates of  $SSB_{max}$  based on nominal footprint of  $0.01 \text{ nm}^2$  and unscaled NEFSC spring trawl survey catch rates. Nonparametric models based on Lowess smooths with tension = 0.6, suggest no change in  $SSB_{max}$  estimates. Biomass corresponding to  $0.01 \text{ nm}^2$  footprint is 215 k mt. This corresponds to a NEFSC Spring Survey average catch of 33.2 kg/tow. Using the Ricker model for 1968-03 inflates the  $SSB_{max}$  to 294 k mt ( 45.2 kg/tow), owing to the low recruitment between 1997-03.



A



B



C

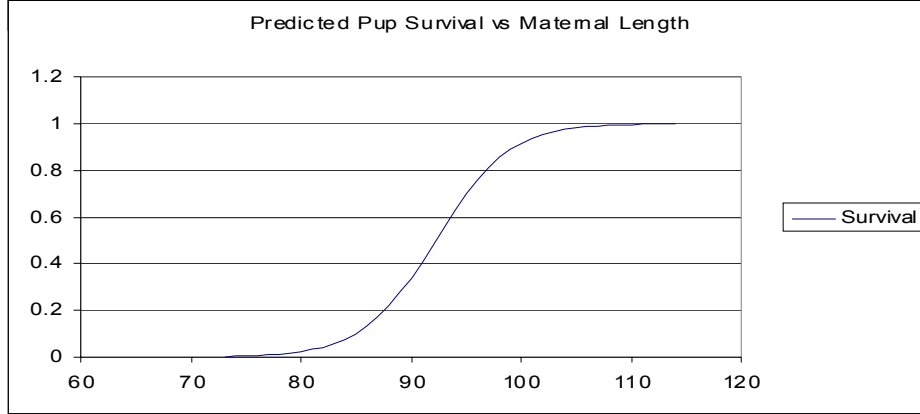


Fig. B8.2. Comparison of observed and predicted numbers of pups for two alternative demographic models. A Constant first year survival, with no maternal effect. B. First year survival increases with maternal size. The empirical estimate of first year survival vs maternal size is depicted in panel C.

# status quo F, Min Footprint

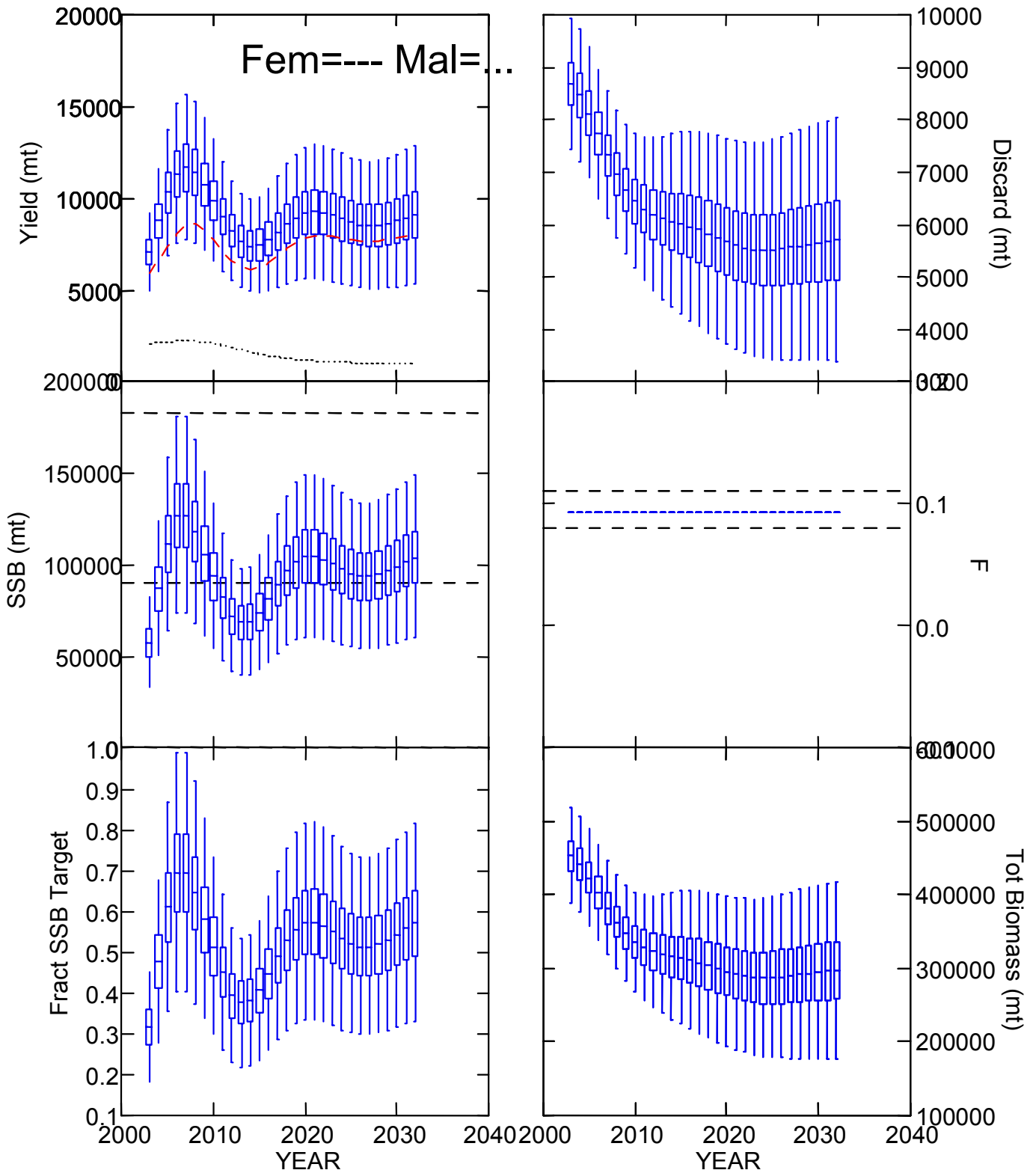


Fig. B9.1 Summary of projection model simulation results under the status quo F scenario. Minimum footprint is assumed. See text for details.

# rebuild F, Min Footprint

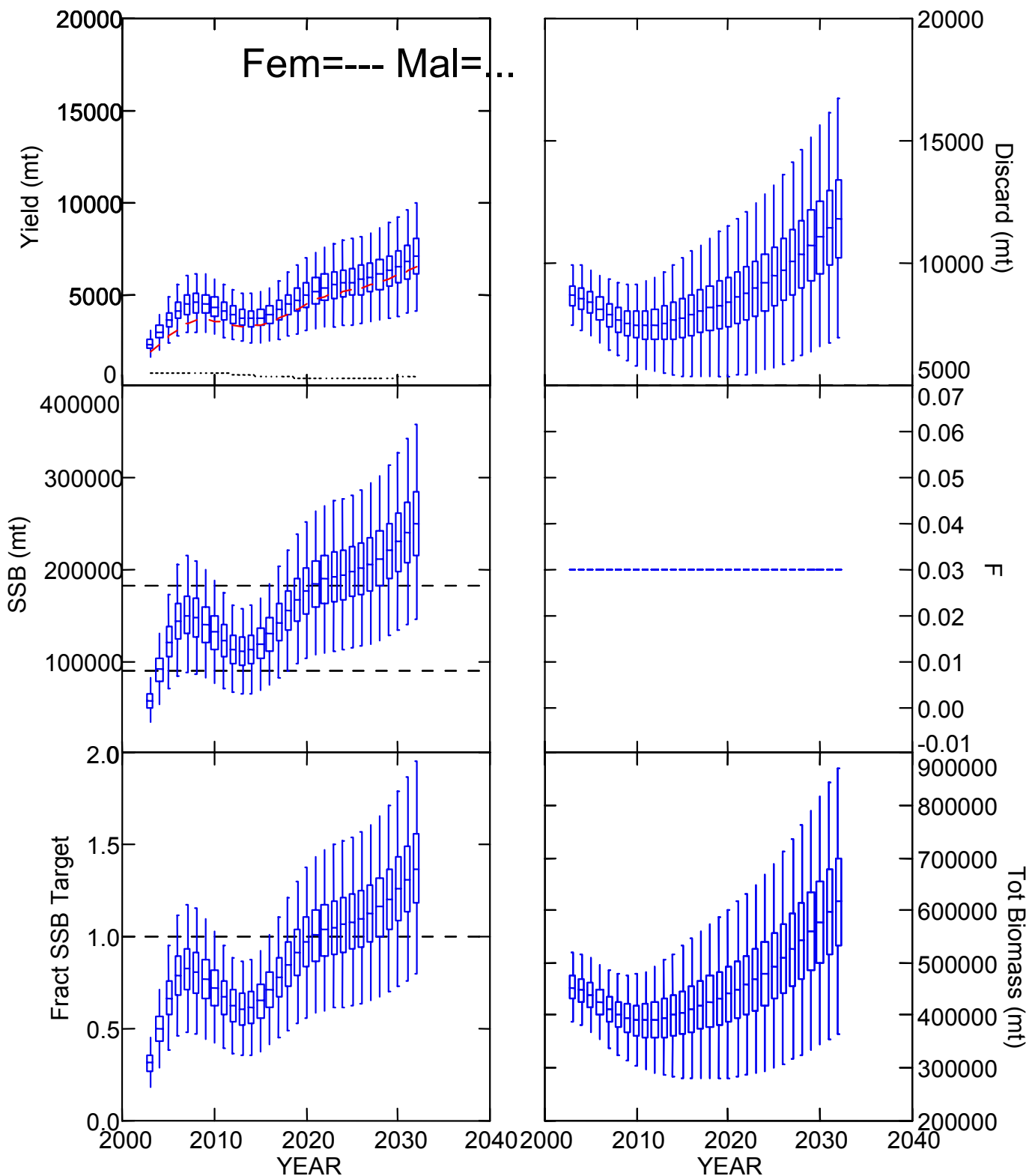


Fig. B9.2 Summary of projection model simulation results under the rebuild F scenario. Minimum footprint is assumed. See text for details.

# Zero F, Min Footprint

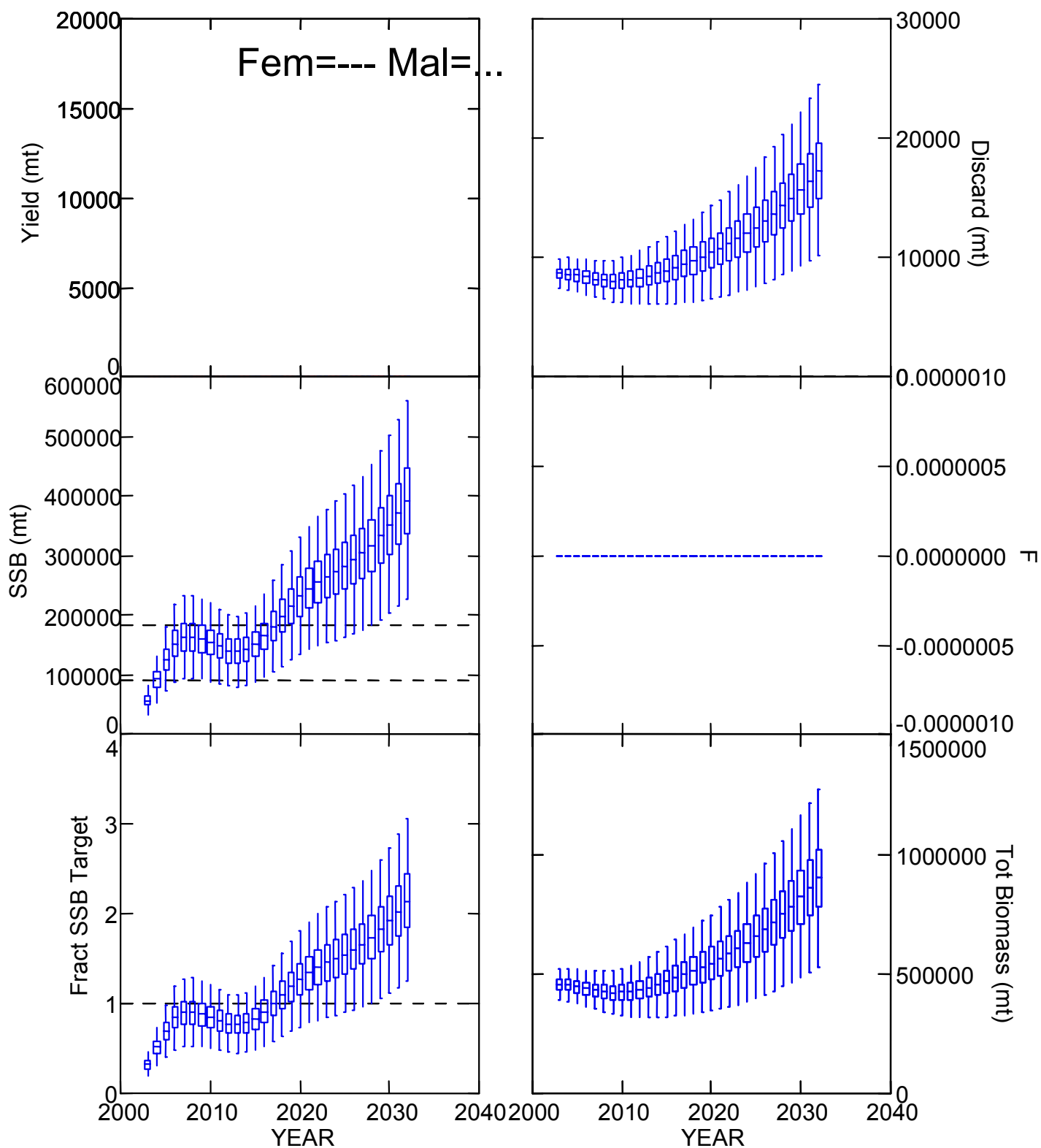


Fig. B9.3 Summary of projection model simulation results under the Zero F scenario. Minimum footprint is assumed. See text for details.

# base Q, Min Footprint

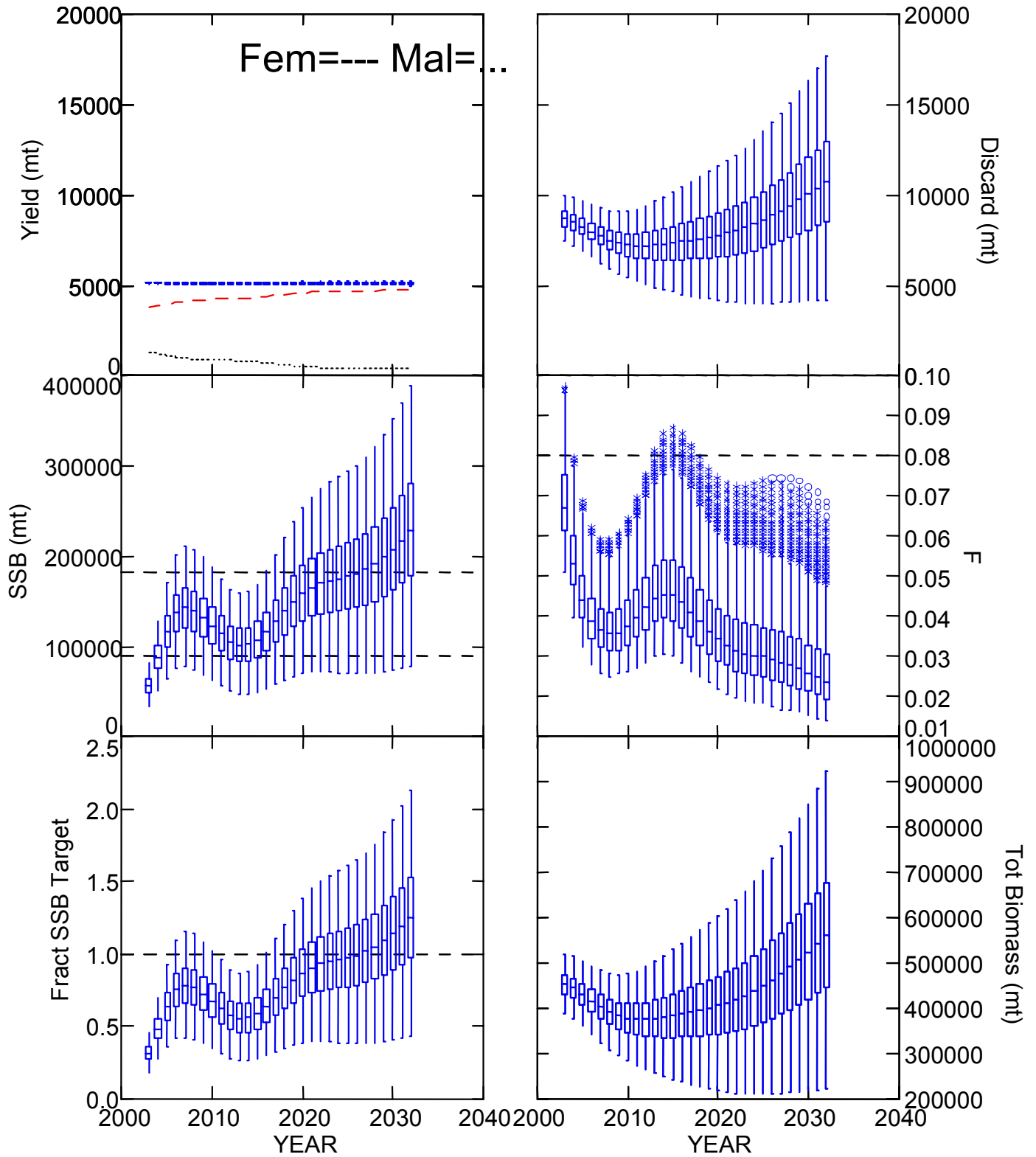


Fig. B9.4 Summary of projection model simulation results under the baseline Quota scenario. Minimum footprint is assumed. See text for details.

# alt Q, Min Footprint

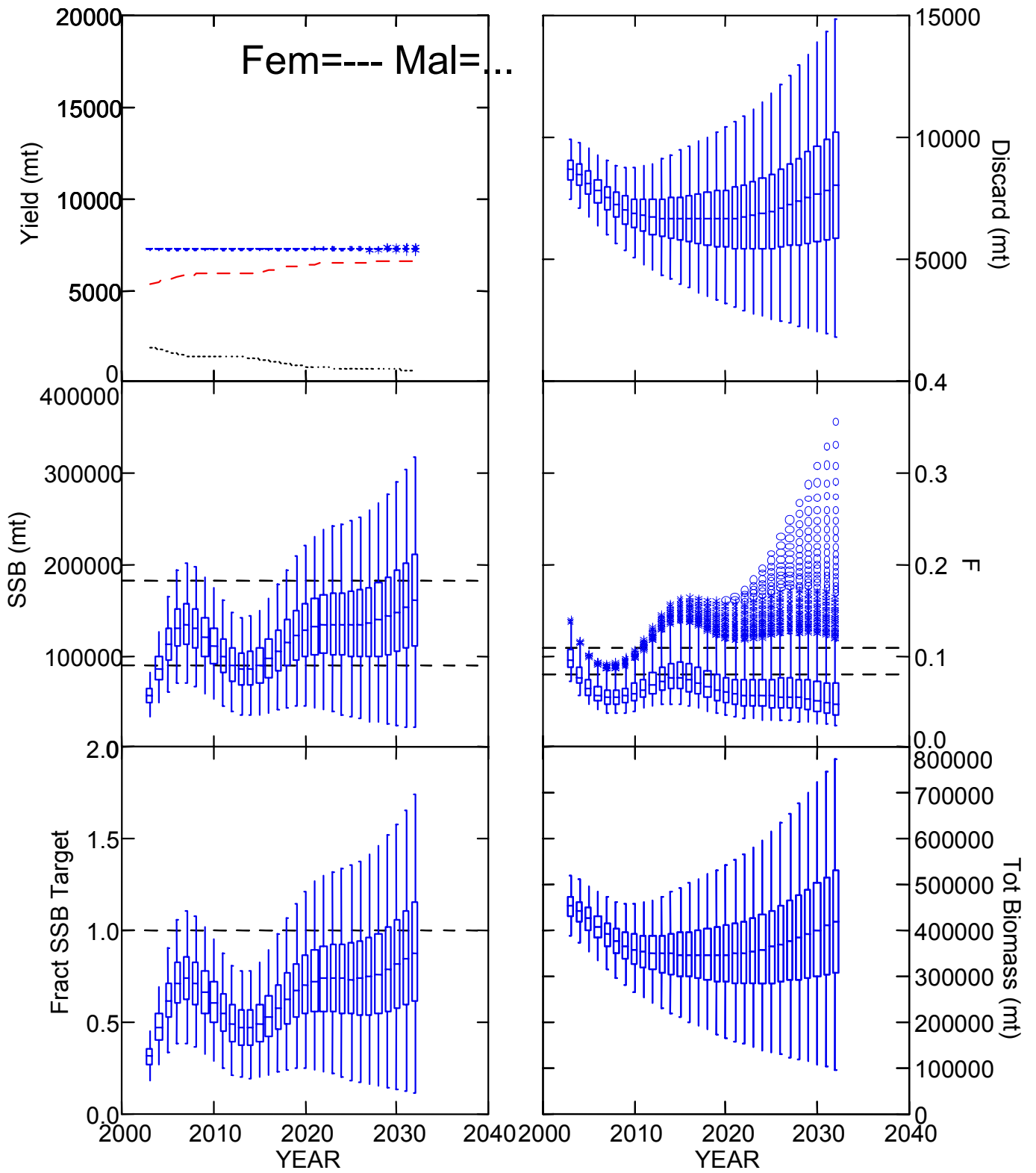


Fig.B 9.5 Summary of projection model simulation results under the alternative Quota scenario. Minimum footprint is assumed. See text for details.

# No Comm Q, Min Footprint

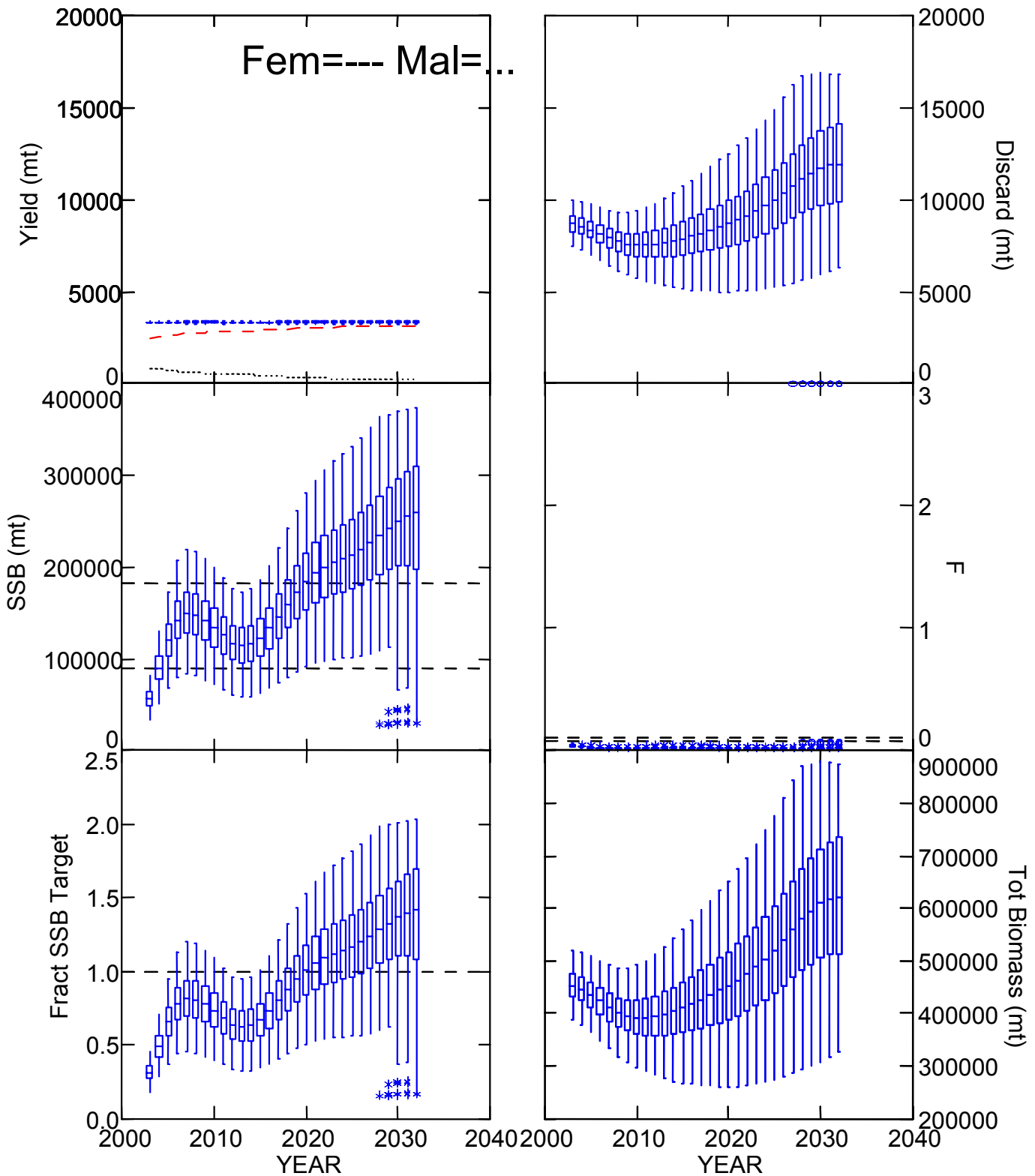


Fig. B9.6 Summary of projection model simulation results under the No Commercial Quota scenario. Minimum footprint is assumed. See text for details.

### F=0.08 in 2004, and after, Min Footprint

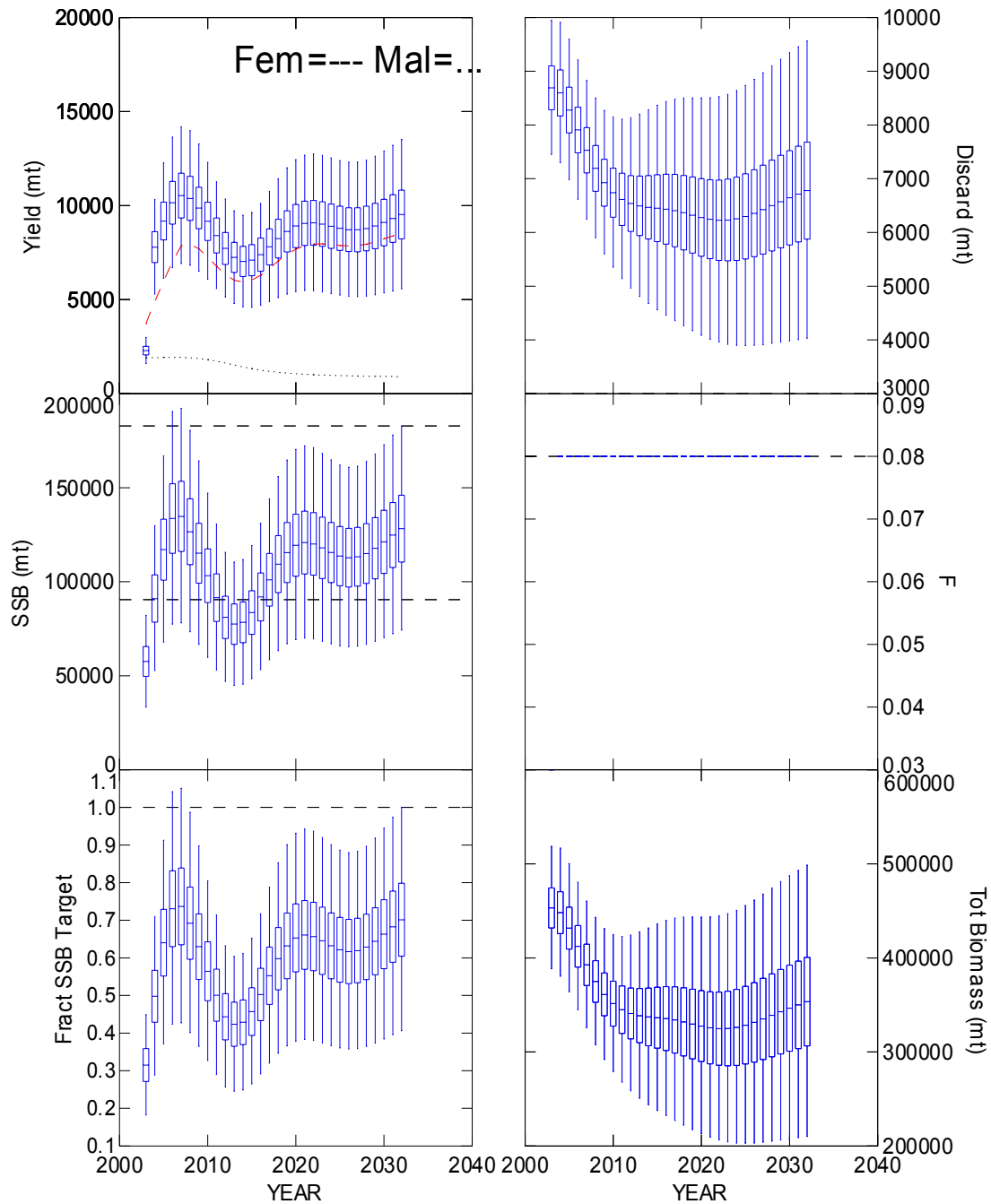


Fig. B9.7 Summary of projection model simulation results under the federal FMP specified F level of 0.08 in 2004. See text for additional details.



## SQ F, Reduced Pup Survival, Min Footprint

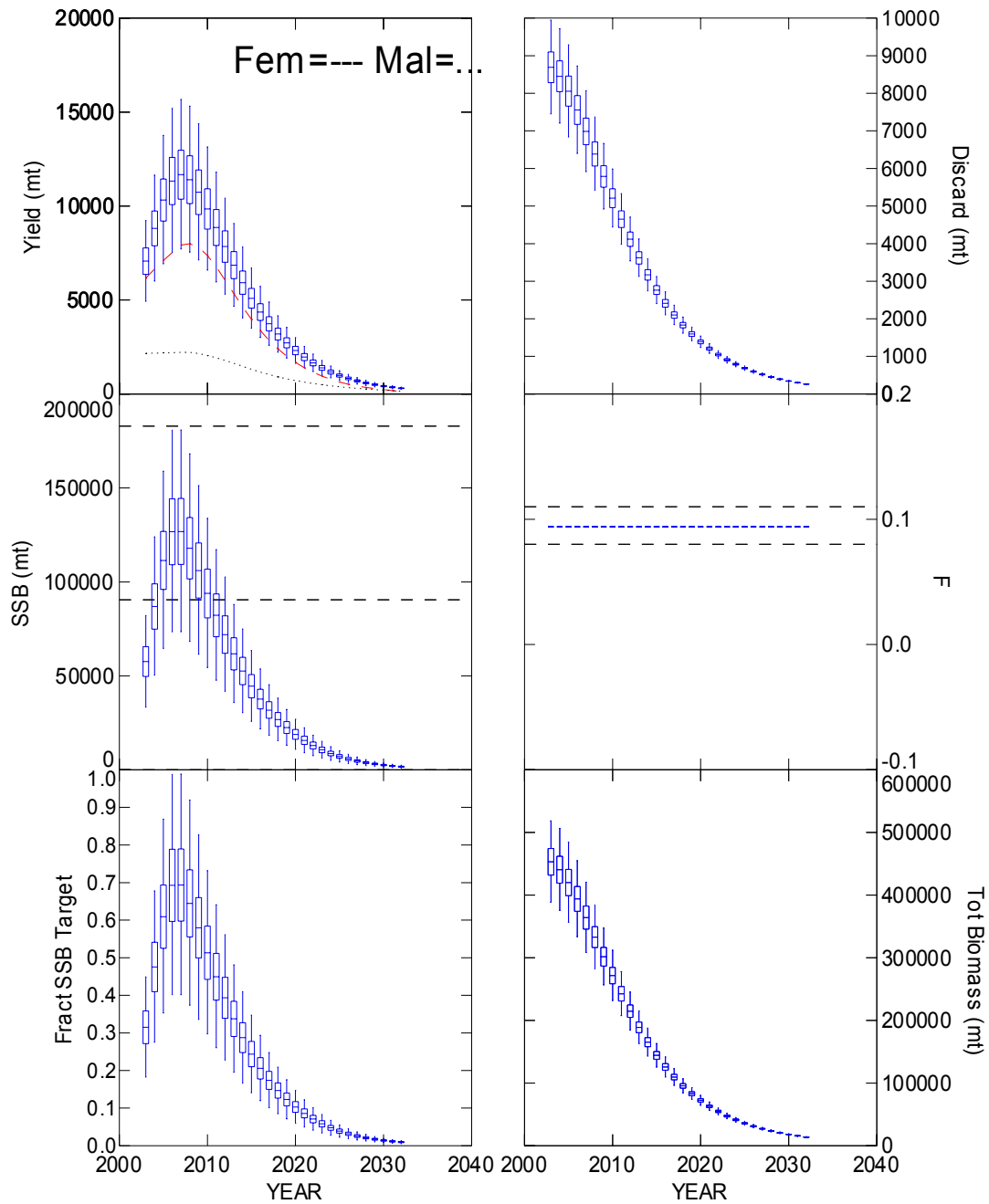


Fig. B9.8 Summary of projection model simulation results under the assumption that the status quo F continues and first year pup survival is expressed as a function of maternal size. This scenario suggests that the population will neither rebuild or stabilize under the status quo F. See text for additional details.

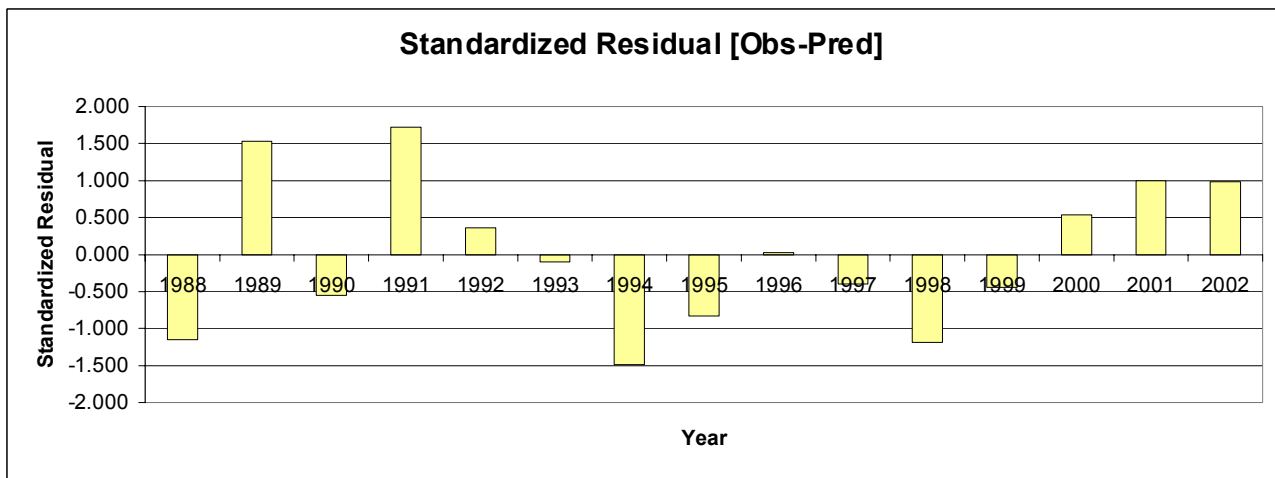
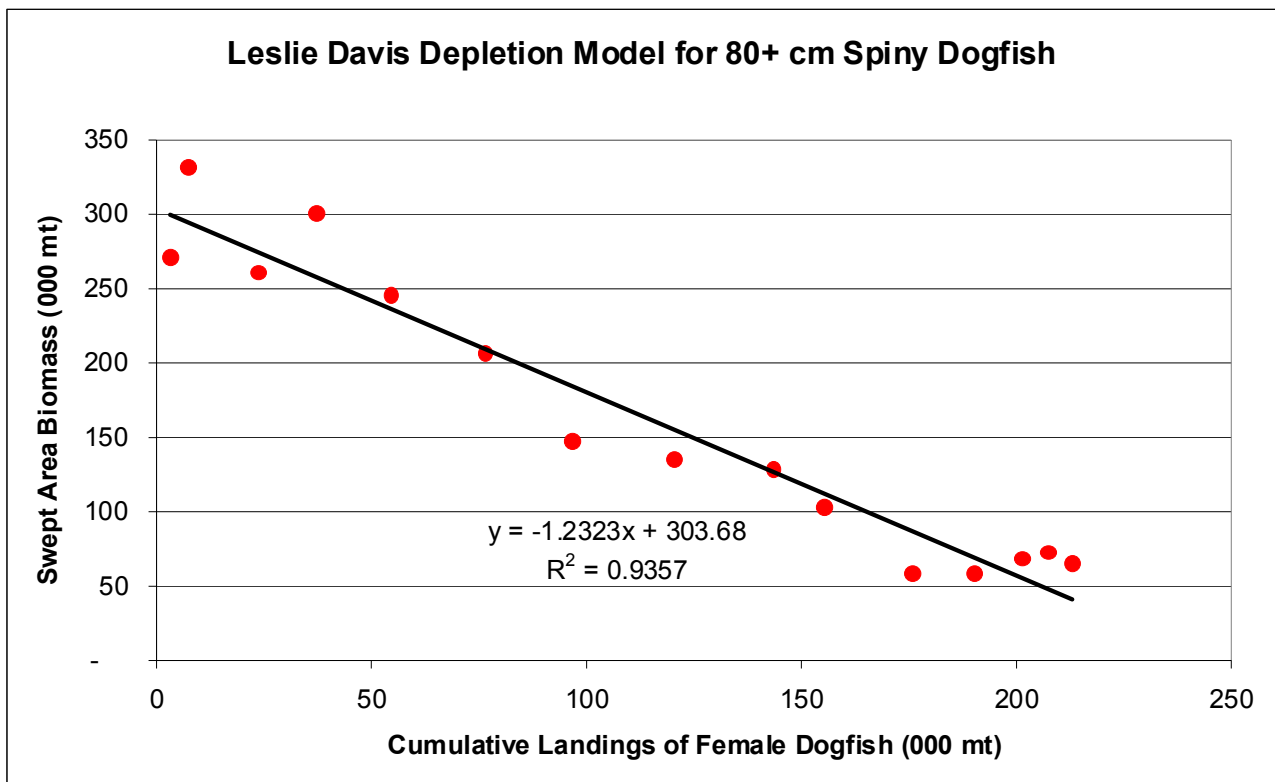


Fig. B10.1. Summary of Leslie-Davis depletion model for female spiny dogfish, assuming a closed population. See text for additional details.

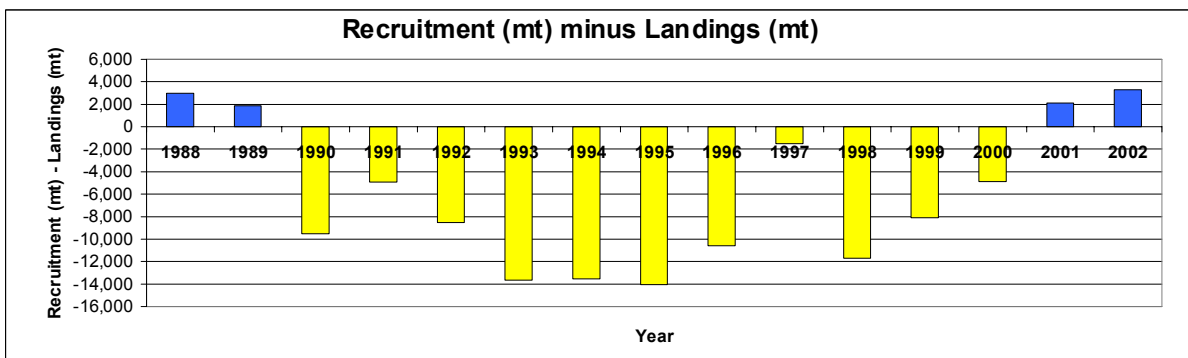
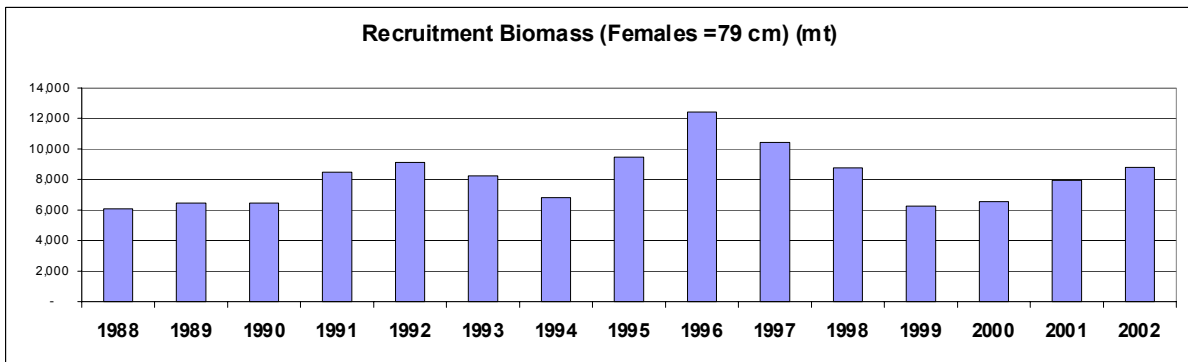
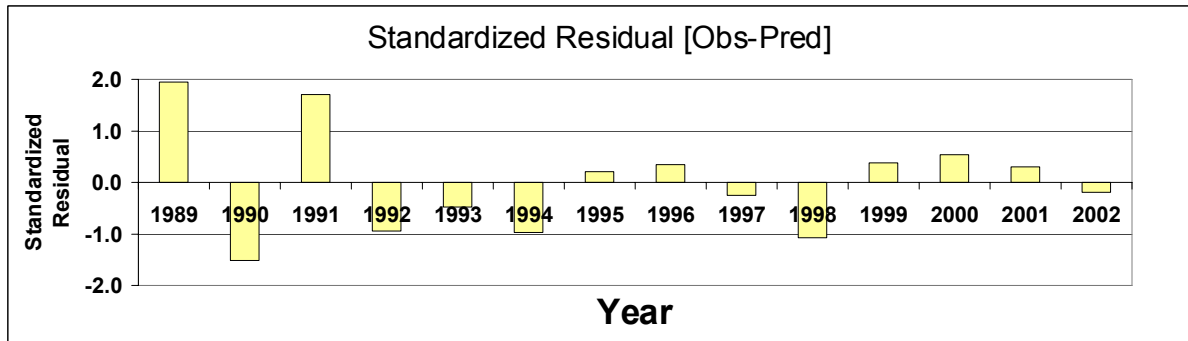
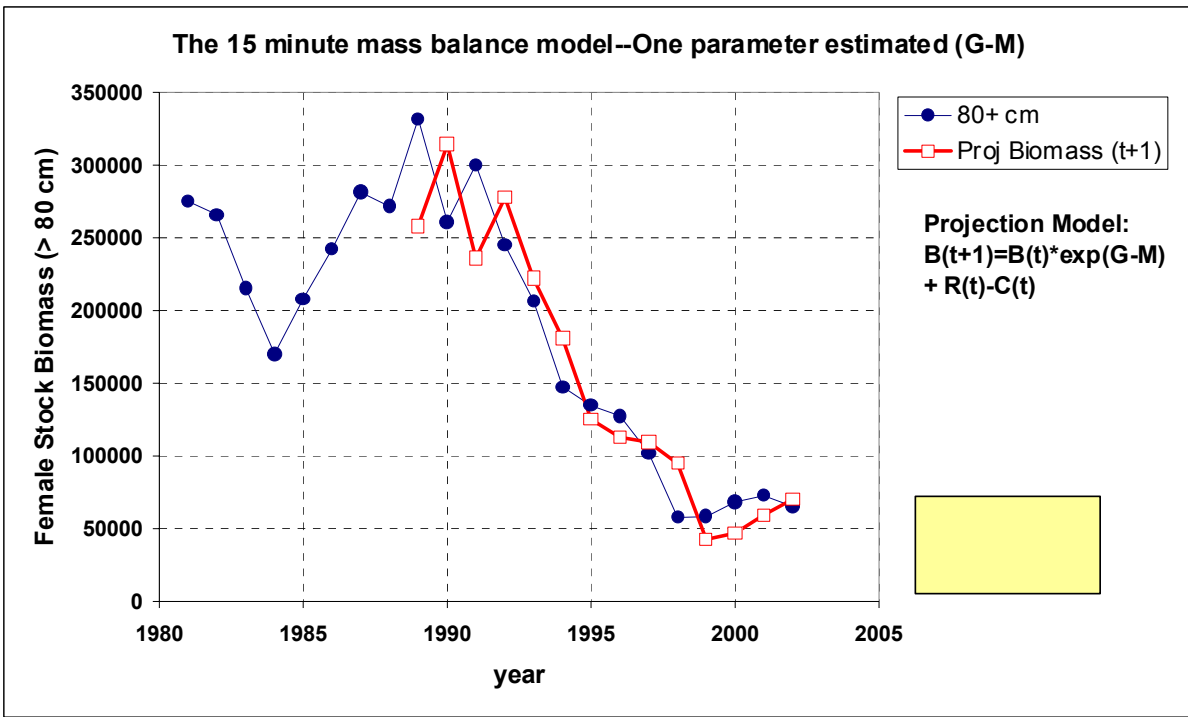


Fig. B10.2. Summary of one-parameter mass balance model. See text for details.

## C. ATLANTIC SURFCLAM

### TERMS OF REFERENCE

1. Characterize fishery performance since the last assessment based on landings, discards, fishing effort and other relevant data.
2. Analyze results of the most recent NEFSC clam survey, including population age structure, growth rates and dredge efficiency.
3. Estimate fishing mortality and stock biomass in absolute or relative terms and characterize uncertainty of estimates.
4. Evaluate stock status relative to current reference points. Update or re-estimate biological reference points based on new information if available.
5. Estimate TAC or TAL based on projected stock status and target fishing mortality rates for years 2004-2007.

### EXECUTIVE SUMMARY

Surfclams in federal waters (the EEZ) are managed as a single stock; however, this assessment considered a number of smaller, stock assessment regions as well.

<b>Abbreviation</b>	<b>Stock Assessment Region</b>
SVA	Southern Virginia and North Carolina
DMV	Delmarva
SNJ	Southern New Jersey
NNJ	Northern New Jersey
LI	Long Island
SNE	Southern New England
GBK	Georges Bank

#### 1. Fishery performance.

The surfclam fishery in the EEZ (beyond 3 miles from land) has been managed with a single annual commercial catch quota, which has been set since 1978. Landings from the EEZ are typically close to annual quotas. EEZ Landings rose from about 18,000 mt in 1997-1998, to about 24,000 mt in 2002. The annual quota also rose during this period.

For the last 17 years, the majority of the EEZ surfclam fishery has been concentrated off the coast of NNJ. Landings from LI and DMV have increased since 1999, but remain small relative to NNJ landings.

Commercial catch rates in the surfclam fishery are measured in units of bushels of clams per hour fishing. In NNJ, LPUE decreased gradually, but steadily, from 1031 kg/hr in 1991, to 801 kg/hr in 2002 for medium and large vessels, a -22% change. Catch rates have also declined over this period in DMV and SNJ.

Trends in LPUE were also examined on a smaller spatial scale, the ten-minute square (TNMS). Numerous TNMSs off the coast of NJ have had declining catch rates during the last decade.

Mean length of clams landed from DMV decreased steadily from 159 mm in 1982, to 123 mm in 1998. Mean length landed from DMV increased to 136 mm in 2002. Mean length of clams landed from NJ has remained relatively steady (140 – 150 mm) throughout the time series.

Surfclams begin to recruit to the fishery at about 5 years of age. However, most of the clams that were landed in 2002 from NJ and DMV were 8-12 years old. The oldest clams landed in 2002 were > 20 yr old.

## 2. NEFSC clam survey and dredge efficiency.

Uncertainty following the 1994 survey highlighted problems in interpretation of survey indices. To reduce this uncertainty, sensors have been used since 1997 to monitor ship and dredge performance during clam surveys.

In 2002, the *RV Delaware II* surveyed over 500 stations across a wide range of depths (10-90m). Differential pressure in the dredge manifold was usually 35 – 40 PSI, implying relatively consistent sampling.

For each random survey tow, distance sampled by the dredge was calculated as the sum of distance traveled per second, during those times when the dredge was potentially fishing. Tow distance is important in estimating biomass. Estimates of tow distance derived from the sensor data are longer than “nominal” and “Doppler” distances because sensor-based distances include any fishing that occurs when the dredge is being set out, towed for 5-min and hauled back. For the most recent three surveys (1997, 1999, 2002) the median sensor-based distances ranged from 0.20 – 0.25 nmi. In contrast, the nominal distance is 0.125 nmi.

Field studies were carried out in 2002 to estimate efficiency of the NMFS clam dredge. Four types of data were collected: 1) the survey vessel Delaware II (DE-II) resampled fixed stations, in unfished areas, from its earlier surveys, 2) a calibration (“depletion”) experiment was conducted by the DE-II, 3) three calibration experiments by a commercial clam vessel were analyzed in conjunction with catches from setup tows made earlier by the DE-II, and 4) stations sampled by the DE-II in 2002 were repeated by a commercial vessel a couple of months later.

Dredge calibration experiments were analyzed using a spatial model. DE-II dredge efficiency estimates from the model for 1997, 1999, and 2002 range from 0.276 to 0.460. The value for 2002 was intermediate, 0.389. The grand mean from the 15 estimates of DE-II dredge efficiency, collected during these three years, was 0.370 (CV = 0.492).

While surfclams have occupied the same general locations since 1980, maps of the catch suggest a recent reduction in abundance of clams in relatively shallow water in DMV. Furthermore, the fraction of random stations in DMV Stratum #9 that captured zero surfclams increased from

about 13% in 1997 to about 39% in 2002. This change was apparently due to higher mortality inshore, perhaps related to rising water temperature; it was not due to commercial harvesting.

Based on survey age-composition data, distinct cohorts are detectable in NJ and DMV. Populations in NJ and DMV consist of over 20 ages, and younger clams are more common than older clams. The maximum age observed in samples from 2002 was 28 yr old (born about 1978). At least some recruitment seems to occur in all years.

In NNJ, survey catch per tow of large (120+mm) clams increased from 1978 to 1997, but declined in 1999 and 2002 to an intermediate level. In DMV, survey catch per tow of large (120+mm) clams increased from 1978 to 1997, but declined in 1999 and 2002 to a relatively low level.

The most recent (1999, 2002) survey catches of 88-119 mm clams, those that will be recruiting in the near future, are near historical lows in both NNJ and DMV. Recruitment in the next few years is expected to be below average.

### 3. Stock biomass and fishing mortality.

Stock biomass and mortality for surfclams in each region were estimated using efficiency-corrected swept area biomass (ESB) information. In addition, the KLAMZ delay-difference stock assessment model used in the last assessment (NEFSC, 2000a) was used for surfclams in NNJ and DMV. ESB estimates are used for status determination because KLAMZ results were not available for all areas.

Total fishable biomass was fairly constant from 1997 (1,146,000 mt) to 1999 (1,460,000 mt). Total fishable biomass declined in 2002 (803,000 mt). In all three of the latest surveys, the region with the greatest fishable biomass was NNJ.

Biomass in NNJ has declined from about 486,000 mt in 1997-1999 to 315,000 mt in 2002. However, estimates are imprecise and trends are uncertain. A stronger decline in fishable biomass was detected in DMV. Estimates of total fishable biomass without GBK, where no fishing occurs, are 915,000 mt in 1997, 1,075,000 in 1999, and 566,000 mt in 2002.

Annual fishing mortality rates during 1997, 1999 and 2002 were estimated directly from the ratio of catch (landings plus an assumed incidental mortality adjustment) and ESB values for each region. The F estimates for total fishable biomass ranged from about 0.018 in 1997-1999, to 0.033 in 2002. In 2002, the 80% CI for F on total fishable biomass was (0.022, 0.049).

The greatest amount of reported landings came from NNJ. In NNJ, F was estimated to be 0.032 in 1997, 0.037 in 1999, and 0.053 in 2002. F estimates in DMV rose from about 0.009 in 1997-1999, to 0.035 in 2002. F's in SNJ have been variable, ranging from 0.011 to 0.107. In LI, F rose recently to 0.111.

In modeling and mortality estimation, fishery induced mortality was estimated based on landings plus discard plus a 12% upper bound incidental mortality adjustment. The incidental mortality adjustment is an upper bound that accounts for clams that are damaged by the dredge during fishing, but never handled on deck.

Trends in LPUE over the last decade were decreasing, while trends in survey data and estimated stock biomass were usually increasing. The commercial fishery concentrates on dense beds while the survey collects samples from random locations within strata. It is likely that declining trends in LPUE represent fishing down of dense beds. Survey trends can differ from LPUE trends because the survey samples the whole stock. However, divergent trends in LPUE and survey data are an important source of uncertainty.

For the DMV region, the ESB estimate was 317,000 mt in 1999 and 143,000 mt in 2002. Average biomass from KLAMZ during 1999-2002 was 289,000 mt. Both models show a decline in biomass in DMV from 1999 to 2002, but the decline from the KLAMZ model is more gradual.

KLAMZ model results for NNJ are shown, but the model suffered problems with residual patterns and bias. For NNJ, results from efficiency corrected swept area biomass (ESB) are probably more reliable.

#### 4. Stock status relative to current reference points.

Target biomass (a  $B_{MSY}$  proxy) for the entire surfclam stock is  $(\frac{1}{2})B_{1999}$ . In SARC-30 (NEFSC, 2000a),  $B_{1999}$  was estimated at 1,596 thousand mt, based on efficiency corrected swept area biomass (ESB), and at 1,268 thousand mt, based on the KLAMZ model. In the present assessment,  $B_{1999}$  was updated to be 1,460 thousand mt, based on ESB. Thus, the updated estimate of target biomass is 730 thousand mt.

Based on efficiency-corrected swept area biomass (ESB) calculations, the entire stock consisted of 803 thousand mt in 2002, with an 80% confidence interval from 542 thousand mt to 1,188 thousand mt (Table C21). Based on these estimates, the stock is not overfished. The stock is much closer to the target biomass than it was in 1999.

The fishing mortality threshold is  $F=M$ , and  $M$  was estimated at 0.15 (NEFSC, 2000a). The estimated  $F$  in 2002 for the entire stock was 0.033, with an 80% CI of 0.022 to 0.050. Based on these estimates, overfishing is not occurring.

#### 5. Short-term projections.

Projections in this section depict potential future trends assuming catches at the quota (near status-quo) and continued low surplus production rates during 2002-2005.

It appears surfclam biomass may have declined during 1997-2002 by about -5.1% per year on average, even in the absence of fishing. Surplus production will probably continue to be low during 2002-2005 because production rates tend to be temporally autocorrelated for surfclam, and because poor recruitment is expected during 2003.

Total stock biomass may decline by about -29% to 656 thousand mt in 2006, if the entire quota is taken and surplus production remains negative during the next three years. For comparison, the target biomass (a  $B_{MSY}$  proxy) for the surfclam stock is 617 thousand mt and the biomass threshold used to identify overfished stock conditions is 309 thousand mt. Declines may range from -26% to -40% for the NNJ, SNJ and DMV regions where most of the catch is taken.

## INTRODUCTION

Atlantic surfclams (*Spisula solidissima*, Dillwyn 1819) are large, fast-growing bivalves that occupy sandy substrates from the shallow subtidal zone to depths of about 50 m. Weinberg and Helser (1996) and Weinberg (1998, 1999, 2002a) describe individual growth rates, size- and age-structure, recruitment and likely effects of rising sea temperature on surfclams. Management and history of the surfclam and ocean quahog fisheries along the Atlantic coast of the United States were described by Murawski and Serchuk (1989). An individual transferable quota (ITQ) system was established in 1990.

Surfclams were assessed in 1992, 1994, 1997 and 1999 (NEFSC 1993, 1995, 1998a,b, 2000a,b), for SARC/SAW-15, -19, -26 and -30. Assessments are generally done after NMFS clam surveys, which are conducted every 2-3 years. Uncertainty in assessment results and the necessity for additional research on abundance were highlighted at SARC-22 (NEFSC 1996a,b) because 1994 survey catch rates were anomalous and the dredge efficiency estimate from a population model was unrealistic.

Due to uncertainty about survey data from 1994, a major effort has been made subsequently to improve understanding of the performance of the dredge used in NMFS clam surveys. Clams are sampled with a 3.2 ton, hydraulic dredge, similar to that used by industry. A submersible pump, mounted above the dredge, shoots water into the sea bottom just ahead of the 1.5m-wide dredge mouth. These jets of water turn the sea bottom into a fluid, which allows the clams to be captured more easily.

An underwater video camera and sensors, used for the first time in 1997, monitored the behavior of the dredge during each tow of the 1997 survey. The video and sensor data allowed for more accurate estimates of distance towed as well as estimates of water pressure at the manifold. In addition, depletion experiments were carried out in the field in 1997 to estimate the efficiency of the NMFS clam dredge. Experiments were done in collaboration with academia and the clam industry. As an additional tool, survey stations occupied during previous NMFS clam surveys in unfished areas were resampled to indicate whether there were gross changes in efficiency of the clam dredge over time.

Sensors on the dredge and ship, depletion experiments, and resampled stations were continued during the 1999 and 2002 clam surveys to monitor dredge efficiency. The new Shipboard Computing System (SCS) and, in 2002, a new Survey Sensor Package mounted on the clam dredge of the R/V DELAWARE II were used to gather continuous data on ship speed, position and dredge angle during every tow. These data allowed for improved direct estimates of distance sampled per tow by the dredge. Additional calibration (“depletion”) studies to measure survey dredge efficiency were carried out in collaboration with the clam industry and academia (see Acknowledgments). Improvements made to the clam survey in 1997, 1999 and 2002 allow for more accurate estimates of current surfclam biomass because tow distance was measured more accurately, variations in survey dredge efficiency were understood better, and dredge efficiency estimates from depletion studies were useful for estimating surfclam biomass directly.

This report summarizes analyses and major research findings. A list of research recommendations, sources of uncertainty, and SARC comments are included. This assessment used existing, improved, and new models to estimate current stock biomass, fishing mortality and annual surplus production for seven stock assessment regions that make up the surfclam



stock (Figure C1). Because this fishery is highly localized and the resource is sedentary, attention was given to temporal and spatial trends in the regional commercial and survey data. The report also compares estimates of F and stock biomass to biological reference points.

Names and abbreviations for the stock assessment regions are listed (from south to north) below.

<b>Abbreviation</b>	<b>Name</b>
SVA	Southern Virginia and North Carolina
DMV	Delmarva
SNJ	Southern New Jersey
NNJ	Northern New Jersey
LI	Long Island
SNE	Southern New England
GBK	Georges Bank

## COMMERCIAL DATA

Commercial landings and effort data from 1980 to 2002 are from mandatory vessel logbooks. It is assumed throughout this assessment that one "industry" bushel (1.88 cubic ft) of surfclams = 17 lbs = 7.711 kg of usable meats. Vessel size class categories are: Class 1 (small, 1-50 GRT), Class 2 (medium, 51-104 GRT), and Class 3 (large, 105+ GRT). Age- and length-frequencies in the commercial catch were estimated from samples collected by port agents in New Jersey and Delmarva.

### Landings

The surfclam fishery in the EEZ (beyond 3 miles from land) is managed with commercial catch quotas. Landings from the EEZ are typically close to annual quotas, which have been set since 1978.

Between 1965 and 1974, total landings rose from 20,000 to 44,000 mt of meats (Table C1, Figure C2). After 1974, total landings declined steadily to 16,000 mt in 1978. A major hypoxic event off New Jersey in 1976 caused high mortality in the stock of that region. Strong recruitment of surfclams in the Mid-Atlantic region from Delmarva through New Jersey in the late 1970s resulted in increased landings throughout the early 1980s. From 1983 to 2002, annual EEZ landings were fairly constant, ranging from 18,000 - 25,000 mt. Landings from the EEZ rose from about 18,000 mt in 1997-1998, to about 24,000 mt in 2002. The annual quota also rose during this period. In the 1980s, approximately 75% of the landings were from the EEZ; other landings were from state waters. From 1990 to 2001, the percentage of landings from the EEZ ranged from 64 to 74%.

Since 1994, virtually all EEZ landings were taken from the Middle Atlantic region. Georges Bank has been closed to surfclam fishing since 1990 due to the risk of paralytic shellfish poison (PSP). For the last 17 years, the majority of the EEZ surfclam fishery has been concentrated off the coast of New Jersey in the NNJ region (Figures C4-C7) (NEFSC, 1998a, 2000a,b). During 1986-2002, 64-91% of Middle Atlantic annual landings came from the Northern New Jersey (NNJ) stock assessment region, 2-19% came from Delmarva (DMV), and 0-22% came from Southern New Jersey (SNJ) (Table C2, Figure C3). This represents a shift away from the DMV region, which was a major source of surfclams in the late 1970s and to a lesser degree in the early 1980s. Starting in 1997, a significant fraction of surfclam landings were taken from a single ten-minute square close to shore at the mouth of the Delaware Bay (NEFSC, 2000a; and Figures C4-C7), which accounts for the increased fraction of landings from the SNJ region (Table C2). There has been an increase in landings from the LI and DMV regions since 1999 (Table C2).

### Catch Rates and Effort

#### *Effort Trends:*

In the early 1980s, consistently high levels of fishery effort (15,000 - 16000 hrs/yr) took place in Delmarva (DMV) and the Southern (SNJ) and Northern New Jersey (NNJ) regions (Figure C8). Effort subsequently declined in DMV and SNJ, but remained high in NNJ. From 1985-1990, hourly trip limits were used to manage the fishery, and effort data during this period are unreliable due to reporting problems. Fishing effort has been fairly stable since 1991, when ITQ management was imposed. Though effort in DMV remains small, relative to NNJ, effort has risen in DMV since 1998 (Figure C8).

#### *Characteristics of Clam Vessels:*

Previous assessments used vessel weight (i.e., tonclass) to assign vessels to groups for examining trends in landings per unit effort (LPUE). We used information about vessels in the 2002 clam fleet to determine if tonclass was a reasonable way to assign vessels to groups. Ton class was positively correlated with other measures of fishing power, including vessel length, engine horse power (HP), pump HP, and dredge width (Figure C9). Although there might be better ways to assign vessels to groups (a Research Recommendation) that reflect fishing power, the analysis suggests that ton class is a simple and reasonable way to make the assignment. Catch rates are presented below for 3 groups of vessels based on ton class: medium, large, and (medium + large). To maintain confidentiality, catch rates for the small ton class are not presented; they often represent a single vessel.

#### *Landings per unit effort (LPUE):*

Commercial catch rates in the surfclam fishery are measured in units of bushels of clams per hour fishing. Data from every trip are reported in logbooks. Trip limits of 6-hr during 1985-1990 make reported effort per trip and LPUE unreliable for those years (NEFSC 1998a). In the Mid-Atlantic region, over 95% of the annual surfclam catch is typically taken by large (105+ GRT) and medium vessels (Table C3). LPUE in the Mid-Atlantic region (Long Island to Southern Virginia) declined slightly from 1991-2002, with a small increase in the 1999 (Figure C10). A fishery for surfclams developed on Georges Bank (GBK) in the mid-1980s, but that area was closed in 1990 due to paralytic shellfish poison (PSP). The LPUE from GBK in the mid-1980s is comparable to that in the Mid-Atlantic during the 1990s, indicating that surfclams were abundant on GBK (Figure C10).

In the Northern New Jersey (NNJ) region, LPUE increased from the early 1980s to the 1990s (Figure C11). For Large + Medium vessels combined, LPUE declined in NNJ from 1991 to 1998, increased slightly in 1999-2000, and then declined in 2001-2002 (Table C3, Figure C11). LPUE decreased from 1031 kg/hr in 1991 to 801 kg/hr in 2002 for vessel class 2+3, a -22% change. Although Class 2 vessels account for only a small fraction of the NJ landings, those vessels often have a higher LPUE than Class 3 vessels.

Off Southern New Jersey, nominal LPUE for class 2+3 vessels peaked in 1993 and 1998 at almost 2000 kg/hr (Table C3, Figure C12). This represents the highest LPUE among all region/vessel class combinations. Considering data from 1991 to 2002, LPUE is presently at a relatively low value (853 kg/hr) for this region.

In the Delmarva region, LPUE has been variable since 1991, probably due to the small number of trips taken in the region (Table C3, Figure C13). Indices have tended downward for Class 2+3 vessels. Considering data from 1991 to 2002, LPUE is presently at a relatively low value (790 kg/hr) for this region.

Trends in LPUE were also examined on a smaller spatial scale, the ten minute square (TNMS; 1 minute of latitude = 1 nmile). For each TNMS, the slope of catch rate vs time was computed, for the period 1991-2002. Data for a given Year/TNMS combination were omitted whenever effort (time fishing) was < 5 hr. TNMSs with negative slopes, which indicate decreasing catch rates during the last 12 years, are coded white, while those TNMSs with positive slopes are coded black (Figure C14). Numerous TNMSs off the coast of NJ have had declining catch rates during the last decade.

#### *General Linear Models (GLM)*

GLMs were used to standardize LPUE data and estimate year effect parameters that may measure trends in surfclam biomass. GLMs were carried out, by region, on the natural log of LPUE. Year and subregion were included as explanatory variables. "Subregions" were created by splitting each region into approximate halves. Data from all medium and large vessels were included, and they were not treated as separate groups in the GLM. Other models, with ton class and month as explanatory variables, gave similar results. As described above, effort reporting problems from 1985-1990 confound interpretation of LPUE as a measure of relative resource abundance. Therefore, data from 1985-1990 were excluded from the analyses. GLM results from NNJ, SNJ and DMV are most important because the fishery is/has been active in these areas and NMFS research surveys have indicated that much of the stock biomass is within these regions.

Across regions, there is a general trend for a rise in LPUE from the early 1980s to the 1990s (Table C4, Figure C15). This is probably due to several factors including recovery of the stock biomass and age structure following the hypoxic event and heavy fishing during the 1970s, ITQ management in the 1990s, and possible changes in fleet composition and harvesting technology.

Back-transformed year coefficients from the GLMs (i.e., standardized LPUEs) follow trends in nominal LPUEs for large vessels, as well as trends in nominal LPUE for medium + large vessels, rather closely. Model results suggest that LPUE in NNJ declined by approximately 19% from 1991 to 2002. LPUE in SNJ and DMV has been highly variable, but each is currently near the minimum value for its region in the last decade (Table C4, Figure C15).

### Size Composition in Landings

Length frequency distributions for surfclams landed between 1982 and 2002 are presented for the New Jersey (NJ) and Delmarva (DMV) regions in Figures C16 and C17, respectively. Sampling data are summarized in Table C5.

Mean length of clams landed from DMV decreased steadily from 159 mm in 1982 to 123 mm in 1998. Mean length increased from 1998 to 2002. Low mean length in 1994 is probably the result of low sample size, because size distributions in 1995 and 1996 were similar to those in 1991-1993.

Mean length of clams landed from the New Jersey area has remained relatively steady throughout the time series, although the percentage of small clams (90 - 110 mm) increased from 1993-1997. The proportion of clams in the 150 mm+ category increased after 1990 off NNJ, and has remained high since then.

Between 1982 and 1990, average size of clams landed from S New England (SNE) (approximately 150 mm - 160 mm) was greater than that from areas to the south (typically 120 mm - 140 mm, Table C5). No data are available from SNE and after 1990.

### Age Composition of Landings

Estimates of age composition for landings involved age-length keys for each region, based on samples collected and aged from the 2002 NMFS survey, and length composition of commercial landings, measured by port agents. Age data from commercial landings were not available.

Surfclams begin recruiting to the fishery at about 5 years of age (Figure C18). However, most of the clams that were landed in 2002 from NJ and DMV were 8-12 years old. The oldest clams landed in 2002 were > 20 yr old. In NJ and DMV the fully recruited surfclam stock in 2002 consisted of about 20 year classes.

## **RESEARCH SURVEYS**

### History of Changes Made to NMFS Clam Survey Gear

The NMFS clam survey has been conducted since 1965. Clam survey data must be used carefully because significant methodological changes have taken place over time. Table C6 summarizes changes that took place in the early years, including changes in and to research vessels, sampling in different seasons, changing dredges, mesh sizes, etc. Changes that have taken place in the last decade are listed in Table C7. Factors that changed recently include refitting the research vessel (which affected how it rides in the water), new winches which operate at different speeds and affect tow distance, and voltage on the ship powering the pump on the dredge.

### Sensor data (1997, 1999, 2002)

Uncertainty following the 1994 survey highlighted problems in interpretation of survey indices. To reduce this uncertainty, changes to operational procedures at sea were implemented in 1997 and have continued to the present. Better monitoring of dredge performance was achieved via the Delaware II's Shipboard Computing System (SCS), which permits continuous monitoring of variables that are critical to operations. In addition to the SCS sensors, sensors were attached to the clam dredge. During most tows, these sensors collected data on ship's speed, ship's position,

dredge angle, power to the hydraulic pump, and water pressure from the pump at depth. Depending on the sensor, the sampling interval in 1997 and 1999 varied from once per second to once per ten seconds. The smallest time unit for analysis was one second, and all sensor data collected in 2002 used this sampling frequency.

Types of sensors and the data they collect have evolved over time. In 1997 and 1999 “old” inclinometers were used to measure dredge angle. In 2002, both “old” inclinometers and a new integrated Survey Sensor Package (SSP) were used. The SSP was developed by collaborative effort between NEFSC and the clamming industry. There is consistency between readings from the “old” and new inclinometers. When the R/V DE-II was at the dock at the conclusion of the 2002 clam survey, these sensors were within 1° of each other in estimating the angle of the dredge on the ramp (33.16°- old vs. 32.3°- SSP). Furthermore, tow distances based on “old” inclinometer and new SSP angle data from 66 stations in Leg 3 were similar and highly correlated. While both old and new sensors work, in practice it is critical to calibrate them properly and to have an accurate estimate of their mounting angles relative to the dredge. The latter measurement is very difficult to make precisely with the “old” inclinometers, and is a source of uncertainty, particularly in 1997 and 1999.

Figure C19 is an example of new (SSP) sensor data collected at every station in 2002. These data were used to compute tow distance and to monitor electrical power and differential pressure from the dredge manifold. Although several pieces of equipment had to be replaced during the 2002 clam survey (Table C8), differential pressure in the manifold remained fairly stable during the entire survey (Figure C20). The survey sampled stations across a wide range of depths (10-90m). Differential pressure was usually about 35 – 40 PSI (Figure C20), implying relatively consistent sampling performance. For comparison with the NMFS clam dredge, commercial clam boats operate with much higher differential pressure, 80 – 100 PSI.

#### *Sensors for calculation of tow distance*

For each random survey tow, distance sampled by the dredge was calculated as the sum of distance traveled per second, during those times when the dredge was potentially fishing (i.e., when dredge angle was  $\leq 5.2^\circ$ ) (Figure C21). Distance traveled during each second was determined from data on ship’s speed, assumed to represent the movement of the dredge. This method may tend to overestimate tow distance due to this assumption. However, tow distance is grossly underestimated by nominal distance. Dredge inclinometer data had been smoothed with a 7-s moving average to eliminate high frequency shocks. Dredge angles  $> 5.2^\circ$  represented times when the dredge was probably not fishing, either because it was not near the bottom or because it had hit a large boulder and bounced up. Using the cutoff angle  $5.2^\circ$  for when the dredge was fishing differs from the criterion used in SARC30; the change resulted in a minor increase in average tow distance for the 1997 and 1999 surveys (ranging from 0 to 5% for tows taken at surfclam depths). The change was made for this assessment based on analysis of dredge angle data collected with both “old” and “new” sensors simultaneously in 2002, and uncertainty about mounting angle of the “old” inclinometer in 1997 and 1999. Switching to the new criterion provides a standard angle that can be applied to inclinometer data and distance calculations from all three surveys: 1997, 1999, and 2002.

In choosing which angle to pick as a cutoff, the Invertebrate Subcommittee also considered the distance from the manifold jets to the sea floor (Figure C22), and the force of water from the jets, as a function of dredge angle. New field studies to measure these relationships would be useful to get a better understanding of dredge behavior.

The use of sensor data has a major effect on estimated tow distance (Table C9; also see Weinberg et al. 2002b; West and Wallace 2000). Nominal tow distance (i.e., 0.125 nmi) is a hypothetical calculation that assumes towing for exactly 5-min at 1.5 knots. Median doppler estimates for each survey of the distance traveled by the ship during the 5-min tow (0.124 – 0.130 nmi) are similar to the nominal distance. Doppler distances are close to nominal distances because the former measures distance of the ship over ground only during the 5-min, timed tow. Both measures underestimate total distance sampled. Estimates of tow distance derived from the sensor data are longer, and for the three surveys the median distances ranged from 0.20 – 0.25 nmi. Sensor-based distances are longer because they include any fishing that occurs when the dredge is being set out, towed for 5-min and hauled back. The higher value in 1997 was due to use of a slower winch on the *R/V DE-II* in that year. Confidence intervals for the median tow distance of each survey, based on sensors, are given in the bottom of Table C9.

#### Surfclam mortality caused by clam dredges

The effects of hydraulic clam dredges on clams and the environment have been described in several studies (Table C10). After a dredge passes through an area, some of the clams are run over or blown out of the tow track and not captured. These clams are often injured and may die or get attacked by predators before they reburrow. This is referred to as “indirect” mortality.

Surfclams that are brought to the surface often die when they are discarded, because the shell may be cracked or because the high pressure water from the dredge can cause internal injury. Surfclams are unable to close their shells completely, and dredging forces sand into the gills and mantle cavity. In the 1980s, discarding was common, but reported levels of discarding have been low in recent years.

#### Efficiency of the Clam Dredge on the *R/V Delaware II*

Field studies were carried out in 1997, 1999 and 2002 to estimate efficiency of the clam dredge. This is an important parameter because it is used in the calculation of stock biomass, and because efficiency may vary between surveys, affecting abundance trend estimates. Four types of data were collected for this purpose: 1) the survey vessel Delaware II resampled fixed stations, in unfished areas, from its earlier surveys, 2) a calibration (“depletion”) experiment was conducted by the DE-II, 3) three calibration experiments by a commercial clam vessel analyzed in conjunction with catches from setup tows made earlier by the DE-II, and 4) stations were sampled by the DE-II in 2002 and repeated by the commercial vessel a couple of months later.

#### *DE-II Resampled Stations from its Earlier Surveys*

Approximately 20 fixed stations in the DMV region have been resampled in each survey since 1997 to indicate whether dredge efficiency changed radically between surveys. Commercial fishing was uncommon in these areas. In theory, changes in catch rates between surveys, with adjustments for growth and natural mortality, indicated changes in dredge efficiency. Data collected from resampled stations in 2002 could not be used to check for changes in dredge efficiency because the number of surfclams per tow in 2002 was unexpectedly low, due probably to higher natural mortality associated with elevated water temperatures in the last few years. Fishing mortality was not a factor because reported catches were very low.

#### *Calibration Experiments – Analytical Models*

Early studies of clam dredge efficiency (Meyer et al., 1981; Smolovitz and Nulk, 1982), did not obtain reliable estimates of dredge efficiency or for the habitat where the clam survey is carried

out. Thus, it has been necessary to carry out new studies in 1997, 1999 and 2002. Results from 1997 and 1999 are described in detail in NEFSC (1998a,c; 1999; 2000a,c).

Calibration or “depletion” field experiments were used to estimate efficiency of the survey dredge. At the most basic level, a depletion study repeatedly samples a closed population in a small area and uses the rate of decline in catch per unit effort to measure population abundance. The total population is estimated from the rate of decline in catch over successive samples and the total quantity caught.

Dr. Paul Rago (NEFSC) extended the model used to estimate surfclam dredge efficiency in 1997 to explicitly consider spatial overlap of tows as a depletion experiment progresses. The extended negative binomial “patch” model (described in NEFSC, 1999 and Rago et al., in press) was applied to the surfclam depletion experiments from 2002. A summary of the fieldwork and final results are given below.

#### *2002 Calibration Experiments – Results*

Surfclam depletion experiments were carried out between June and August, 2002 (Figure C23, Table C11). The main purpose of the experiments was to estimate efficiency of the clam dredge on the *R/V Delaware II* (DE-II). Most depletion experiments involved the DE-II and a commercial vessel (*F/V Jersey Girl*), but the DE-II also carried out its own depletion study at a site off the coast of NJ, labeled DE-II in Figure C23. These data provided a “direct” estimate of efficiency for the DE-II. Another type of experiment involved the DE-II making 5 setup tows at a site and then having the commercial clamming vessel, perform a depletion experiment at that site. Comparison of the DE-II surfclam catch (from its set up tows) with the estimate of density and efficiency from the commercial vessel’s data set was used to compute an “indirect” estimate of DE-II dredge efficiency. In 2002, three “indirect” estimates of efficiency were obtained in this manner at sites called: sc02-2, sc02-3, and sc02-4. The number of tows made by the commercial vessel at these sites was 16, 20, and 18, respectively.

For each experiment, tracks of the DE-II and commercial vessel are shown (Figures C24-C27). In general, the DE-II setup tows and FV Jersey Girl depletion tows were done at the same general area, as intended (Figures C25-C27).

Because dredge efficiency probably varies with bottom type, bottom characteristics were measured. Two independent sediment samples, from the top 4 cm, were collected from two VanVeen grab samples at each depletion site (Figure C28, Table C11). The most common particle sizes in the samples were 0.25 – 0.5 mm. Some larger particles, >4mm, were also present in some samples.

To analyze the depletion experiments, it was necessary to compare clam density estimates from the two vessels at each site, restricting the calculation to clams fully recruited to both the survey and commercial dredges. Thus, it was necessary to determine the selectivity of the *FV Jersey Girl* relative to *RV DE-II* with respect to surfclam shell length. Data used to examine relative selectivity came from measurements of surfclams from the DE-II setup tows and from every 5<sup>th</sup> tow of each of the three Jersey Girl depletion experiments. Two additional data sources came from the 9 stations sampled by both vessels in NJ, and the 9 stations sampled by both in DMV. The cumulative size distributions of clams were compared between vessels (Figure C29), and a relative selectivity function was estimated for each site using the model shown in Figure C30. The DE-II was more likely to retain smaller individuals.

Because the goal was to find the size where the vessels had similar selectivity, without eliminating too many of the clams that were measured, we chose as a cutoff the clam size where the relative selectivity of the Jersey Girl was 0.75 that of the DE-II. From the data we obtained 4 estimates of the “0.75 point”, and the median of those estimates was 130 mm (Table C12A). All subsequent analyses that were related to gear efficiency and involved data from the FV Jersey Girl excluded clams smaller than 130 mm in length. The fraction of clams  $\geq 130$  mm is listed by dataset (Table C12B). Compared with samples from NJ, those from DMV had more small clams.

Rago’s model was used to analyze each of the 4 depletion experiments from 2002. The cell size used in the model was twice the width of the dredge, and no indirect losses (clams lost but not counted as part of the catch) were assumed. Model estimates for dredge efficiency and density are listed in Table C13, and profile likelihood confidence intervals for these parameters are shown in Figures C31-C34.

Table C14 demonstrates how model results from the commercial depletions were used along with data from the DE-II setup tows to estimate DE-II efficiency. Efficiency of the Jersey Girl was variable across sites (0.45 – 0.95). The DE-II was never more efficient than the Jersey Girl, but at site sc02-3, both vessels had a dredge efficiency near 45%. The mean of the 3 “indirect” estimates of DE-II efficiency was 0.406. The “direct” estimate of DE-II dredge efficiency was 0.695.

#### *DE-II Stations Resampled by the Jersey Girl, all in 2002*

Other information about DE-II dredge efficiency came from comparing the catches at the stations sampled by both vessels in 2002 (Table C15). The 9 stations in DMV were each sampled once by both vessels. The 9 stations in NJ were sampled 3 times by the DE-II (once on each leg of the cruise) and one time by the Jersey Girl. The relative efficiency of the DE-II to the Jersey Girl could be computed from the ratio of the average density (i.e., number of surfclams per square foot) using data on surfclam catch and tow distance from each vessel. It was also possible to compute an absolute efficiency for the DE-II, by assuming that the efficiency of the Jersey Girl at these stations was 0.9. The 90% efficiency applied to the Jersey Girl is the best estimate for the efficiency of that vessel (i.e., calculated as the median of efficiency estimates for that vessel from depletion studies based on data collected since 1997). From this approach, the estimate of DE-II dredge efficiency was 0.187 and 0.236 in DMV and NJ (Table C16).

#### *DE-II Dredge Efficiency Summary*

DE-II dredge efficiency estimates for 1997, 1999, and 2002 are listed in Table C17. The annual values range from 0.276 to 0.460. The value for 2002 was intermediate, 0.389. The grand mean from the 15 estimates of DE-II dredge efficiency, collected during these three years, was 0.370 (CV = 0.492).

### Survey Results

#### *Description of Surveys*

A series of 23 research vessel survey cruises were conducted between 1965 and 2002 to evaluate the distribution, relative abundance and size composition of surf clam and ocean quahog populations in the Middle Atlantic, Southern New England and Georges Bank (Figure C1).



Assessment regions were defined by groups of strata which remain fixed through time (Figure C1). Surveys are performed using a stratified random sampling design, allocating a pre-determined number of tows to each stratum. One tow is collected per station, and nominal tow duration and speed are 5 minutes and 1.5 knots, respectively. Catch in meat weight per tow is computed by applying length-weight equations to numbers caught in each 1 mm size category. Surfclams were measured and weighed during several DE-II clam surveys to determine the shell length meat weight relationship for important regions (see Table C18 for parameter estimates). Values used in the 1999 surfclam stock assessment were an average of fitted curves from the 1997 survey and the earlier relationships reported by Serchuk and Murawski (1980) and Gledhill (1984). Although new data were collected during the 2002 survey (Table C18), due to seasonal and annual variability that is possible in surfclam length-weight, and for consistency, we have assumed the same length/weight relationship as in the previous assessment (NEFSC, 2000a,b).

By computing simple unweighted averages from all tows within a stratum, size frequency distributions per tow were computed by stratum. Size frequency distributions and mean number of clams per tow were computed for each region by averaging over strata, weighted by stratum area.

In surveys conducted prior to 1997, doppler distance was used to standardize every tow's catch to a common tow distance (0.15 n. mi). As described in previous sections, tow distances in the 1997, 1999 and 2002 surveys were standardized by calculating tow distance from ship's velocity (measured by GPS) and contact by the dredge on the bottom as measured by the inclinometer. For the purpose of computing swept area biomass, distance-standardized catches per tow from 1997 - 2002 were computed by multiplying catch at each station by the ratio of (0.15/sensor tow distance). For analysis of trend, catches were standardized by the ratio 0.15/Doppler distance.

Locations of random stations in the 2002 clam survey are shown in Figure C35. Sampling intensity was greater in some areas (e.g. NNJ) because estimation of population abundance via area-swept methods was anticipated (Table C21). Samples were not collected in 2002 from the lower part of the S. Virginia - N. Carolina region, the Great S. Channel just to the west of Georges Bank, or from the NW corner of Georges Bank (Strata 67, 72). This was necessary to allocate enough cruise time for dredge calibration experiments.

In 1999, a new sampling policy was adopted regarding randomly chosen stations with rocky bottom that could not be sampled with the clam dredge without a high risk of severe gear damage. If the bottom was too rocky, pilots were told to search for towable bottom within 0.5 nmi of the station. If the search was unsuccessful, the log sheet for that station was filled out with a special code (SHG = 151), and the vessel moved on to the next random station. In previous surveys, pilots may have searched for good bottom and then taken a tow, even if it was a considerable distance from the original station location, without keeping a record. This procedural change in 1999 is important in providing a better estimate of the area of clam habitat on Georges Bank (NEFSC 1998a,c). In the current assessment, nominal individual stratum areas on Georges Bank were reduced in proportion to the fraction of tows from GBK that had been assigned code 151 (Table C21). The effect of this was to reduce the biomass estimate.

#### *Spatial Distribution of Survey Catches*

Clam abundance per tow data from the 2002 survey were partitioned into three size classes: small (1-87 mm), medium (88-119 mm), and large ( $\geq 120$  mm). Detailed distribution data by size class are plotted in Figures C36 - C41. These catches were standardized to a tow distance of

0.15nmi (using tow distances from the SSP sensor and a 5.2° critical dredge angle). On a large spatial scale, surfclams were found primarily on shallow or inshore locations (typically  $\leq 25$  fathoms, or 45 m) on Georges Bank, S. New England, New Jersey and Delmarva. The largest patch of surfclams occurred off NJ. “Submergence” (i.e., species distribution shifted to deeper, cooler water) is evident at the southern extreme of the range (Figure C36).

Another series of maps shows the unadjusted catch per tow in number of surfclams ( $\geq 88$ mm) over time, from 1982 to 2002 (Figures C42 - C47). The purpose of these maps is to show trends in surfclam distribution. While surfclams have occupied the same general locations throughout the entire period, there appears to have been a reduction in clam abundance in shallow water in DMV, close to 37° N (Figure C44). This conclusion is supported by Table 20, which summarizes a presence/absence analysis of survey data from Stratum #9 (Figure C1), historically a primary surfclam stratum in DMV. The fraction of random stations in Stratum #9 that captured zero surfclams increased from about 13% in 1997 to about 39% in 2002 (Table C20).

#### *Age-Structure based on Survey Data*

During clam surveys, surfclam shells of live individuals are saved from every station for aging. Age estimation in the laboratory is based on annual lines in the shell. The data are used to compute age-length keys for each year/region combination. Keys were applied to survey length frequency distributions to infer age-structure in the population (Figure C48). Distinct cohorts are detectable in the figure for two regions (NJ, DMV) which have similar patterns. To interpret the data, note that the youngest age that is retained consistently by the NMFS survey dredge is about age 4 yr. A cohort of 5-yr olds is evident in data from 1997; another new cohort of 3-4 yr olds is evident in the data from 2002. Populations in NJ and DMV both consist of over 20 cohorts, and younger clams are more common than older clams. The maximum age observed in samples from 2002 was 28 yr old (born about 1978).

#### *Trends in Numbers and Biomass, based on Survey Data*

Numbers and biomass of surfclams per tow, standardized to a distance of 0.15 nmi using Doppler distances, are shown from 1978 – 2002 (Figures C49-C55). The data have been separated into two size groups and by region. The “88-119 mm” group can loosely be considered as clams that will recruit to the fishery in the coming year or two. The “120+mm” group can be considered as fully-recruited to the fishery.

These plots are useful for examining trends over time and for noting which regions have the most surfclams. Note that the data collected before 1980 must be interpreted cautiously because the sampling gear changed (Table C6). Also, the data from 1994 were collected using a higher voltage to the pump (Table C7), which probably increased differential pressure, dredge efficiency and catch in that year (NEFSC, 2000a,c).

In NNJ (Figure C52), catch per tow of 120+mm clams increased from 1978 to 1997, but has since declined in 1999 and 2002 to an intermediate level for the time series. The number and weight of 88-119 mm clams had peaks in the early 1980s and perhaps (see cautions above regarding 1994 data) the mid-1990s. The most recent values (1999, 2002) for the 88-119 mm clams are near the historical low for this time series. Therefore, recruitment in the next few years is expected to be below average in NNJ.

In DMV (Figure C50) catch per tow of 120+mm clams increased from 1978 to 1997, but has since declined in 1999 and 2002 to a relatively low level for the time series. The number and

weight of 88-119 mm clams had peaks in the early 1980s and perhaps (see cautions above regarding 1994 data) the mid-1990s. The most recent values (1999, 2002) for the 88-119 mm clams are near the historical lows for this time series. Therefore, recruitment in the next few years is expected to be below average in DMV.

In both SNJ (Figure C51) and GBK (Figure C55), abundance of 120+mm clams appears to have increased over time.

## MODELS TO ESTIMATE BIOMASS AND MORTALITY

Following NEFSC (2000a), stock biomass and mortality for surfclams in each region were estimated using efficiency-corrected swept area biomass (ESB) information. As in NEFSC (2000a,b), the KLAMZ delay-difference stock assessment model (Appendix A) was also used for surfclams in several stock assessment areas. ESB estimates are used for status determination. KLAMZ estimates show historical trends for two of the most important stock assessment regions. ESB and KLAMZ estimates for recent years tend to agree because ESB information is used in tuning the KLAMZ model. The natural mortality rate used in all calculations was  $0.15 \text{ y}^{-1}$ .

### Efficiency-corrected swept area biomass (ESB)

Efficiency corrected swept-area biomass estimates (Table C21) for surfclams (120+ mm in SNJ and NNJ; 100+ mm in other areas) were calculated:

$$B = \frac{\bar{C}A'}{ae} * 10^{-6}$$

where  $e$  is the best estimate of survey-specific dredge efficiency for surfclams in the region (Table C17),  $C$  is mean catch per standard tow ( $\text{kg tow}^{-1}$ , see below for standardization details),  $A'$  is habitat area ( $\text{nm}^2$ ),  $a = 0.0008225d_n \text{ nm}^2 \text{ tow}^{-1}$  is the area covered by the 5' wide survey dredge during a standard tow of nominal distance ( $d_n = 0.15 \text{ nm}$ ), and the factor  $10^{-6}$  converts kilograms to thousand metric tons. Port samples from commercial catches show that surfclams begin recruiting to the commercial fishery at about 120 mm in length in NNJ and SNJ, and at about 100 mm in other areas (Figures C16 and C17). Thus ESB estimates for clam sizes  $\geq 120$  or  $\geq 100$  mm are crude estimates of the fishable stock.

Habitat area for surfclams in the region was estimated:

$$A' = Au$$

where  $u$  is the proportion of random tows in the region not precluded by rocky or rough ground (surfclams occupy smooth sandy habitats, NEFSC 2000a), and  $A$  is the total area computed by summing GIS area estimates for each survey stratum in the region. Mean catch per standard tow ( $\bar{C}$ ) is the stratified mean catch in individual tows ( $C_i$ ), after adjustment to nominal tow distance based on an estimate of the actual tow distance from sensor data ( $d_s$ ):

$$C_i = \frac{c_i d_n}{d_s}$$

where  $c_i$  is the original, unadjusted catch in tow  $i$ . In the cases where sensor data were absent, the median tow distance from that survey/stratum combination was assumed.

ESB for the entire surfclam stock (for clams 120+mm in NNJ and SNJ and 100+mm in other areas) during 1997-2002 (Table C21) was computed by adding estimates for individual regions. However, whole stock estimates are difficult to interpret because of unsampled strata,

particularly in the GBK and SVA regions, which could not be filled by borrowing data from earlier or subsequent surveys (Table C19). In addition, dredge efficiency changed during 1997-2002 (Table C21) and borrowed records were not adjusted for changes in dredge efficiency in the database during borrowing.

For consistency in comparing the commercial catch with survey biomass, length-weight parameters used to calculate survey weight per tow for ESB calculations (Table C21) were the same as in NEFSC (2000a). Length-weight data for the 2002 survey data indicate that average meat weights have declined in some regions (Table C18). Survey catch weights and ESB estimates were not adjusted for declines in meat weights, however, because commercial catch weight estimates could not be adjusted, and because meat weights vary between seasons and years.

Efficiency corrected swept area biomass (ESB) values and 80% confidence intervals from NMFS survey data are given for 1997, 1999, and 2002 in Table C21. The ESB estimates for 1997 and 1999 have been revised from the last assessment (NEFSC 2000a,b). Changes made in the calculation include: 1) a new algorithm to borrow data from adjacent surveys to fill holes, 2) use of more accurate estimates of stratum area, 3) a new efficiency estimate for 1997, based on updated information, and 4) revised tow distances for 1997 and 1999 based on critical dredge angle of 5.2°.

Taking into account the confidence intervals (CI) in Table C21, total fishable biomass was fairly constant from 1997 (1,146,000 mt) to 1999 (1,460,000 mt), but declined in 2002 (803,000 mt). The region with the greatest fishable biomass in all three of the latest surveys was NNJ. The point estimate for biomass in NNJ has declined from about 486,000 mt in 1997-1999 to 315,000 mt in 2002. However, the point estimate from the 2002 survey is within the 80% CIs from the two previous surveys (1997 and 1999). A stronger decline in fishable biomass was detected in DMV. Estimates of total fishable biomass without GBK are 915,000 mt in 1997, 1,075,000 in 1999, and 566,000 mt in 2002.

#### Annual Fishing Mortality Rates (F) based on Catch and ESB

Fishing mortality rates during 1997, 1999 and 2002 were estimated directly from the ratio of catch (landings plus an assumed incidental mortality adjustment) and ESB values for each region in each year (Table C22). The F estimates for total fishable biomass ranged from about 0.018  $y^{-1}$  in 1997-1999, to 0.033  $y^{-1}$  in 2002. In 2002, the 80% CI for F on total fishable biomass was (0.022, 0.049). In NNJ, which accounts for the greatest amount of reported landings, F was estimated to be 0.032  $y^{-1}$  in 1997, 0.037  $y^{-1}$  in 1999, and 0.053  $y^{-1}$  in 2002. F estimates in DMV rose from about 0.009  $y^{-1}$  in 1997-1999, to 0.035  $y^{-1}$  in 2002. F's in SNJ have been variable, ranging from 0.011 to 0.107  $y^{-1}$ . In LI, F recently rose to 0.111  $y^{-1}$ .

#### Uncertainty in ESB and catch-ESB ratios

The variance of ESB estimates was important in tuning the KLAMZ model and in interpreting mortality estimates from catch and ESB data (Tables C21 and C22). CV's for original survey densities ( $c_i$ ) in ESB variance calculations were computed in the clam survey database using standard formulas for stratified random means. The CV for dredge efficiency ( $e$ ) was from the mean and standard deviation of all efficiency estimates for surfclam during 1997-2002 (Table C17). For lack of better information, CVs for sensor tow distances ( $d_s$ ), area swept per standard tow ( $a$ ), total area of region ( $A$ ), percent suitable habitat ( $u$ ), and catch were all assumed to be 10%. The CV for area swept in a standard tow is understood to include variance due to Doppler

distance measurements and variability in fishing power during the tow due, for example, to rocky or muddy ground.

Uncertainty in ESB and catch-ESB ratio estimates for each region and survey, and for the stock as a whole, was measured by CV's calculated using a formula for independent lognormal random variables in products and ratios (Demming 1960):

$$CV\left(\frac{ab}{c}\right) = \sqrt{CV^2(a) + CV^2(b) + CV^2(c)}$$

The accuracy of Demming's formula for ESB estimates was checked by parametric bootstrap analysis (8000 iterations) that assumed all variables in ESB calculations were from independent lognormal distributions. CV's by the two methods were similar as long as variables were assumed to follow a lognormal distribution. However, the skewed and apparently lognormal distribution of parametric bootstrap estimates was useful in gauging shape of uncertainty about ESB biomass estimates and catch-ESB fishing mortality estimates (Figure C56).

#### Survey data used in KLAMZ modeling

Survey trend indices for surfclam (Table C23) used in the KLAMZ model were mean meat weights (kg) per tow during 1978-2002 adjusted to an arbitrary standard tow distance of 0.15 nm (see below). Data for surveys prior to 1980 require care in interpretation (see below) because early surveys used different survey gear or were carried out during the winter (Table C6). Trend indices used data for random and nearly random "fill" tows (database RANDLIKE code 1 or 2, Table C24). Data for surveys beginning in 1982 were for tows with database codes  $1 \leq \text{HAUL} \leq 3$  and  $1 \leq \text{STATYPE} \leq 6$ . Survey data for 1978-1981 did not use these criteria because HAULTYPE and STATYPE data were not recorded (Table C24).

Following NEFSC (2000a), survey data for 1994 were omitted from modeling because of anomalously high catches, probably due to the voltage used to power the submersible pump on the dredge (480 v instead of 460 v). As described in NEFSC (2000a), survey data for 1979 were not used in modeling and survey data in modeling for 1978 and 1980 were averages for two surveys during each year. As described below, the influence of survey data for 1978 and 1980 on stock biomass estimates was minimized in modeling through use of survey covariates. The main purpose of including data for 1978 and 1980 was to estimate changes in gear efficiency that may have occurred as the current survey gear was phased in.

Survey trend information used in the KLAMZ model were for "prerecruits" (ages  $k-1$  to  $k$ , where  $k$  is the age at recruitment), "new recruits" (ages  $k$  to  $k+1$ ) and "old recruits" (ages  $k+1$  and older). In modeling, the pre-recruit index was shifted forward one year and used as an additional recruitment index. For example, the pre-recruit index for 1986 was used as an index of recruitment in 1987, when no survey was actually conducted.

For each area, the age at recruitment ( $k$ ) was estimated based on fishery length composition data and von Bertalanffy growth curves in NEFSC (2000a). Taking  $k$  as the age at either 100 or 120 mm, growth curves in NEFSC (2000a) were used to calculate lengths at ages  $k-1$ ,  $k$  and  $k+1$  (Table C25). The predicted lengths for each region define upper and lower length bounds for pre-, new- and old recruits and were used to aggregate survey data for use in the KLAMZ model. For example, the prerecruit index for NNJ and SNJ was for clams 107-119 mm, the

recruit index was for clams 120-129 mm and the old recruit index was for clams 130+ mm (Tables C24 and C25).

Doppler tow distance measurements were used to adjust survey data to a nominal distance of 0.15 nm for trend calculations (Table C24) using  $D=C*N/d_d$  where  $D$  is the standardized catch for one tow,  $C$  is the unadjusted meat weight for the tow,  $n$  is the nominal tow distance, and  $d_d$  was the tow distance estimated by Doppler measurements. For a few tows with no Doppler data, the nominal tow distance was used instead.

Length-weight parameters used by NEFSC (2000a) for swept area biomass calculations were used in this assessment for swept area biomass and to calculate trends in weight per tow from numbers at length (database code REV\_DATE\_FOR\_LW= 1999, Table C24). NEFSC (2000a) used an older set of length weight parameters for trends based on frozen, rather than fresh, samples (REV\_DATE\_FOR\_LW = 0). However, choice of length weight parameters has little effect on estimated trends.

Where possible, “holes” in the survey data (strata not sampled during a survey, Table C19) were filled by borrowing (using data from the previous and or subsequent survey). Borrowing was in both directions. Adjacent holes (same strata during adjacent surveys) and holes in the first or most recent surveys, for example, could not be filled in both directions. In addition, holes in the middle of a string of three or more holes could not be filled.

“Zeros” can be used in stock assessment models (e.g. Butler et al. 2003) but the KLAMZ model has not yet been programmed to accommodate them. Therefore, a few zero values in survey trend data for surfclam were omitted.

Survey trend data in this assessment were extracted from a database that was not available for the previous surfclam assessment. The new database (also used for ocean quahog in NEFSC 2000c), was tested extensively by independent calculations and by comparison to results for surfclam in the last assessment (Table C24).

In the absence of a flexible database, NEFSC (2000a) used survey data for surfclam aggregated by predefined 10 mm size groups and it was necessary to use survey trend data for both numbers and weight per tow in tuning the KLAMZ biomass dynamic model. In particular, NEFSC (2000a) used survey data for pre-recruits (mean numbers per tow for surfclam 80-99 or 100-119 mm), recruits (mean numbers per tow for surfclam 100-109 or 120-129 mm) and all size groups (mean kg per tow for all size groups) rather than the more precisely defined groups used in this assessment. Holes in the survey trend data used by NEFSC (2000a) were not filled. These factors, and other small differences in calculation of survey indices, result in survey data and KLAMZ model biomass that have different values and trends than in the last assessment (see below).

### Somatic growth in modeling

The KLAMZ model assumes von Bertalanffy growth in weight for biomass dynamic calculations. In the model, the growth parameter  $\rho=e^K$  (where  $K$  is the von Bertalanffy growth parameter for weight) is constant but the growth parameters  $J_t = w_{k-1} / w_k$ , (where  $w_j$  is predicted weight at age  $j$ ) can vary over time. Growth parameters used in this assessment were the same as in NEFSC (2000a).  $J_t$  values varied over time for the NNJ, SNJ and DMV areas (Table C26).

### Catch and LPUE in the KLAMZ model

Total catch for surfclam in modeling included landings plus discards for 1982-1992 (Table D4 in NEFSC 1995). Discards were probably close to zero after 1992.

In modeling and mortality estimation, fishery induced mortality was estimated based on landings plus discard plus a 12% upper bound incidental mortality adjustment. The incidental mortality adjustment accounts for clams that are damaged by clam dredge during fishing, but never handled on deck. NEFSC (2000a) used an incidental mortality adjustment of 20%. The adjustment used in this assessment (12%) is a new upper bound estimate based on information about commercial dredge efficiency and published mortality studies. The average efficiency of commercial clam dredges in fourteen depletion studies carried out during 1997- 2002 was 75%. Based on published indirect and discard mortality estimates (Table C10) indirect mortality due to contact with a clam dredge is in the range 5-20% with 50% as an extreme upper bound. Using this information, the upper bound incidental mortality adjustment was estimated as  $0.5 \cdot (1 - 0.75) = 0.12$ .

### Tuning and likelihood calculations in the KLAMZ model

CV's for survey index data were used in calculating goodness of fit to trend data in the KLAMZ model. The alternative internal weighting approach based on residual variance (Appendix B) was not used because CVs likely measure relative precision of indices derived from the same survey.

ESB data were used in the KLAMZ model to estimate scale (absolute biomass level) but not trend. ESB data were not used to estimate trend because other survey data in the model contain nearly the same information. Tuning the KLAMZ model to scale information in ESB data assumed that estimates of the survey scaling parameter for ESB data ( $Q_{ESB}$ ) were from a prior distribution (Appendix A) assumed to be lognormal with arithmetic mean equal one and arithmetic CV=49%. The arithmetic CV was converted to a lognormal standard deviation using  $\sigma^2 = \ln(CV^2 + 1)$ .

Catch data were assumed to be accurate in KLAMZ model runs for surfclam. This means that the fishing mortality rates and biomass levels estimated in the model produce catch levels exactly equal to the catch data.

In contrast to NEFSC (2000a), standardized LPUE data were not used to tune the KLAMZ model. Trends in LPUE over the last decade were decreasing, while trends in survey data and estimated stock biomass were usually increasing. For NNJ, it was not possible to reconcile the divergent trends in the KLAMZ model for this assessment, even assuming a nonlinear relationship between LPUE and stock biomass. The commercial fishery concentrates on dense beds whereas the survey collects samples from random locations within strata. It is likely that declining trends in LPUE represent fishing down of dense beds, whereas the survey is measuring stock as a whole. Future stock assessment models for surfclam should include the ability to model fishing down of large surfclam in dense beds so that LPUE data can be incorporated in the assessment model. Trends in LPUE are important information, even though they were not used to tune the KLAMZ model.

### Instantaneous growth rates

An assumed level of variance in instantaneous rates of somatic growth (IGR) for age groups in the old recruit category is used in the KLAMZ model to estimate the initial age structure of the

stock in the first model year and estimates of escapement biomass and recruitment for the early years (Appendix A). For surfclam, IGR values during 1978-1979 were constrained using a lognormal distribution with arithmetic mean equal to the estimated IGR for 1980 ( $G_{1980}^{Old}$ ) and an arithmetic CV for years 1981-2002 estimated in a preliminary run. Assumptions about IGR levels in early years affect biomass and recruitment estimates for the earliest years primarily.

### Recruitment modeling in KLAMZ

Following NEFSC 2000, surfclam recruitments were estimated assuming a “random walk” recruitment process (Appendix A). In effect, the random walk recruitment approach keeps the recruitment estimate in year  $t$ , the same as in year  $t-1$ , unless there is good reason, in terms of goodness of fit, to change it. Random walk recruitment estimates tend to be relatively smooth with runs of consecutive recruitments that are higher or lower than average and with at least some recruitment in every year. The random walk recruitment assumption might be perfectly appropriate for a stock with reproductive success that is similar from year to year (autocorrelated) or for a stock that recruits to the fishery over a wide range of ages (so that recruitment to the fishery is a smooth weighted average of yearclasses from many years). For surfclam, however, the random walk recruitment approach was used primarily to fill gaps with no survey data, to avoid excessive variance in recruitment estimates, and ensuring that some recruitment was estimated to occur in all years. Highly variable random recruitment patterns with almost no recruitment in some years often result when survey data are limited (Jacobson et al. 1994) but seemed unreasonable because survey age composition indicated that surfclam recruitment levels are not highly variable from year to year.

Quantifying the variability in recruitment around the underlying recruitment model was an issue in modeling for surfclam. In this context, the “*random walk recruitment variance*”  $\sigma_r^2$  is the variance in sequential log scale steps in the random walk recruitment process (Appendix A). For example, if the recruitment estimates were  $\{R_1, R_2, R_3, R_4\}$ , then the random walk recruitment variance would be the variance of  $\{\ln(R_1/R_2), \ln(R_2/R_3), \ln(R_3/R_4)\}$ . In contrast, the “*variance of log scale recruitments*” would be the variance of  $\{\ln(R_1), \ln(R_2), \ln(R_3)$  and  $\ln(R_4)\}$ . The random walk recruitment variance and variance of log scale recruitments are both measures of recruitment variability and can both be computed for any set of recruitment estimates, although the former will generally be smaller than the latter. The two types of variances are similar to the extent that smaller values for either imply smoother time series of estimate recruitment. In particular, as random walk recruitment variance increases, recruitment estimates tend to become noisy (random). As random walk recruitment variance approaches zero, recruitment estimates approach a constant value.

Variability in recruitment estimates affects estimates of  $F$ , biomass, etc. from the KLAMZ model. Preliminary results from this assessment (not shown) indicate that model results may be biased if an inappropriate fixed level of recruitment variability is assumed. Ideally, recruitment variance is not fixed but instead estimated along with other parameters as the model is fit to all of the available data. However, it may be necessary to assume a fixed level of recruitment variability when data are limited. For example, NEFSC (2000a) assumed that the random walk recruitment variance was  $\sigma_r^2=0.2^2=0.04$  for surfclam in all regions because survey index data for prerecruits and new recruits were not available for many years and noisy. Based on residual patterns, NEFSC (2000a) commented that a higher level of random walk recruitment variance might have been used instead to achieve better fit to survey data for the late 1970s and early 1980s. In this assessment, survey data for early years are treated differently (with survey



covariates, see above) so than a higher level of random walk recruitment variance may not be necessary. In NEFSC (2000a), assumptions about recruitment variance had relatively little effect on recent biomass or fishing mortality estimates, but effects on estimates for other years were not evaluated.

Based on NEFSC (2000a), we estimated the random walk recruitment variance based on a log normal prior (Appendix A). In preliminary runs, the mean for the log normal prior was  $\ln(\sigma_r^2)=\ln(0.2^2)$  and the standard deviation was 1. Decisions about the level of recruitment variability (fixed or estimated) in final runs were based on goodness of fit, patterns in time series of recruitment estimates and bootstrap estimates of model bias.

DMV (KLAMZ model results)

Based on preliminary runs, the CV for old recruit IGR was about 41%. Variance for the random walk recruitment model was estimated internally around a lognormal prior with mean  $\ln(0.2^2)$  and log scale standard deviation equal 1.

There were no pathological patterns in residual plots (Figure C57). As in runs for all other areas (not shown), changes in survey scaling parameters ( $Q$ ) between 1980 and 1981 were larger for pre- and new recruits, than for old recruits (Figure C57). The scaling parameter estimate for ESB data was 0.84, suggesting that ESB data were about 16% too low. Mean CVs for survey data and CV for surveys based on goodness of fit were similar for old recruits and new recruits, but not for prerecruits suggesting that the model did include enough process error for prerecruits (see below). Bootstrap runs showed that biomass estimates for DMV surfclam were reasonably precise and not biased (Table C27 and Figure C58).

Run summary	DMV		
$Q_{ESB}$	0.84	Mean 1999-2002 Biomass	289
		Mean 1999-2002 F	0.01
Survey CVs	Prerecruits	New Recruits	Old Recruits
Mean data CV	0.48	0.50	0.28
Goodness of fit CV	1.07	0.41	0.31

(dmvfinal1.out)

As described above, there were a number of changes to survey and ESB data (Figure C62) for surfclam used in this assessment and to the assessment model (e.g. changes in treatment of the 1978-1980 survey data). In DMV surfclam, these changes resulted in different trends in estimated recruitment and biomass (Figure C62). Changes were due primarily to using survey covariates to break the NEFSC clam survey time series into two parts between 1980 and 1981 (see above). Estimated trends changed because the model did not have to scale survey data for 1978-1980 to biomass in the same way as survey data for 1981-2002. This result, which was more pronounced in results (not shown) for other regions, highlights uncertainty in long term trends and the importance of ESB data, which measure biomass directly, in surfclam stock assessments.

### DMV Sensitivity analyses

There was no evidence of retrospective bias in KLAMZ estimates for surfclam in DMV (Figure C59). However, time series of biomass, recruitment and F estimates were somewhat sensitive to omitting ESB estimates in 1997, 1999 and 2002. In addition, biomass estimates became implausibly high when 1996 was the terminal year and all ESB estimates were omitted. The time series of survey and catch data for surfclam in DMV do not contain enough information to estimate biomass in the absence of ESB estimates.

A series of sensitivity runs were used to determine the sensitivity of model results to the prior for random walk recruitment variance. Model runs for DMV surfclam with priors for random walk recruitment variance ranging from  $\sigma_r^2=0.1^2$  to  $0.5^2$  and standard deviation equal 1 showed that model estimates were very robust to choice of mean for the prior because biomass estimates were almost unchanged (Figure C60). In contrast to models for most other regions (not shown), data for surfclam in DMV seem to contain information about variability in recruitment.

The variance of log scale recruitments was 0.19 in the basecase run with random walk recruitment variance  $\sigma_r^2=0.2^2$ . Sensitivity to the assumption of a random walk recruitment model instead of an uncorrelated random recruitment model was evaluated in a sensitivity run using random uncorrelated recruitment and a lognormal prior for the variance of log scale recruitments with mean 0.19 and standard deviation 1 (Appendix B). Results showed that biomass estimates were not sensitive to choice of the underlying recruitment model (Figure C60). However, as expected estimated recruitment time series were smoother and less variable using the random walk recruitment assumption (Figure C61).

### NNJ (KLAMZ model results)

KLAMZ model results shown for NNJ are for documentation only because KLAMZ model estimates were not reliable enough for use by managers. In the absence of model results, ESB estimates provide the best available information about recent biomass and fishing mortality in NNJ.

Problems with model estimates for NNJ were not as severe as for SNJ and LI (see below) but were probably due to the same general problems. The first general problem was a tendency for pathological patterns in survey residual plots due to incompatible trends in indices for pre- and new recruits, relative to trends for old recruits. In particular, peaks in pre- and new recruit survey data during the 1980s are not reflected in trends for old recruits during subsequent years. (Figure C63) The second general problem was bias in model estimates demonstrated by bootstrap results. Experience suggests that the bias was probably due to lack of fit to survey data. Lack of fit to survey data might be due to noise in surveys, substantial changes in survey selectivity or scaling parameters over time, higher fishing or natural mortality on young surfclams during the 1980s (so that they didn't survive to be old recruits), or to other problems.

Preliminary results for NNJ (Figure C64) indicated a CV for old recruit IGR of about 24%. The standard deviation for recruitment variability ( $\sigma_r$ ) in the final run for NNJ was estimated internally around a lognormal prior with mean  $\ln(0.2^2)$  and log scale standard deviation of 1. Changes in survey scaling parameters ( $Q$ ) between 1980 and 1981 were larger for pre- and new recruits, than for old recruits (Figure C64). Mean CVs for survey data and CV for surveys based on goodness of fit were similar for old recruits (see below) suggesting that the model's estimates of process error relative to measurement error in the old recruit survey data were about right. For

pre- and new recruits, however, goodness of fit CVs were larger, suggesting that the model did not include enough process error.

Run summary	NNJ		
$Q_{ESB}$	1.20	Mean 1999-2002 Biomass	343
		Mean 1999-2002 F	0.05
Survey CVs	Prerecruits	New Recruits	Old Recruits
Mean data CV	0.39	0.34	0.23
Goodness of fit CV	0.74	0.52	0.23

#### SNJ, LI, SNE, GBK and SVA regions (KLAMZ model)

A large number of model configurations were tried for surfclam in the SNJ and LI areas, but KLAMZ model results were not sufficiently reliable for use by managers. Problems were similar to problems described above for NNJ and seemed to stem from incompatible trends in survey data for pre- and new recruits, in comparison to survey data for old recruits. The KLAMZ model was not used for surfclam in the SNE area due to lack of time. Survey data for the GBK and SVA areas (Table C19) were too incomplete, even after filling holes (Table C23). In the absence of model estimates, the best available information about biomass is efficiency corrected swept area biomass (ESB) for recent years.

### **STOCK STATUS RELATIVE TO CURRENT REFERENCE POINTS**

Target biomass (a  $B_{MSY}$  proxy) for the entire surfclam stock is  $(\frac{1}{2})B_{1999}$ . In SARC-30 (NEFSC, 2000a),  $B_{1999}$  was estimated at 1,596 thousand mt, based on efficiency corrected swept area biomass (ESB), and at 1,268 thousand mt, based on the KLAMZ model. In the present assessment,  $B_{1999}$  was updated to be 1,460 thousand mt, based on ESB. Thus, the updated estimate of target biomass is 730 thousand mt.

Based on efficiency-corrected swept area biomass (ESB) calculations, the entire stock consisted of 803 thousand mt in 2002, with an 80% confidence interval from 542 thousand mt to 1,188 thousand mt (Table C21). Based on these estimates, the stock is not overfished. The stock is much closer to the target biomass than it was in 1999.

The fishing mortality threshold is  $F=M$ , and  $M$  was estimated at 0.15 (NEFSC, 2000a). The estimated  $F$  in 2002 for the entire stock was 0.033, with an 80% CI of 0.022 to 0.050 (Table C22). Based on these estimates, overfishing is not occurring.

## SHORT-TERM STOCK PROJECTIONS

Projections in this section depict potential trends assuming maximum (near status-quo) catch and consistently low surplus production rates during 2002-2005. Results are feasible, but possibly pessimistic, because surplus production rates may increase during 2002-2005. Low surplus production rates during recent years (1997-2002) were due to low recruitment (indicated by recent survey data, Table C23) and high natural mortality (indicated by loss of surfclam from traditional DMV shallow water habitats). In addition, recent surplus production was further reduced by low meat weights (Table C18), although this was not included in projection analysis.

The future is uncertain, but surplus production may be low during 2002-2005 because surplus production rates tend to be autocorrelated for surfclam with runs of positive or negative values lasting 5-10 years (Figures C57 and C64) and because prerecruit clam survey data (Table C23 and Figures C49 – C52) indicate that recruitment will be poor during 2003. Years with negative surplus production are natural events that occur more frequently in lightly or unfished stocks like surfclam (otherwise unfished stocks would grow indefinitely), and the frequency of years with negative surplus production varies by stock and species (Jacobson et al. 2001). NEFSC (2000a,b) concluded that the surfclam stock was at a relatively high biomass level during 1997-1999 so declines should probably have been expected.

Traditional projection calculations were not feasible for surfclam because biomass, recruitment and F estimates for recent years were not available for most regions. Instead, efficiency corrected swept area biomass (ESB) estimates, annual instantaneous rates for fishing mortality ( $F_t$ ) and surplus production ( $\rho_t$ ) were used in the simple biomass dynamic model:

$$B_{t+1} = B_t e^{\rho - F_t}$$

Based on this model, projected catch for a specified level of  $F_t$  can be calculated using a modified catch equation:

$$C_t = -\frac{F_t (1 - e^{\rho - F_t}) B_t}{\rho - F_t}$$

If catch is known, then the modified catch equation can be solved numerically for  $F_t$ .

A regression line (Figure C65) fit to efficiency corrected swept area biomass estimates to smooth the data and reduce measurement errors (Table C21), indicates that stock biomass (all areas) was about 921 thousand mt during 2002, averaged about 1,136 thousand mt during 1997-2002 and declined, on average, by 81 thousand mt per year during the same period. During the same period, catch (landings plus a 12% maximum adjustment for incidental mortality) averaged 24 thousand mt per year. These figures imply that surplus production for the stock as a whole was negative during 1997-2002 and averaged about  $P_t = -81 + 24 = -57$  thousand mt  $y^{-1}$ . The average instantaneous surplus production rate for the whole stock was

$\rho = \ln[(B_t + P_t)/B_t] = \ln[(1136 - 57)/1136] = -0.051 y^{-1}$  (Jacobson et al. 2002; Jacobson et al. 2001). Thus, recent trends are uncertain, but it appears surfclam biomass may have declined during 1997-2002 by about -5.1% per year on average in the absence of fishing.

Stock projections were used to illustrate potential effects of harvesting the entire surfclam quota (28.068 thousand mt removed based on the 25.061 thousand mt  $y^{-1}$  quota plus a 12% maximum

adjustment for incidental mortality) during 2003-2005, assuming constant surplus production rates of  $P_t = -0.051$  in all regions. For comparison, average catch during 2002 (landings plus 12%) was 26.294 thousand mt. Projections for each region were summed to obtain projected values for the entire stock. The sum is important because overfishing is judged for the stock as a whole. The regional values are important because most of the catch is taken from three areas (NNJ, SNJ and DMV).

Biomass in each region during 2002 for projection calculations was approximated based on average ESB estimates for 1997-2002. For example, NNJ accounted for 38% of average biomass during 1997-2002 in the whole stock (Table C28) so biomass in NNJ during 2002 for projection calculations was  $0.38 \times 921 = 348$  thousand mt. Similarly, catch from NNJ averaged 69% of the total during 1997-2002 (Table C28) and the catch used in projections for NNJ during 2003-2005 (including the quota and a 12% maximum adjustment for incidental mortality) was  $0.69 \times 28.068 = 19.5$  thousand mt.

Results suggest that total stock biomass may decline by about -29% to 656 thousand mt in 2006 if the entire quota is taken and surplus production remains consistently negative during the next three years (Table C28). For comparison, the target biomass (a  $B_{MSY}$  proxy) for the surfclam stock is 617 thousand mt and the biomass threshold used to identify overfished stock conditions is 309 thousand mt. Declines may range from -26% to -40% for the NNJ, SNJ and DMV regions where most of the catch is taken. Based on these calculations, the relatively lightly fished surfclam stock can experience a significant drop in biomass during relatively short periods of negative surplus production due to poor recruitment, low meat weights, poor growth or increased natural mortality.

## RESEARCH RECOMMENDATIONS

### Modeling

- Consider using year- and region-specific or episodic natural mortality rates. The natural mortality rate of surfclams assumed in this assessment was  $0.15 \text{ y}^{-1}$ . The estimate is reasonable as an average based on age data and longevity (NEFSC 2000a). However, based on mass mortality during 1976 off New Jersey and evidence in this assessment of increased natural mortality during recent years off Delmarva, natural mortality rates probably vary over time and among areas.
- Try to develop a forward-casting age-structured numbers-based stock assessment model. A model based on numbers of clams, rather than biomass, would probably be the best approach because there are fewer restrictions on assumptions regarding growth. It would be advantageous to structure the model so that fishery and survey length composition data could be used in tuning.
- Reconcile survey trends for pre- and new-recruits, relative to trends in survey data for old recruits. Preliminary work for this assessment (not shown) showed that models with time dependent survey scaling parameters (Q), models that estimated surfclam “catches” during the 1980s (allowing for additional discard), and models that assume higher natural mortality rates during the 1980s may be useful.

- Reconcile survey data with the consistently declining trends in LPUE during the last decade. This may require a model that accommodates scenarios with the commercial fishery targeting large clams in dense beds. It may also be necessary to model productive areas with commercial concentrations of surfclam separately from areas that are less productive, support lower surfclam densities, and are seldom fished.
- Focus on analysis of declining LPUE trends and examine new approaches for describing fishing power among commercial clamming vessels.

#### Commercial Catch

- Collect age and length composition data on an annual basis from commercial catches to monitor and better predict recruitment and to support the age-structured stock assessment model. Survey data about recruitment are useful but tend to be noisy and are not available every year.
- Reexamine traditional coefficients used to convert commercial catches in bushels to meat weights, and determine number of clams per bushel. Collect data on meat yield and spawning condition.

#### Research Surveys

- Consider using a sensor that tracks dredge position for use during depletion studies. This would likely provide better estimates of dredge efficiency. Also, give additional consideration to winch speed and distance of dredge nozzles from the bottom to better estimate tow distance and dredge efficiency.
- Survey more frequently than every three years in critical areas such as off DMV, where natural mortality may have increased, and off NJ, where future recruitment is uncertain and likely to be below average. This could be accomplished via cooperative research with industry, assuming the data collected in that manner are of high quality and acceptable for stock assessment work.
- Select a new set of fixed stations in unfished areas to monitor dredge efficiency changes between surveys.
- Consider new technological methods to be used during surveys that rely less heavily on estimating dredge efficiency.
- Consider new methods to estimate variability in the spatial distribution of biomass (e.g., kriging).

#### Other

- Continue to bring outside experts to working meetings of the Invertebrate subcommittee (see Appendix B).

## SARC COMMENTS

The SARC discussed whether apparent declines in abundance might be due to or confounded with over-estimation of dredge efficiency. There was some concern that the use of annual estimates (being the mean of estimates obtained within each year) was not justified given their estimated precision. The use of a single efficiency estimate would change the trend of the 1997, 1999, and 2002 indices but would not substantially alter the absolute estimate in 2002. The SARC accepted the efficiency estimates for 1997, 1999, and 2002. The estimates were uncertain but the uncertainty was adequately addressed in the assessment.

The projections presented in this assessment are illustrative of potential trends, if production rates are negative over the short term, and should be viewed with caution.

The SARC discussed potential causes for apparent reductions in biomass production in recent years. Some of these factors include reduced condition factors, increases in M and below average recruitment. Trends in some of these factors may be confounded with variation in survey data, and thus a series of research recommendations to evaluate such factors were proposed.

In the discussion of the KLAMZ model results it was suggested that the basis for rejecting the model results was not well founded. One of the main arguments for rejecting model results was that bootstrap estimates revealed bad estimation bias. It was pointed out that the bias was only established at a single point in the parameter space (i.e., the estimate) and that much more extensive simulations were needed to establish whether the estimator performed well or not. There was no general acceptance of this point.

## SOURCES OF UNCERTAINTY

Survey and LPUE trends were dissimilar. An explanation for this has been provided (i.e., the fishing down of dense clam beds by industry vs the survey which samples randomly from all locations), but this needs further research.

The KLAMZ model for the NNJ region suffered from residual patterns and bias. The causes of this have not been resolved.

Estimates of tow distance and analyses of dredge calibration experiments require information about dredge angle, location and speed. Location and speed are presently assumed equivalent to the ship track. A sensor to monitor dredge position directly could improve efficiency estimates and make estimates of tow distance more accurate.

Accuracy and precision of the annual dredge efficiency estimates are uncertain.

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Table C1. Total USA surfclam landings (metric tons of meats), total landings from the Exclusive Economic Zone (EEZ), landings from state waters, percent of total from the EEZ<sup>1</sup>, and annual quotas. Landings not from the EEZ are from State waters.

Year	Total Landings	EEZ Landings	State Waters Landings	Percent of Total Landed from EEZ	EEZ Quota
1965	19,998	14,968	5,029	75	-
1966	20,463	14,696	5,766	72	-
1967	18,168	11,204	6,964	55	-
1968	18,394	9,072	9,322	49	-
1969	22,487	7,212	15,275	32	-
1970	30,535	6,396	24,139	21	-
1971	23,829	22,704	1,126	95	-
1972	28,744	25,071	3,674	87	-
1973	37,362	32,921	4,441	88	-
1974	43,595	33,761	9,834	77	-
1975	39,442	20,080	19,362	51	-
1976	22,277	19,304	2,982	87	-
1977	23,149	19,490	3,660	84	-
1978	17,798	14,240	3,558	80	13,880
1979	15,836	13,186	2,650	83	13,880
1980	17,117	15,748	1,369	92	13,882
1981	20,910	16,947	3,964	81	13,882
1982	22,552	16,688	5,873	74	18,506
1983	25,373	18,592	4,887	73	18,892
1984	31,862	22,888	7,086	72	18,892
1985	32,894	22,480	9,204	68	21,205
1986	35,720	24,520	10,797	69	24,290
1987	27,553	21,744	5,406	79	24,290
1988	28,824	23,377	4,873	81	24,290
1989	30,424	21,887	8,089	72	25,184
1990	32,556	24,018	8,528	74	24,282
1991	30,037	20,615	9,399	69	21,976
1992	33,831	21,685	11,722	64	21,976
1993	33,527	21,859	11,565	65	21,976
1994	31,048	21,942	9,106	71	21,976
1995	28,733	19,627	9,429	68	19,779
1996	28,775	19,771	8,980	69	19,779
1997	26,298	18,611	7,687	71	19,779
1998	24,509	18,233	6,276	74	19,779
1999	26,685	19,567	7,118	73	19,779
2000	31,093	19,778	11,315	64	19,779
2001	31,237	22,016	9,221	70	21,976
2002	29,614	23,838	5,776	80	24,174
2003	-	-	-	-	25,061

<sup>1</sup> Landings through 1982 are from the U.S. Dept. Of Commerce series "Fisheries of the United States". For 1983 - 2003, EEZ landings were computed from the logbook database, total landings were from "Fisheries of the US", and state landings were computed as (Total - EEZ landings). 1 bushel of SC is assumed = 17 lbs meat = 7.711 kg.

Table C2. Annual EEZ surfclam landings from areas of the Mid-Atlantic region, and percent of Mid-Atlantic landings by region.

Year	Long Island		Northern New Jersey		Southern New Jersey		Delmarva		Southern Virginia North Carolina	
	mt	%	mt	%	mt	%	mt	%	mt	%
1978	0	0	1,348	31	53	1	2,927	68	0	0
1979	0	0	1,463	38	97	3	2,268	59	0	0
1980	0	0	1,692	41	132	3	2,300	56	0	0
1981	0	0	6,462	97	114	2	95	1	0	0
1982	49	4	7,440	44	434	3	6,777	41	1,988	12
1983	212	1	5,515	34	999	6	5,772	36	3,779	24
1984	6	4	8,787	49	1,776	10	5,303	30	1,897	11
1985	0	0	8,427	50	1,077	6	6,636	39	772	5
1986	16	1	14,703	75	1,474	8	2,604	13	849	4
1987	0	0	17,238	87	749	4	1,306	7	387	2
1988	0	0	19,196	91	195	1	1,147	5	591	3
1989	0	0	16,415	82	90	<1	3,118	16	461	2
1990	0	0	16,996	74	891	4	3,546	15	1,502	7
1991	15	<1	17,623	86	1,289	6	1,634	8	0	0
1992	61	<1	18,334	85	2,064	10	1,221	6	0	0
1993	62	<1	16,338	75	2,023	9	3,418	16	0	0
1994	71	<1	17,754	81	664	3	3,454	16	35	<1
1995	0	0	15,749	82	713	4	2,752	14	5	<1
1996	26	<1	16,077	82	1,331	7	2,237	11	0	0
1997	73	<1	14,060	76	2,934	16	1,540	8	5	<1
1998	89	<1	13,142	76	3,625	21	379	2	0	0
1999	157	<1	14,432	74	4,277	22	667	3	0	0
2000	119	<1	13,658	71	3,569	18	2,008	10	0	0
2001	913	4	16,137	75	1,172	6	3,175	15	0	0
2002	1,160	5	14,939	64	2,847	12	4,450	19	79	<1

Table C3. Mid-Atlantic EEZ surfclam landings per unit effort (LPUE, kilograms per hour fishing time) & percent of total annual catch from each region, by year and vessel class (Class 3 = largest, 105 tons +) for records with catch >0 and effort >0. Data Source: Logbooks. LPUE is not shown when % is <1, when few vessels took the catch, or for 1985-1990, when LPUE was unreliable due to effort reporting problems.

Region/Year	Vessel Class 1		Vessel Class 2		Vessel Class 3		Class 2 + 3	
	LPUE	%	LPUE	%	LPUE	%	LPUE	%
<b>Northern NJ</b>								
1980	-	5	407	36	646	59	528	95
1981	-	4	363	36	476	60	426	96
1982	-	7	219	44	317	49	261	93
1983	-	6	353	68	372	26	358	94
1984	-	5	569	72	697	23	596	95
1985	-	5	-	57	-	38	-	95
1986	-	3	-	35	-	61	-	96
1987	-	2	-	35	-	63	-	98
1988	-	2	-	33	-	64	-	97
1989	-	3	-	35	-	62	-	97
1990	-	2	-	33	-	66	-	99
1991	-	<1	959	29	1,063	71	1,031	100
1992	-	<1	1,018	22	851	77	884	99
1993	-	<1	1,118	20	904	79	941	99
1994	-	<1	1,058	26	791	73	847	100
1995	-	<1	1,179	29	796	70	880	99
1996	-	<1	971	35	764	65	826	100
1997	-	<1	863	28	745	72	775	100
1998	-	<1	1,031	26	663	74	730	100
1999	-	<1	1,104	27	817	73	879	100
2000	-	<1	1,161	36	770	64	876	100
2001	-	<1	944	33	721	67	781	100
2002	-	<1	915	28	764	72	801	100
<b>Southern NJ</b>								
1980	-	4	130	35	284	62	199	98
1981	-	5	290	32	342	63	322	95
1982	-	7	182	40	289	53	230	93
1983	-	12	236	54	399	35	281	89
1984	-	10	438	31	595	59	529	90
1985	-	4	-	12	-	84	-	96
1986	-	3	-	17	-	80	-	97
1987	-	<1	-	22	-	78	-	100
1988	-	0	-	31	-	69	-	100
1989	-	3	-	47	-	50	-	97
1990	-	<1	-	37	-	62	-	99
1991	-	<1	1,454	39	1,701	61	1,595	100
1992	-	0	1,589	43	2,008	57	1,804	100
1993	-	<1	2,238	54	1,694	46	1,949	100
1994	-	1	2,072	16	1,272	83	1,355	99
1995	-	0	997	14	1,033	86	1,027	100
1996	-	4	1,042	25	866	71	905	96
1997	-	2	1,334	60	1,256	38	1,303	98
1998	-	2	2,272	44	1,803	54	1,986	98
1999	-	2	2,089	36	1,610	62	1,760	98
2000	-	0	1,572	51	1,230	48	1,385	99
2001	-	<1	913	38	820	61	853	99
2002	-	<1	969	63	706	36	853	99
<b>Delmarva</b>								
1980	-	2	157	21	308	77	255	98
1981	-	2	211	15	437	83	377	98
1982	-	5	197	14	309	81	285	95
1983	-	6	234	15	408	80	366	95
1984	-	5	444	15	734	80	664	95
1985	-	3	-	13	-	84	-	97
1986	-	4	-	13	-	83	-	96
1987	-	3	-	3	-	94	-	97
1988	-	2	-	10	-	88	-	98
1989	-	<1	-	13	-	87	-	100
1990	-	0	-	21	-	79	-	100
1991	-	0	1,008	20	1,406	80	1,302	100
1992	-	0	1,733	34	1,326	66	1,442	100
1993	-	0	1,361	44	1,353	56	1,356	100
1994	-	0	1,612	43	1,937	57	1,782	100
1995	-	0	1,772	40	1,756	60	1,762	100
1996	-	0	1,443	56	1,362	44	1,406	100
1997	-	<1	1,594	47	1,278	53	1,409	100
1998	-	0	1,768	81	869	19	1,472	100
1999	-	0	1,223	12	691	88	901	100
2000	-	0	1,183	53	956	47	1,065	100
2001	-	<1	1,309	51	1,048	49	1,167	100
2002	-	0	894	42	729	58	790	100

Table C4. Standardized LPUE from a general linear model (GLM) for each major surfclam region. The model included Year and Subregion. Data from “small” vessels were excluded. Coefficients from this model were highly correlated with raw catch rates, as well as with coefficients from other GLMs that included Year, Tonclass, Subregion and Month.

Year	DMV		NNJ		SNJ	
	GLM Year Coef.	Backtransf. Coeffs.	GLM Year Coef.	Backtransf. Coeffs.	GLM Year Coef.	Backtransf. Coeffs.
1980	0.000	1.000	0.000	1.000	0.000	1.000
1981	0.369	1.447	-0.240	0.787	0.615	1.850
1982	0.150	1.162	-0.776	0.460	0.238	1.268
1983	0.363	1.437	-0.346	0.707	0.389	1.476
1984	0.990	2.690	0.157	1.170	1.019	2.772
1991	1.829	6.229	0.729	2.072	2.292	9.898
1992	1.962	7.112	0.601	1.825	2.367	10.663
1993	1.902	6.696	0.670	1.954	2.533	12.585
1994	2.299	9.968	0.583	1.792	2.403	11.061
1995	2.217	9.177	0.611	1.843	2.055	7.808
1996	1.953	7.048	0.546	1.727	2.114	8.284
1997	1.967	7.148	0.491	1.634	2.265	9.628
1998	1.996	7.358	0.418	1.520	2.663	14.345
1999	1.504	4.498	0.586	1.797	2.427	11.329
2000	1.655	5.235	0.584	1.794	2.190	8.935
2001	1.744	5.720	0.455	1.576	1.644	5.177
2002	1.330	3.781	0.520	1.682	1.706	5.506

Table C5. Summary statistics on surf clam commercial length frequency data by region/year. Data were collected by port agents taking random samples from landings.

Region/Year	Mean Length (mm) <sup>1</sup>	Min L	Max L	Number of Clams Measured <sup>2</sup>
<b>New Jersey</b>				
1982 <sup>3</sup>	140.5	75	205	7477
1983	142.5	75	205	11253
1984	142.1	45	195	12751
1985	140.4	55	195	7674
1986	136.3	105	175	5130
1987	134.4	95	185	900
1988	137.7	85	165	900
1989	139.9	105	175	919
1990	136.5	95	175	901
1991	143.0	93	188	2272
1992	141.1	64	186	1710
1993	139.8	80	170	928
1994	138.5	85	185	900
1995	141.9	85	175	510
1996	138.0	85	185	1117
1997	136.7	75	195	957
1998	147.3	95	205	690
1999	144.3	95	205	856
2000	147.0	103	195	2655
2001	145.0	107	180	1080
2002	148.0	97	184	961
<b>Delmarva</b>				
1982	159.0	85	205	7756
1983	151.5	45	205	5923
1984	138.8	95	195	3066
1985	132.0	95	175	1832
1986	130.0	95	155	1260
1987	131.4	105	165	730
1988	136.0	115	165	420
1989	136.6	115	175	866
1990	139.1	95	175	892
1991	125.5	20	183	1080
1992	123.5	73	198	1170
1993	122.4	77	155	1392
1994	109.2	85	135	119
1995	125.1	105	155	720
1996	124.0	95	155	1154
1997	127.1	95	175	1622
1998	122.7	95	155	1560
1999	130.4	105	205	1720
2000	131.0	75	178	1290
2001	131.0	106	159	1060
2002	136.0	90	174	360
<b>S. New England</b>				
1982	153.7	135	175	30
1983	150.0	125	165	30
1984	147.9	115	175	90
1985	151.6	115	175	150
1986	161.0	125	195	330
1987	160.9	115	195	569
1988	154.3	105	185	810
1989	155.8	115	185	449
1990 <sup>4</sup>	164.1	135	185	209

<sup>1</sup> "Mean length" is the expected value from the length frequency distribution, using size classes of 1 cm. Length frequency distributions were derived by weighting trips by their respective landings.

<sup>2</sup> Total number of clams used in this assessment. Typically, 30 clams are measured per trip.

<sup>3</sup> Values from 1987-1990 and 1994 are from subsamples of the data. Subsamples contained data from 30 randomly selected trips, when available.

<sup>4</sup> "-" = no data available after 1990

Table C6. List of research clam surveys and gear changes from 1965-1981, and 1997-2002. Column entries are shifted to accentuate changes. Changes in the gear and survey season did not occur from August, 1980 to 1992. Sources of information for 1978 - 1981 are Smolovitz and Nulk 1982 and NEFSC Cruise Reports. Sources of information for 1965 - 1977 are NEFSC 1995a and NEFSC Survey Reports. "Sensors Used" : refers to the velocity, tilt and pump pressure sensors, used in computing tow distance and pump performance. These were used for the first time in 1997. "-" : undetermined.

Cruise	Date	Vessel	Season	Purpose	Pump	Dredge Type	Mesh Size Width (cm)	Mesh Size (cm)	Doppler Measured	Sensors Used
65-	5/65	Undaunted	Spring	Survey	Surface	76	5.1		-	No
65-10	10/65	Undaunted	Fall	Survey	Surface	76	5.1		-	No
66-6,11	8/66	Albatross	IV Summer	Survey	Surface	76	5.1		-	No
69-1,7	6/69	Albatross	IV Summer	Survey	Surface	76	5.1		-	No
70-6	8/70	Delaware	Summer	Survey	Surface	122	3		-	No
SM742	6/74	Delaware	Summer	Survey	Surface	76	5.1		-	No
76-1	4/76	Delaware	Spring	Survey	Surface	122	3		-	No
77-2	1/77	Delaware	Winter	Survey	Surface	122	3		-	No
7801	1/78	Delaware	Winter	Survey	Surface	122	1.91		No	No
7807	12/78	Delaware	Winter	Survey	Surface	122	1.91		Yes	No
7901	1/79	Delaware	Winter	Survey	Submerse	152	2.54		Yes	No
7908	8/79	Delaware	Summer	Gear test	Submerse	152	2.54 & 5.08		Yes	No
8001	1/80	Delaware	Winter	Survey	Submerse	152	5.08		Yes	No
8006	8/80	Delaware	Summer	Survey	Submerse	152	5.08		Yes	No
8105	8/81	Delaware	Summer	Survey	Submerse	152	5.08		Yes	No
9704	7/97	Delaware	Summer	Survey	Submerse	152	5.08		Yes	Yes <sup>1</sup>
9903	7/99	Delaware	Summer	Survey	Submerse	152	5.08		Yes	Yes <sup>2</sup>
200206	6/02	Delaware	Summer	Survey	Submerse	152	5.08		Yes	Yes <sup>3</sup>

<sup>1</sup>. Individual sensors were used.

<sup>2</sup>. A prototype integrated sensor package was used for the first 2/3 of the cruise. After that, individuals sensors were used.

<sup>3</sup>. First use of Survey Sensor Package (SSP) from Woods Hole Group. Used for entire cruise. Individ. sensors used as backup.

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Table C7. Recent gear changes related to the NMFS Clam Survey, 1992-2002. Column entries were shifted to accentuate changes. Changes in the gear and survey season did not occur from August, 1980 to 1992, or from 1999 to 2002. Sources of information are NEFSC Cruise Meetings. "-" : undetermined.

Cruise	Date	Vessel	Ship	Winch Modified	Winch Changed	Winch Speed Out (met/min)	Winch Speed In (met/min)	Voltage to Pump
pre-92		Delaware II				60	60	460
9203	6/92	Delaware II		--	--	--	80	460
9404	8/94	Delaware II				Free spool	80	480
9704	7/97	Delaware II	1/97	1/97		20	20	460
9903	7/99	Delaware II			5/99	50-60	50-60	460
200206	7/02	Delaware II			5/99	50-60	50-60	460

Table C8. Equipment replaced during the 2002 Delaware II clam shakedown and survey legs.

**Gear Changes , by Leg :**

	Shakedown	Leg 1	Leg 2	Leg 3
Cruise Stations	200205 1~40	200206 1-235	200206 236-401	200206 402-552
Dates	5/17-5/31	6/3-6/14	6/17-6/28	7/1-7/12
Electrical Cable	#1A	#1A	#2	#1B
Pump	P1	P1	P1	P2

**Gear Descriptions:**

Elec. Cables	#1A	= New, purchased for 2002 clam survey, black, flexible, loose mesh wrap insulation, 1200'
	#1B	= twin of #1A
	#2	= Old cable used in 2nd half of 1999 clam survey. White, stiffer, tight insulation like fire hose. When loaded on, some metal pieces in this cable too (from previous use).
Pumps	P1	= Used in 1999 and first 2/3 of 2002
	P2	= Spare pump; May have been used pre-1999.

**Table C9. Nominal and computed tow distances and CIs for Delaware II clam surveys. Distances computed from "Sensors" use actual data on dredge bottom contact and vessel speed. "Nominal" distance assumes speed of 1.5 knot for 5-min. Only good tows that captured surfclams were used to compute median lengths, with cutoff dredge angle 5.15 deg. The longer computed tow length in 1997 was caused by use of a slower winch than in 1999 and 2002.**

Method	Year	DredgeWidth		Length (nmi)	Tow Area (nmi^2)	Comments/Conditions
		(inches)	(nmi)			
<b>Nominal</b>		60	0.00082289	<b>0.125</b>	0.000102862	Not based on data. (1.5kn, 5 min)
<b>Doppler</b>	<b>1997</b>	60	0.00082289	<b>0.130</b>	0.000106976	Median Doppler (5-min only).
	<b>1999</b>	60	0.00082289	<b>0.130</b>	0.000106976	"
	<b>2002</b>	60	0.00082289	<b>0.124</b>	0.000102039	"
<b>Sensors</b>	<b>1997</b>	60	0.00082289	<b>0.2528</b>	0.000208028	Median from sensors
	<b>1999</b>	60	0.00082289	<b>0.2135</b>	0.000175688	"
	<b>2002</b>	60	0.00082289	<b>0.2086</b>	0.000171656	"

CI for Tow Length (nmi), for Stations w/ Surfclams (based on Sensors).						
		<b>0.05</b>	<b>0.1</b>	<b>median L</b>	<b>0.9</b>	<b>0.95</b>
<b>Sensors</b>	<b>1997</b>	0.1833	0.2067	<b>0.2528</b>	0.3146	0.3405
	<b>1999</b>	0.1616	0.1701	<b>0.2135</b>	0.2739	0.2984
	<b>2002</b>	0.1729	0.1769	<b>0.2086</b>	0.2355	0.2424

Source of Mortality	Species	Magnitude of Mortality	Reference	Comments
Indirect	Surfclam	20%	Meyer, et al. 1981	NMFS dredge used; % of large clams (90-130 mm) on bottom w/ broken shells; Diver observations in windrow area.
	Ocean quahog	"significant" (greater than for sea scallop, which was <5%)	Murawski and Serchuk, 1989b	Commercial vessel and dredge used. Observations from submersible.
Discard	Surfclam	>50%	Murawski and Serchuk, 1989b	Observed reburrowing of marked clams from submersible.
		33%-50%	Haskin and Starypan, 1976	Replanting experiments with divers.
	Ocean quahog	<10%	Murawski and Serchuk, 1989b	Observations from submersible; Details of dredge and dredging not given.

Table C10 .

Summary of mortality studies on surfclams and ocean quahogs. "**Indirect**" mortality is death in those clams that encountered the dredge, but they were not captured (i.e., they remained on the ocean floor). "**Discard**" mortality is death in clams that were captured, had intact shells, and died after being returned to the ocean floor.

SITE	LATITUDE (dd)	LONGITUDE (dd)
DEII	39.272609	73.782036
SC02-1	40.109080	73.844233
SC02-2	39.269225	73.781163
SC02-3	38.857905	74.408881
SC02-4	36.771116	75.049794
OQ02-1	40.727620	71.737299
OQ02-2	40.103116	73.191079
OQ02-3	38.814912	73.813348
OQ02-4	37.887552	74.644855
OQ02-5	40.730020	70.118408
OQ02-6	40.896190	71.213913

Table C11. Locations of NMFS clam dredge calibration experiments and sediment samples during the 2002 Delaware-II clam survey.

**A.**

Code	Location	Length (mm)
1	NJ - Repeats	137
2	DMV - Repeats	122
3	SC-02	132
4	SC-03	129
5	SC-04	-- Bimodal, Not Used
<b>Median</b>		<b>130</b>

**B.**

Code:	1	2	3	4	5	1	2	3	4	5
Vessel	DE-2	DE-2	DE-2	DE-2	DE-2	JG	JG	JG	JG	JG
Region	NJ	DMV	NNJ	SNJ	DMV	NJ	DMV	NNJ	SNJ	DMV
Purpose	Random	Random	SC02-2 setups	SC02-3 setups	SC02-4 setups	Repeat DE-II	Repeat DE-II	SC02-2	SC02-3	SC02-4
Fraction	0.866	0.303	0.868	0.921	0.359	0.971	0.459	0.940	0.996	0.528

**Table C12 .**

**A. Shell length , for each data set (code), at which the relative selectivity of the FV Jersey Girl to the RV Delaware II was 0.75.**

**B. Fraction of surfclams  $\geq 130$  mm collected at locations that were sampled by the FV Jersey Girl and RV Delaware II. 130 mm was the shell size where the selectivity of the Jersey Girl was about 75% that of the Delaware. The Delaware had higher selectivity of smaller clams.**

Table C13. Likelihood profile results for estimated dredge efficiency and density (N/ft<sup>2</sup>) from the Patch model for surfclams in 2002 depletion studies based on data from depletion studies carried out by the R/V Delaware II (experiment DE02) and the F/V Jersey Girl (experiments JG02-2 to JG02-4). All estimates assume no indirect effects (clams lost but not caught). Results from JG01-JG03 are for surfclams 130+ mm. Results from DE02 are for all size groups captured.

**CI for Efficiency**

Experiment	Best Estimate	Lo 50%	Hi 50%	Lo 90%	Hi 90%	Comments
DE02	0.695	0.61	0.78	0.46	0.93	
JG02-2	0.934	0.87	0.99	0.75	NA	a
JG02-3	0.457	0.35	0.57	0.23	0.71	
JG02-4	0.950	0.84	NA	0.57	NA	c

**CI for Density**

Experiment	Best Estimate	Lo 50%	Hi 50%	Lo 90%	Hi 90%	Comments
DE02	0.054	0.048	0.061	0.044	0.077	
JG02-2	0.058	0.056	0.060	0.051	0.065	
JG02-3	0.011	0.010	0.012	0.008	NA	b
JG02-4	0.044	0.037	0.051	0.032	0.061	

a) Efficiency estimate near upper bound (e=1); profile hit upper bound on efficiency before hitting upper 90% bound.

b) Profile hit lower bound on efficiency (e=0) before hitting upper 90% bound on density.

c) Efficiency estimate near upper bound (e=1); profile hit upper bound bound on efficiency (e=1) before hitting upper 50% or 90% confidence interval bounds.

Table C14. Summary of *Delaware-II* dredge efficiency for surfclams in 2002 (Cruise 200206), inferred by comparing catches in DE-II Setup Tows with Patch Model Estimates, assuming no indirect losses, from data collected with commercial clam vessel *F/V Jersey Girl*.  
 Formula used to compute DEL-II dredge efficiency (EFF) in experiments with the Jersey Girl (JG):

$$\text{EFF(DEL)} = [\text{EFF(JG)} * \text{Density(DEL)}] / \text{Density(JG)}$$

Experiment	Region	Jersey Girl Density (#/ft <sup>2</sup> )	Jersey Girl Efficiency	Delaware Station #	Delaware Density (#/ft <sup>2</sup> )	Delaware Density (#/ft <sup>2</sup> )	Delaware vs Jersey Girl Relative Efficiency	Delaware Efficiency
					Setup Tows	Setup Tows		(from formula)
SC02-2	NJ, offshore	0.0575	0.934	87	0.0280	0.0143	0.249	<b>0.233</b>
				88	0.0073			
				89	0.0077			
				90	0.0119			
				91	0.0169			
				Average:	0.0143			
SD of samples:	0.0085							
SC02-3	SNJ	0.0108	0.457	202	0.0153	0.0106	0.982	<b>0.449</b>
				203	0.0029			
				204	0.0344			
				205	0.0004			
				206	0.0000			
				Average:	0.0106			
SD of samples:	0.0147							
SC02-4	DMV	0.0439	0.949	335	0.0194	0.0248	0.564	<b>0.536</b>
				336	0.0364			
				337	0.0574			
				338	0.0043			
				339	0.0063			
				Average:	0.0248			
SD of samples:	0.0223							
					Grand Mean			<b>0.406</b>
					SD of 3			<b>0.156</b>
					averages:			<b>0.156</b>
					N			<b>3</b>



Region: Vessel:	DMV		NJ		NJ		NJ	
	DE-II (Leg 2)	F/V JG	DE-II (Leg 1)	F/V JG	DE-II (Leg 2)	F/V JG	DE-II (Leg 3)	F/V JG
	# SC / tow	# SC / tow	# SC / tow	# SC / tow	# SC / tow	# SC / tow	# SC / tow	# SC / tow
	9	90	213	523	82	523	59	523
	90	237	74	848	22	848	41	848
	44	97	86	738	42	738	43	738
	7	458	122	1101	17	1101	45	1101
	1	36	42	390	12	390	59	390
	5	42	41	384	22	384	84	384
	14	13	139	561	65	561	170	561
	1	39	23	280	25	280	5	280
	30	1044	64	191	5	191	22	191
<b>Aver. catch</b>	<b>22.33</b>	<b>228.41</b>	<b>89.33</b>	<b>557.43</b>	<b>32.44</b>	<b>557.43</b>	<b>58.67</b>	<b>557.43</b>
SD catch	29.15	336.88	59.89	292.19	25.72	292.19	47.44	292.19
CV of catch (%)	130.54	147.49	67.04	52.42	79.26	52.42	80.87	52.42
<b>Aver. area (ft<sup>2</sup>) / tow</b>	<b>6,289.3</b>	<b>13,398.1</b>	<b>6,044.9</b>	<b>15,187.4</b>	<b>6,087.6</b>	<b>15,187.4</b>	<b>6,600.7</b>	<b>15,187.4</b>
SD (area)	453.80	1995.41	551.83	2017.26	407.51	2017.26	378.98	2017.26
CV of area (%)	7.22	14.89	9.13	13.28	6.69	13.28	5.74	13.28
<b>Density (no./ft<sup>2</sup>)</b>	<b>0.00355</b>	<b>0.01705</b>	<b>0.01478</b>	<b>0.03670</b>	<b>0.00533</b>	<b>0.03670</b>	<b>0.00889</b>	<b>0.03670</b>

**Table C15.**

**Estimates of relative efficiency between the Delaware II and FV Jersey Girl (JG) in Delmarva and New Jersey, 2002.**

Estimates are based on the ratio, between vessels, of the average density (SC catch per area towed) from 9 stations in each region, sampled by both vessels. For each vessel/region combination, average distance towed was computed from sensor data. To achieve similar clam size-selectivity between vessels, surfclams <130 mm were excluded.

	DMV Stations	NJ Stations
DE-II catch (# per tow)	22.33	180.44
DE-II area (ft <sup>2</sup> per tow)	6289	18731
DE-II ratio (= density)	0.003551	0.009633
JG catch	228.41	557.43
JG area	13398	15187
JG ratio (raw)	0.017048	0.036704
JG ratio (adjusted)	0.018942	0.040783
Adjustment	0.9	0.9
Efficiency of DEII (no/adj)	0.208	0.262
Efficiency of DEII (w/adj)	<b>0.187</b>	<b>0.236</b>

Table C16.

Analysis of Delaware II surfclam stations Repeated by the F/V Jersey Girl. (9 stations in Delmarva and 9 in New Jersey. Assumed Jersey Girl (JG) efficiency is 0.9.

Data Source	Year 1997	Data Source	Year 1999	Data Source	Year 2002	All years combined
DE depl (patch)	0.727	DE depl patch	0.148	DE depl patch	0.695	
PP1A (patch)	0.277	Median of five experiments from SARC 30	0.246	SC02-2 patch	0.233	
AC2 (patch)	0.290	Christy Cross Check	0.243	SC02-3 patch	0.449	
AC1 (patch)	0.544	Repeated stations	0.389	SC02-4 patch	0.536	
		99-97 ratio random stations	0.353	JG Repeats, DMV	0.187	
				JG Repeats, NJ	0.236	
<b>average</b>	<b>0.460</b>		<b>0.276</b>		<b>0.389</b>	<b>0.370</b>
var	0.0469		0.0093		0.0414	0.0331
sd	0.2166		0.0963		0.2035	0.1820
CV	0.471		0.349		0.523	0.492
n	4		5		6	15

**Table C17.**  
**Efficiency estimates for the Delaware II (DE) survey dredge catching Atlantic surfclams in 1997, 1999, 2002 and for all years combined. Values for 1997 and 1999 are from SARC31, Table C10, p 222. "Patch" = Rago Patch model with cell size set at 2 dredge widths. Revised 17 May 2003.**

REGION	ALPHA	BETA	Year Data Collected or Source of Data
SVA	-7.05830	2.30330	Murawski
DMV	-9.10630	2.76750	Serchuk and Murawski (1980)
NJ	-9.20610	2.82510	Serchuk and Murawski (1980)
LI	-7.98370	2.58020	Murawski
SNE	-7.98370	2.58020	Murawski
GBK	-7.99670	2.57720	Gledhill (1984)
DMV	-9.92060	2.96190	1997 Survey
SNJ	-9.41160	2.89970	1997 Survey
NNJ	-9.41160	2.89970	1997 Survey
GBK	-8.55830	2.73070	1997 Survey
DMV	-10.83117	3.13644	2002 Survey
SNJ	-9.68603	2.93156	2002 Survey
NNJ	-9.68603	2.93156	2002 Survey
GBK	-10.27049	3.06418	2002 Survey
SVA	-7.05830	2.30330	Values used in SARC-30 (NEFSC 2000a)
DMV	-9.489134	2.860176	"
NNJ and SNJ	-9.312103	2.863716	"
LI	-7.98370	2.58020	"
SNE	-7.98370	2.58020	"
GBK	-8.274427	2.654215	"

Table C18.

Parameter estimates for the relationship between drained meat weight (gr) and shell length (mm) in surfclams, by region and time. Samples collected in 1997 and 2002 include all tissue minus shell, weighed fresh at sea.  $Weight = (e^{\alpha}) * (L^{\beta})$ .

Table C19. Number of NEFSC clam survey tows during 1982-2002 (random and nearly random "fill" tows) by survey, region and stratum. "Holes" (strata with zero tows) are highlighted.

Stratum	Region	Cruise									
		8204	8305	8403	8604	8903	9203	9404	9704	9903	200206
9	DMV	30	26	35	29	37	37	39	39	38	39
10	DMV	2	2	3	3	3	3	3	3	3	3
13	DMV	19	18	25	20	20	20	21	22	19	20
14	DMV	2	2	3	3	3	3	5	3	3	3
82	DMV	1	1	1	1	1	1	1	1	2	2
83	DMV	2	2	2	2	2	2	2	2	2	2
84	DMV	4	3	3	4	4	4	4	4	3	4
85	DMV	6	5	4	5	5	5	5	5	5	5
86	DMV	2	2	3	3	3	2	3	2	3	3
54	GBK			3	3		3	3	3		
55	GBK	3			3	1	3	3	3	2	2
57	GBK				2	1	2	5	2	2	2
59	GBK	1	4		1	2	6	5	5	4	5
61	GBK	8	1		5		7	6	6	6	6
65	GBK				3		2	2	3		1
67	GBK			5	5	7	7	7	7		
68	GBK	1		7	3	6	6	5	5		
69	GBK	2	5		6	6	6	7	6	7	
70	GBK	1	2		4		4	4	4	3	2
71	GBK			2	3	1	2	3	3	1	2
72	GBK	2		8	1	8	8	8	8	6	
73	GBK	1	1		3	6	6	6	6	5	6
74	GBK	3		1	3		4	4	4	3	3
29	LI	11	10		10	10	10	10	10	11	10
30	LI	7	8		6	6	6	6	6	7	6
33	LI	4	4		4	4	4	5	4	4	4
34	LI	2	2		2	2	2	5	2	2	2
91	LI	3	2	4	4	3	3	3	3	3	3
92	LI	2	2	3	2	2	2	2	2	2	2
93	LI	1	1	2	1	1	1	1	1	1	2
21	NNJ	18	18	22	19	20	20	23	26	39	29
25	NNJ	9	9	13	8	9	9	9	12	8	9
88	NNJ	15	15	24	17	20	20	20	21	22	20
89	NNJ	15	15	21	15	18	17	17	19	18	18
90	NNJ	2	2	3	2	2	2	2	2	2	2
37	SNE	7	4		3		3	5	4	4	3
38	SNE	3	2		3	3	3	5	3	3	3
41	SNE	6	5	7	5	6	6	6	6	5	6
45	SNE	3	7	9	4	4	4	4	4	4	3
46	SNE	2	5	5	3	2	3	5	3	3	2
47	SNE	4	3	4	2	2	4	5	4	3	1
94	SNE	1	2				1	2	2		2
95	SNE	4	14	11	4	4	4	4	4	4	4
96	SNE		12		1	1	3	2	4		
17	SNJ	11	11	18	12	12	12	12	14	12	12
87	SNJ	8	7	10	9	9	9	9	9	9	16
1	SVA		10	14	7	10	10	11	10		
2	SVA					1	2	1	1		
5	SVA	4	9	13	8	8	8	8	8		8
6	SVA	1	1	1	1	1	1	1	1		2
80	SVA		6	9	3	7	7	8	7		
81	SVA		4	7	3	5	5	5	5		5
Total		233	264	305	273	288	324	347	343	283	284

NMFS Survey	1982	1983	1984	1986	1989	1992	1994	1997	1999	2002
Total # of Station in Strata 9	30	26	35	29	37	37	39	39	37	38
# of Stations w/one or more clams	24	18	26	25	27	29	35	34	26	23
# of Stations w/zero clams	6	8	9	4	10	8	4	5	11	15
p= Proportion of Zeros	<b>0.20</b>	<b>0.31</b>	<b>0.26</b>	<b>0.14</b>	<b>0.27</b>	<b>0.22</b>	<b>0.10</b>	<b>0.13</b>	<b>0.30</b>	<b>0.39</b>
Var(p)	0.0053	0.0082	0.0055	0.0041	0.0053	0.0046	0.0024	0.0029	0.0056	0.0063

Table C20. Trends in percentage of random stations in Stratum # 9, off DMV, that captured no surfclams.  $Var(p)=pq/n$ .

Table C21. Efficiency corrected swept-area biomass estimates (1000 mt) by stock assessment area and CVs for surfclam during 1997, 2000 and 2002.

	Estimate	CV				
<b>INPUT: Nominal tow distance (<math>d_n</math>, nm) and CV for Doppler tow distance</b>	0.15					
<b>INPUT: Dredge width (nm)</b>	0.0008225					
Area swept per standard tow ( $a$ , nm <sup>2</sup> )	1.23375E-04	10%				
<b>Area of assessment region (<math>A</math>, nm<sup>2</sup>) - no correction for stations with unsuitable clam habitat</b>						
Northern New Jersey (NNJ)	3,284	10%				
Southern New Jersey (SNJ)	1,059	10%				
Delmarva (DMV)	4,660	10%				
S. Virginia and N. Carolina (SVA)	3,119	10%				
Long Island (LI)	2,917	10%				
Southern New England (SNE)	4,321	10%				
Georges Bank (GBK)	5,772	10%				
Total	25,132					
<b>INPUT: Fraction suitable habitat (<math>u</math>)</b>						
Northern New Jersey (NNJ)	100%	10%				
Southern New Jersey (SNJ)	100%	10%				
Delmarva (DMV)	100%	10%				
S. Virginia and N. Carolina (SVA)	100%	10%				
Long Island (LI)	100%	10%				
Southern New England (SNE)	100%	10%				
Georges Bank (GBK)	88%	10%				
<b>Habitat area in assessment region (<math>A'</math>, nm<sup>2</sup>)</b>						
Northern New Jersey (NNJ)	3,284	14%				
Southern New Jersey (SNJ)	1,059	14%				
Delmarva (DMV)	4,660	14%				
S. Virginia and N. Carolina (SVA)	3,119	14%				
Long Island (LI)	2,917	14%				
Southern New England (SNE)	4,321	14%				
Georges Bank (GBK)	5,079	14%				
<b>INPUT: Original survey mean survey catch (kg/tow, for tows adjusted to nominal tow distance using sensors)</b>						
	<b>Estimates for 1997</b>	<b>CV</b>	<b>Estimates for 1999</b>	<b>CV</b>	<b>Estimates for 2002</b>	<b>CV</b>
Northern New Jersey (NNJ) 120+ mm	8.3896	12%	5.0454	12%	4.6001	18%
Southern New Jersey (SNJ) 120+ mm	1.9938	38%	3.7458	73%	1.9190	44%
Delmarva (DMV) 100+ mm	3.5577	21%	2.3135	21%	1.4707	17%
S. Virginia and N. Carolina (SVA) 100+ mm	0.1065	50%	0.1045	35%	0.2826	54%
Long Island (LI) 100+ mm	0.3514	66%	0.9832	57%	0.1918	63%
Southern New England (SNE) 100+ mm	1.0006	34%	0.4854	64%	0.4046	23%
Georges Bank (GBK) 100+ mm	2.5842	26%	2.5836	32%	2.2333	44%
<b>INPUT: Survey dredge efficiency (<math>e</math>)</b>						
	0.460	49%	0.276	49%	0.389	49%
<b>Efficiency adjusted swept area biomass (<math>B</math>, 1000 mt)</b>						
Northern New Jersey (NNJ) 120+ mm	485	53%	487	53%	315	55%
Southern New Jersey (SNJ) 120+ mm	37	64%	116	90%	42	68%
Delmarva (DMV) 100+ mm	292	56%	317	56%	143	55%
S. Virginia and N. Carolina (SVA) 100+ mm	6	72%	10	62%	18	75%
Long Island (LI) 100+ mm	18	84%	84	77%	12	82%
Southern New England (SNE) 100+ mm	76	62%	62	82%	36	57%
Georges Bank (GBK) 100+ mm	231	58%	385	61%	236	68%
Total fishable biomass less GBK (100+ and 120+ mm)	915	34%	1,075	32%	566	34%
Total fishable biomass (100+ and 120+ mm)	1,146	30%	1,460	28%	803	31%
<b>Lower bound for 80% confidence intervals on biomass (1000 mt, for lognormal distribution with no bias correction)</b>						
	<b>Estimates for 1997</b>	<b>Estimates for 1999</b>	<b>Estimates for 2002</b>			
Northern New Jersey (NNJ) 120+ mm	256	256	163			
Southern New Jersey (SNJ) 120+ mm	18	44	19			
Delmarva (DMV) 100+ mm	150	162	74			
S. Virginia and N. Carolina (SVA) 100+ mm	3	5	8			
Long Island (LI) 100+ mm	7	35	5			
Southern New England (SNE) 100+ mm	37	25	18			
Georges Bank (GBK) 100+ mm	116	188	107			
Total fishable biomass less GBK (100+ and 120+ mm)	599	723	370			
Total fishable biomass (100+ and 120+ mm)	791	1,022	542			
<b>Upperbound for 80% confidence intervals on biomass (1000 mt, for lognormal distribution with no bias correction)</b>						
	<b>Estimates for 1997</b>	<b>Estimates for 1999</b>	<b>Estimates for 2002</b>			
Northern New Jersey (NNJ) 120+ mm	922	924	607			
Southern New Jersey (SNJ) 120+ mm	79	311	93			
Delmarva (DMV) 100+ mm	570	618	275			
S. Virginia and N. Carolina (SVA) 100+ mm	13	20	43			
Long Island (LI) 100+ mm	46	202	29			
Southern New England (SNE) 100+ mm	158	155	72			
Georges Bank (GBK) 100+ mm	462	792	521			
Total fishable biomass less GBK (100+ and 120+ mm)	1,398	1,599	867			
Total fishable biomass (100+ and 120+ mm)	1,661	2,086	1,188			

Table C22. Fishing mortality rates ( $F$  yr<sup>-1</sup>) during 1997, 1999 and 2002 with CVs from catch and efficiency corrected swept-area biomass estimates.

<b>INPUT: Upper bound incidental mortality allowance</b>	12%					
<b>INPUT: Assumed CV for catch</b>	10%					
<b>INPUT: Landings (1000 mt, discard ~ 0)</b>	<b>Estimates for 1997</b>	<b>Estimates for 1999</b>	<b>Estimates for 2002</b>			
Northern New Jersey (NNJ)	14.060	14.432	14.939			
Southern New Jersey (SNJ)	2.934	4.277	2.847			
Delmarva (DMV)	1.540	0.667	4.450			
S. Virginia and N. Carolina (SVA)	0.005	0.000	0.079			
Long Island (LI)	0.073	0.157	1.160			
Southern New England (SNE)	0.000	0.016	0.124			
Georges Bank (GBK)	0.000	0.000	0.000			
Total	18.611	19.548	23.600			
<b>Catch (1000 mt, landings + upper bound incidental mortality allowance)</b>						
Northern New Jersey (NNJ)	15.747	16.163	16.732			
Southern New Jersey (SNJ)	3.286	4.790	3.189			
Delmarva (DMV)	1.725	0.747	4.984			
S. Virginia and N. Carolina (SVA)	0.005	0.000	0.088			
Long Island (LI)	0.081	0.175	1.300			
Southern New England (SNE)	0.000	0.018	0.139			
Georges Bank (GBK)	0.000	0.000	0.000			
Total	20.844	21.894	26.432			
<b>INPUT: Efficiency Corrected Swept Area Biomass (1000 mt)</b>	<b>Estimates for 1997</b>	<b>CV</b>	<b>Estimates for 1999</b>	<b>CV</b>	<b>Estimates for 2002</b>	<b>CV</b>
Northern New Jersey (NNJ) 120+ mm	485	53%	487	53%	315	55%
Southern New Jersey (SNJ) 120+ mm	37	64%	116	90%	42	68%
Delmarva (DMV) 100+ mm	292	56%	317	56%	143	55%
S. Virginia and N. Carolina (SVA) 100+ mm	6	72%	10	62%	18	75%
Long Island (LI) 100+ mm	18	84%	84	77%	12	82%
Southern New England (SNE) 100+ mm	76	62%	62	82%	36	57%
Georges Bank (GBK) 100+ mm	231	58%	385	61%	236	68%
Total fishable biomass less GBK (100+ and 120+ mm)	915	34%	1,075	32%	566	34%
Total fishable biomass (100+ and 120+ mm)	1,146	30%	1,460	28%	803	31%
<b>Fishing mortality (<math>y^{-1}</math>)</b>						
Northern New Jersey (NNJ) 120+ mm	0.032	54%	0.033	54%	0.053	56%
Southern New Jersey (SNJ) 120+ mm	0.088	65%	0.041	90%	0.075	69%
Delmarva (DMV) 100+ mm	0.006	57%	0.002	57%	0.035	56%
S. Virginia and N. Carolina (SVA) 100+ mm	0.001	NA	0.000	NA	0.005	75%
Long Island (LI) 100+ mm	0.004	84%	0.002	78%	0.111	82%
Southern New England (SNE) 100+ mm	0.000	63%	0.000	83%	0.004	58%
Georges Bank (GBK) 100+ mm	0.000	NA	0.000	NA	0.000	NA
Total fishable biomass less GBK (100+ and 120+ mm)	0.023	35%	0.020	33%	0.047	36%
Total fishable biomass (100+ and 120+ mm)	0.018	31%	0.015	30%	0.033	33%
<b>Lower bound for 80% confidence intervals for fishing mortality (<math>y^{-1}</math>, for lognormal distribution with no bias correction)</b>	<b>Estimates for 1997</b>	<b>Estimates for 1999</b>	<b>Estimates for 2002</b>			
Northern New Jersey (NNJ) 120+ mm	0.017	0.017	0.027			
Southern New Jersey (SNJ) 120+ mm	0.041	0.015	0.034			
Delmarva (DMV) 100+ mm	0.003	0.001	0.018			
S. Virginia and N. Carolina (SVA) 100+ mm	NA	NA	0.002			
Long Island (LI) 100+ mm	0.002	0.001	0.044			
Southern New England (SNE) 100+ mm	NA	0.000	0.002			
Georges Bank (GBK) 100+ mm	NA	NA	NA			
Total fishable biomass less GBK (100+ and 120+ mm)	0.015	0.013	0.030			
Total fishable biomass (100+ and 120+ mm)	0.012	0.010	0.022			
<b>Upper bound for 80% confidence intervals for fishing mortality (<math>y^{-1}</math>, for lognormal distribution with no bias correction)</b>						
Northern New Jersey (NNJ) 120+ mm	0.062	0.064	0.104			
Southern New Jersey (SNJ) 120+ mm	0.189	0.110	0.167			
Delmarva (DMV) 100+ mm	0.012	0.005	0.068			
S. Virginia and N. Carolina (SVA) 100+ mm	NA	NA	0.011			
Long Island (LI) 100+ mm	0.011	0.005	0.280			
Southern New England (SNE) 100+ mm	NA	0.001	NA			
Georges Bank (GBK) 100+ mm	NA	NA	NA			
Total fishable biomass less GBK (100+ and 120+ mm)	0.035	0.031	0.073			
Total fishable biomass (100+ and 120+ mm)	0.027	0.022	0.050			



Table C23 (1 of 7). Survey trend data used in the KLAMZ model for surfclam.

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
SVA	7801	83-99	Prerecruits	0.1639	0.76	0.0049	0.76	40	2	5
SVA	7807	83-99	Prerecruits	0.1639	0.76	0.0049	0.76	40	2	5
SVA	<i>78 Mean</i>	83-99	<i>Prerecruits</i>	<i>0.1639</i>	<i>0.76</i>	<i>0.0049</i>	<i>0.76</i>	<i>80</i>	<i>4</i>	<i>NA</i>
SVA	7901	83-99	Prerecruits	9.8913	1.00	0.2985	1.00	16	2	4
SVA	8001	83-99	Prerecruits	9.8063	1.00	0.2959	1.00	21	2	5
SVA	8006	83-99	Prerecruits	9.8913	1.00	0.2985	1.00	16	2	4
SVA	<i>80 Mean</i>	83-99	<i>Prerecruits</i>	<i>9.8488</i>	<i>1.00</i>	<i>0.2972</i>	<i>1.00</i>	<i>37</i>	<i>4</i>	<i>NA</i>
SVA	8105	83-99	Prerecruits	0.0000	.	0.0000	.	5	0	2
SVA	8204	83-99	Prerecruits	0.7931	0.68	0.0212	0.68	25	4	5
SVA	8305	83-99	Prerecruits	0.9569	0.57	0.0260	0.57	30	7	5
SVA	8403	83-99	Prerecruits	1.5296	0.43	0.0435	0.44	44	12	5
SVA	8604	83-99	Prerecruits	0.1118	0.93	0.0032	0.93	23	2	6
SVA	8903	83-99	Prerecruits	1.3304	0.80	0.0367	0.79	32	6	6
SVA	9203	83-99	Prerecruits	1.2098	0.38	0.0353	0.40	33	12	6
SVA	9404	83-99	Prerecruits	2.6695	0.36	0.0766	0.37	34	14	6
SVA	9704	83-99	Prerecruits	2.0080	0.40	0.0595	0.41	32	11	6
SVA	9903	83-99	Prerecruits	2.7725	0.41	0.0779	0.40	42	14	6
SVA	200206	83-99	Prerecruits	7.9737	0.72	0.2139	0.71	15	4	3
SVA	7801	100-112	New recruits	0.1144	1.00	0.0047	1.00	40	1	5
SVA	7807	100-112	New recruits	0.1144	1.00	0.0047	1.00	40	1	5
SVA	<i>78 Mean</i>	<i>100-112</i>	<i>New recruits</i>	<i>0.1144</i>	<i>1.00</i>	<i>0.0047</i>	<i>1.00</i>	<i>80</i>	<i>2</i>	<i>NA</i>
SVA	7901	100-112	New recruits	13.9301	1.00	0.5275	1.00	16	2	4
SVA	8001	100-112	New recruits	13.8519	1.00	0.5245	1.00	21	3	5
SVA	8006	100-112	New recruits	13.9301	1.00	0.5275	1.00	16	2	4
SVA	<i>80 Mean</i>	<i>100-112</i>	<i>New recruits</i>	<i>13.8910</i>	<i>1.00</i>	<i>0.5260</i>	<i>1.00</i>	<i>37</i>	<i>5</i>	<i>NA</i>
SVA	8105	100-112	New recruits	0.4846	1.00	0.0189	1.00	5	1	2
SVA	8204	100-112	New recruits	1.9710	0.95	0.0815	0.95	25	3	5
SVA	8305	100-112	New recruits	3.1862	0.68	0.1315	0.68	30	5	5
SVA	8403	100-112	New recruits	2.6895	0.42	0.1094	0.42	44	10	5
SVA	8604	100-112	New recruits	0.5201	0.42	0.0211	0.43	23	6	6
SVA	8903	100-112	New recruits	0.4841	0.61	0.0194	0.61	32	5	6
SVA	9203	100-112	New recruits	9.6412	0.95	0.3960	0.95	33	7	6
SVA	9404	100-112	New recruits	6.3030	0.57	0.2557	0.57	34	12	6
SVA	9704	100-112	New recruits	3.6891	0.61	0.1475	0.61	32	8	6
SVA	9903	100-112	New recruits	2.2219	0.52	0.0881	0.53	42	12	6
SVA	200206	100-112	New recruits	1.5710	0.45	0.0593	0.45	15	4	3
SVA	7801	113+	Old recruits	1.8229	0.34	0.1736	0.33	40	10	5
SVA	7807	113+	Old recruits	1.8229	0.34	0.1736	0.33	40	10	5
SVA	<i>78 Mean</i>	<i>113+</i>	<i>Old recruits</i>	<i>1.8229</i>	<i>0.34</i>	<i>0.1736</i>	<i>0.33</i>	<i>80</i>	<i>20</i>	<i>NA</i>
SVA	7901	113+	Old recruits	0.8328	0.83	0.0470	0.75	16	2	4
SVA	8001	113+	Old recruits	2.9293	0.71	0.2007	0.74	21	5	5
SVA	8006	113+	Old recruits	0.8328	0.83	0.0470	0.75	16	2	4
SVA	<i>80 Mean</i>	<i>113+</i>	<i>Old recruits</i>	<i>1.8810</i>	<i>0.83</i>	<i>0.1238</i>	<i>0.75</i>	<i>37</i>	<i>7</i>	<i>NA</i>
SVA	8105	113+	Old recruits	26.3764	0.92	1.9494	0.91	5	3	2
SVA	8204	113+	Old recruits	4.3047	0.93	0.2847	0.89	25	5	5
SVA	8305	113+	Old recruits	7.2900	0.59	0.4812	0.57	30	9	5
SVA	8403	113+	Old recruits	24.6144	0.31	1.7467	0.30	44	13	5
SVA	8604	113+	Old recruits	22.7574	0.74	1.5810	0.74	23	8	6
SVA	8903	113+	Old recruits	9.9908	0.82	0.7682	0.81	32	8	6
SVA	9203	113+	Old recruits	18.6504	0.65	1.1278	0.66	33	8	6
SVA	9404	113+	Old recruits	10.2603	0.48	0.6142	0.42	34	6	6
SVA	9704	113+	Old recruits	1.5904	0.45	0.0835	0.45	32	6	6
SVA	9903	113+	Old recruits	1.8460	0.36	0.1141	0.38	42	10	6
SVA	200206	113+	Old recruits	5.9706	0.56	0.4139	0.55	15	4	3

Table C23 (cont) (p.2 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
DMV	7801	83-99	Prerecruits	1.7443	0.43	0.0544	0.44	61	9	9
DMV	7807	83-99	Prerecruits	1.9197	0.31	0.0607	0.31	58	14	9
<i>DMV</i>	<i>78 Mean</i>	<i>83-99</i>	<i>Prerecruits</i>	<i>1.8320</i>	<i>0.43</i>	<i>0.0576</i>	<i>0.44</i>	<i>119</i>	<i>23</i>	<i>NA</i>
DMV	7901	83-99	Prerecruits	0.5520	0.59	0.0182	0.57	49	3	9
DMV	8001	83-99	Prerecruits	31.8887	0.90	0.9399	0.90	70	27	9
DMV	8006	83-99	Prerecruits	22.1965	0.56	0.6822	0.60	51	22	9
<i>DMV</i>	<i>80 Mean</i>	<i>83-99</i>	<i>Prerecruits</i>	<i>27.0426</i>	<i>0.90</i>	<i>0.8110</i>	<i>0.90</i>	<i>121</i>	<i>49</i>	<i>NA</i>
DMV	8105	83-99	Prerecruits	79.3071	0.62	2.5299	0.61	47	14	9
DMV	8204	83-99	Prerecruits	56.0215	0.62	1.8850	0.62	68	25	9
DMV	8305	83-99	Prerecruits	3.4159	0.32	0.1081	0.32	61	23	9
DMV	8403	83-99	Prerecruits	63.8289	0.85	1.7656	0.82	79	26	9
DMV	8604	83-99	Prerecruits	4.9484	0.34	0.1668	0.35	70	25	9
DMV	8903	83-99	Prerecruits	2.4888	0.50	0.0837	0.53	78	25	9
DMV	9203	83-99	Prerecruits	2.6017	0.21	0.0800	0.21	77	38	9
DMV	9404	83-99	Prerecruits	11.0529	0.25	0.3408	0.25	83	57	9
DMV	9704	83-99	Prerecruits	21.4606	0.23	0.6608	0.23	81	51	9
DMV	9903	83-99	Prerecruits	2.2844	0.26	0.0745	0.27	78	31	9
DMV	200206	83-99	Prerecruits	5.2042	0.31	0.1548	0.31	81	34	9
DMV	7801	100-112	New recruits	0.6232	0.55	0.0290	0.56	61	8	9
DMV	7807	100-112	New recruits	1.8929	0.31	0.0875	0.31	58	13	9
<i>DMV</i>	<i>78 Mean</i>	<i>100-112</i>	<i>New recruits</i>	<i>1.2580</i>	<i>0.55</i>	<i>0.0583</i>	<i>0.56</i>	<i>119</i>	<i>21</i>	<i>NA</i>
DMV	7901	100-112	New recruits	0.9719	0.55	0.0431	0.55	49	7	9
DMV	8001	100-112	New recruits	3.3542	0.49	0.1521	0.47	70	19	9
DMV	8006	100-112	New recruits	11.8311	0.90	0.5172	0.89	51	18	9
<i>DMV</i>	<i>80 Mean</i>	<i>100-112</i>	<i>New recruits</i>	<i>7.5926</i>	<i>0.90</i>	<i>0.3346</i>	<i>0.89</i>	<i>121</i>	<i>37</i>	<i>NA</i>
DMV	8105	100-112	New recruits	67.7290	0.84	3.1077	0.84	47	16	9
DMV	8204	100-112	New recruits	80.5405	0.45	3.6940	0.45	68	25	9
DMV	8305	100-112	New recruits	11.7466	0.49	0.5814	0.51	61	23	9
DMV	8403	100-112	New recruits	24.3551	0.58	1.1603	0.58	79	35	9
DMV	8604	100-112	New recruits	18.8035	0.40	0.9347	0.40	70	26	9
DMV	8903	100-112	New recruits	8.0890	0.69	0.3876	0.68	78	25	9
DMV	9203	100-112	New recruits	3.0911	0.26	0.1506	0.28	77	35	9
DMV	9404	100-112	New recruits	25.5786	0.50	1.2493	0.51	83	52	9
DMV	9704	100-112	New recruits	24.5648	0.21	1.1750	0.21	81	51	9
DMV	9903	100-112	New recruits	12.6531	0.32	0.6232	0.32	78	32	9
DMV	200206	100-112	New recruits	3.9517	0.31	0.1861	0.31	81	32	9
DMV	7801	113+	Old recruits	7.2558	0.21	1.0545	0.20	61	34	9
DMV	7807	113+	Old recruits	9.5939	0.34	1.3085	0.34	58	18	9
<i>DMV</i>	<i>78 Mean</i>	<i>113+</i>	<i>Old recruits</i>	<i>8.4248</i>	<i>0.34</i>	<i>1.1815</i>	<i>0.34</i>	<i>119</i>	<i>52</i>	<i>NA</i>
DMV	7901	113+	Old recruits	15.1010	0.50	2.0363	0.43	49	22	9
DMV	8001	113+	Old recruits	15.6895	0.21	2.1606	0.22	70	38	9
DMV	8006	113+	Old recruits	13.5695	0.24	1.8941	0.24	51	29	9
<i>DMV</i>	<i>80 Mean</i>	<i>113+</i>	<i>Old recruits</i>	<i>14.6295</i>	<i>0.24</i>	<i>2.0273</i>	<i>0.24</i>	<i>121</i>	<i>67</i>	<i>NA</i>
DMV	8105	113+	Old recruits	23.7939	0.44	2.3456	0.31	47	26	9
DMV	8204	113+	Old recruits	38.4884	0.30	3.7702	0.27	68	43	9
DMV	8305	113+	Old recruits	44.6220	0.56	3.9819	0.43	61	36	9
DMV	8403	113+	Old recruits	46.7133	0.28	4.2844	0.26	79	49	9
DMV	8604	113+	Old recruits	107.2927	0.43	8.6805	0.37	70	44	9
DMV	8903	113+	Old recruits	37.3597	0.24	3.4548	0.23	78	48	9
DMV	9203	113+	Old recruits	33.7532	0.33	3.2207	0.26	77	47	9
DMV	9404	113+	Old recruits	77.7309	0.23	6.9976	0.20	83	55	9
DMV	9704	113+	Old recruits	76.8682	0.24	6.2856	0.22	81	52	9
DMV	9903	113+	Old recruits	39.9086	0.23	3.2314	0.21	78	45	9
DMV	200206	113+	Old recruits	23.6741	0.21	2.4152	0.19	81	48	9

Table C23 (cont) (p.3 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
SNJ	7801	107-119	Prerecruits	0.7375	0.58	0.0508	0.59	26	4	2
SNJ	7807	107-119	Prerecruits	0.3893	0.76	0.0245	0.77	11	2	2
SNJ	78 Mean	107-119	Prerecruits	0.5634	0.76	0.0377	0.77	37	6	NA
SNJ	7901	107-119	Prerecruits	0.0000	.	0.0000	.	10	0	2
SNJ	8001	107-119	Prerecruits	0.5680	0.34	0.0405	0.34	18	5	2
SNJ	8006	107-119	Prerecruits	0.3603	0.61	0.0247	0.62	18	3	2
SNJ	80 Mean	107-119	Prerecruits	0.4642	0.61	0.0326	0.62	36	8	NA
SNJ	8105	107-119	Prerecruits	0.2101	1.00	0.0158	1.00	16	1	2
SNJ	8204	107-119	Prerecruits	13.0322	0.98	0.9156	0.98	19	5	2
SNJ	8305	107-119	Prerecruits	0.5427	0.46	0.0364	0.48	18	5	2
SNJ	8403	107-119	Prerecruits	0.0461	1.00	0.0032	1.00	28	1	2
SNJ	8604	107-119	Prerecruits	0.4665	0.66	0.0302	0.68	21	4	2
SNJ	8903	107-119	Prerecruits	0.4315	0.68	0.0300	0.71	21	4	2
SNJ	9203	107-119	Prerecruits	1.0162	0.49	0.0696	0.49	21	5	2
SNJ	9404	107-119	Prerecruits	14.5266	0.72	0.9910	0.72	21	12	2
SNJ	9704	107-119	Prerecruits	1.4060	0.36	0.0993	0.37	23	10	2
SNJ	9903	107-119	Prerecruits	6.1756	0.99	0.4561	0.99	21	2	2
SNJ	200206	107-119	Prerecruits	1.1262	0.22	0.0754	0.22	28	15	2
SNJ	7801	120-129	New recruits	0.5585	0.59	0.0501	0.59	26	3	2
SNJ	7807	120-129	New recruits	0.5053	1.00	0.0421	1.00	11	1	2
SNJ	78 Mean	120-129	New recruits	0.5319	1.00	0.0461	1.00	37	4	NA
SNJ	7901	120-129	New recruits	0.0000	.	0.0000	.	10	0	2
SNJ	8001	120-129	New recruits	0.9737	0.46	0.0879	0.47	18	6	2
SNJ	8006	120-129	New recruits	0.4426	0.70	0.0388	0.70	18	2	2
SNJ	80 Mean	120-129	New recruits	0.7081	0.70	0.0633	0.70	36	8	NA
SNJ	8105	120-129	New recruits	0.0000	.	0.0000	.	16	0	2
SNJ	8204	120-129	New recruits	4.9934	0.84	0.4353	0.84	19	7	2
SNJ	8305	120-129	New recruits	0.3868	0.49	0.0347	0.49	18	4	2
SNJ	8403	120-129	New recruits	0.2450	0.58	0.0229	0.58	28	4	2
SNJ	8604	120-129	New recruits	0.1397	0.57	0.0131	0.57	21	3	2
SNJ	8903	120-129	New recruits	0.3229	0.57	0.0287	0.57	21	4	2
SNJ	9203	120-129	New recruits	0.6666	0.44	0.0599	0.43	21	6	2
SNJ	9404	120-129	New recruits	14.3583	0.72	1.2528	0.71	21	12	2
SNJ	9704	120-129	New recruits	3.6370	0.54	0.3320	0.54	23	8	2
SNJ	9903	120-129	New recruits	23.5977	1.00	2.1528	1.00	21	3	2
SNJ	200206	120-129	New recruits	1.8377	0.43	0.1711	0.44	28	9	2
SNJ	7801	130+	Old recruits	12.7466	0.28	2.4382	0.27	26	14	2
SNJ	7807	130+	Old recruits	4.2720	0.33	0.7629	0.33	11	6	2
SNJ	78 Mean	130+	Old recruits	8.5093	0.33	1.6006	0.33	37	20	NA
SNJ	7901	130+	Old recruits	4.1451	0.31	0.8564	0.39	10	6	2
SNJ	8001	130+	Old recruits	10.2916	0.29	2.0474	0.28	18	10	2
SNJ	8006	130+	Old recruits	12.3756	0.37	2.6891	0.39	18	13	2
SNJ	80 Mean	130+	Old recruits	11.3336	0.37	2.3682	0.39	36	23	NA
SNJ	8105	130+	Old recruits	12.2688	0.38	2.8345	0.39	16	10	2
SNJ	8204	130+	Old recruits	20.0771	0.34	4.1156	0.33	19	13	2
SNJ	8305	130+	Old recruits	11.6226	0.34	2.5251	0.35	18	10	2
SNJ	8403	130+	Old recruits	10.9630	0.29	2.2941	0.28	28	16	2
SNJ	8604	130+	Old recruits	19.2820	0.50	4.1915	0.52	21	13	2
SNJ	8903	130+	Old recruits	10.5571	0.31	2.0856	0.30	21	11	2
SNJ	9203	130+	Old recruits	6.8826	0.42	1.4120	0.43	21	8	2
SNJ	9404	130+	Old recruits	58.5203	0.68	9.0087	0.66	21	14	2
SNJ	9704	130+	Old recruits	21.0333	0.36	3.0911	0.34	23	14	2
SNJ	9903	130+	Old recruits	31.3131	0.71	4.1551	0.62	21	12	2
SNJ	200206	130+	Old recruits	16.5809	0.44	2.8528	0.48	28	20	2

Table C23 (cont) (p.4 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
NNJ	7801	107-119	Prerecruits	0.2529	0.43	0.0171	0.43	67	6	5
NNJ	7807	107-119	Prerecruits	1.3798	0.46	0.0912	0.46	40	6	5
<i>NNJ</i>	<i>78 Mean</i>	<i>107-119</i>	<i>Prerecruits</i>	<i>0.8164</i>	<i>0.46</i>	<i>0.0541</i>	<i>0.46</i>	<i>107</i>	<i>12</i>	<i>NA</i>
NNJ	7901	107-119	Prerecruits	0.4291	0.57	0.0279	0.55	36	4	5
NNJ	8001	107-119	Prerecruits	5.5509	0.43	0.3646	0.43	59	22	5
NNJ	8006	107-119	Prerecruits	24.5250	0.80	1.6827	0.81	50	22	5
<i>NNJ</i>	<i>80 Mean</i>	<i>107-119</i>	<i>Prerecruits</i>	<i>15.0380</i>	<i>0.80</i>	<i>1.0236</i>	<i>0.81</i>	<i>109</i>	<i>44</i>	<i>NA</i>
NNJ	8105	107-119	Prerecruits	9.4792	0.28	0.6648	0.28	41	23	5
NNJ	8204	107-119	Prerecruits	18.9602	0.42	1.3045	0.42	59	34	5
NNJ	8305	107-119	Prerecruits	24.9287	0.57	1.7088	0.57	59	32	5
NNJ	8403	107-119	Prerecruits	8.4357	0.22	0.5861	0.22	83	50	5
NNJ	8604	107-119	Prerecruits	5.9367	0.22	0.4126	0.22	61	39	5
NNJ	8903	107-119	Prerecruits	6.6141	0.32	0.4630	0.32	69	36	5
NNJ	9203	107-119	Prerecruits	11.8811	0.58	0.8253	0.58	68	47	5
NNJ	9404	107-119	Prerecruits	25.6020	0.21	1.7717	0.21	71	59	5
NNJ	9704	107-119	Prerecruits	14.6337	0.20	1.0251	0.20	80	65	5
NNJ	9903	107-119	Prerecruits	3.6851	0.24	0.2574	0.24	89	45	5
NNJ	200206	107-119	Prerecruits	3.9985	0.19	0.2758	0.19	78	63	5
NNJ	7801	120-129	New recruits	0.0741	0.69	0.0067	0.70	67	2	5
NNJ	7807	120-129	New recruits	0.5520	0.37	0.0501	0.37	40	7	5
<i>NNJ</i>	<i>78 Mean</i>	<i>120-129</i>	<i>New recruits</i>	<i>0.3130</i>	<i>0.69</i>	<i>0.0284</i>	<i>0.70</i>	<i>107</i>	<i>9</i>	<i>NA</i>
NNJ	7901	120-129	New recruits	0.3336	0.84	0.0300	0.84	36	2	5
NNJ	8001	120-129	New recruits	1.0253	0.40	0.0915	0.40	59	16	5
NNJ	8006	120-129	New recruits	7.8636	0.74	0.6722	0.73	50	19	5
<i>NNJ</i>	<i>80 Mean</i>	<i>120-129</i>	<i>New recruits</i>	<i>4.4445</i>	<i>0.74</i>	<i>0.3819</i>	<i>0.73</i>	<i>109</i>	<i>35</i>	<i>NA</i>
NNJ	8105	120-129	New recruits	8.1425	0.31	0.7304	0.31	41	24	5
NNJ	8204	120-129	New recruits	16.6014	0.25	1.4897	0.25	59	33	5
NNJ	8305	120-129	New recruits	16.3749	0.33	1.4629	0.33	59	32	5
NNJ	8403	120-129	New recruits	14.7170	0.27	1.3238	0.27	83	50	5
NNJ	8604	120-129	New recruits	9.6039	0.28	0.8779	0.29	61	42	5
NNJ	8903	120-129	New recruits	9.8082	0.21	0.8857	0.21	69	43	5
NNJ	9203	120-129	New recruits	7.2160	0.28	0.6432	0.28	68	45	5
NNJ	9404	120-129	New recruits	25.7885	0.22	2.3034	0.22	71	56	5
NNJ	9704	120-129	New recruits	19.8317	0.23	1.8029	0.23	80	66	5
NNJ	9903	120-129	New recruits	6.0189	0.19	0.5507	0.19	89	61	5
NNJ	200206	120-129	New recruits	4.0246	0.28	0.3638	0.28	78	58	5
NNJ	7801	130+	Old recruits	0.4969	0.37	0.0895	0.39	67	10	5
NNJ	7807	130+	Old recruits	2.3121	0.41	0.4074	0.43	40	9	5
<i>NNJ</i>	<i>78 Mean</i>	<i>130+</i>	<i>Old recruits</i>	<i>1.4045</i>	<i>0.41</i>	<i>0.2484</i>	<i>0.43</i>	<i>107</i>	<i>19</i>	<i>NA</i>
NNJ	7901	130+	Old recruits	1.1416	0.55	0.1820	0.59	36	5	5
NNJ	8001	130+	Old recruits	6.0932	0.32	1.0637	0.33	59	23	5
NNJ	8006	130+	Old recruits	4.6301	0.31	0.7597	0.31	50	21	5
<i>NNJ</i>	<i>80 Mean</i>	<i>130+</i>	<i>Old recruits</i>	<i>5.3617</i>	<i>0.32</i>	<i>0.9117</i>	<i>0.33</i>	<i>109</i>	<i>44</i>	<i>NA</i>
NNJ	8105	130+	Old recruits	20.0586	0.42	2.9222	0.40	41	28	5
NNJ	8204	130+	Old recruits	26.7880	0.28	3.4843	0.27	59	35	5
NNJ	8305	130+	Old recruits	18.9996	0.22	2.5772	0.22	59	44	5
NNJ	8403	130+	Old recruits	28.1055	0.20	3.7137	0.20	83	57	5
NNJ	8604	130+	Old recruits	30.0218	0.19	4.2175	0.18	61	46	5
NNJ	8903	130+	Old recruits	35.9347	0.15	4.9326	0.14	69	56	5
NNJ	9203	130+	Old recruits	26.2561	0.17	3.8198	0.16	68	55	5
NNJ	9404	130+	Old recruits	86.4794	0.13	12.4319	0.13	71	56	5
NNJ	9704	130+	Old recruits	101.6671	0.13	14.7857	0.12	80	71	5
NNJ	9903	130+	Old recruits	55.5655	0.13	8.2520	0.12	89	79	5
NNJ	200206	130+	Old recruits	44.2097	0.18	7.1699	0.18	78	69	5

Table C23 (cont) (p.5 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
LI	7801	82-99	Prerecruits	0.0498	1.00	0.0016	1.00	46	1	7
LI	7807	82-99	Prerecruits	0.1793	1.00	0.0074	1.00	23	1	7
LI	<i>78 Mean</i>	82-99	<i>Prerecruits</i>	<i>0.1146</i>	<i>1.00</i>	<i>0.0045</i>	<i>1.00</i>	69	2	NA
LI	7901	82-99	Prerecruits	0.1583	0.71	0.0064	0.71	33	2	7
LI	8001	82-99	Prerecruits	0.1789	0.61	0.0066	0.61	28	3	7
LI	8006	82-99	Prerecruits	0.1131	0.37	0.0047	0.35	28	2	7
LI	<i>80 Mean</i>	82-99	<i>Prerecruits</i>	<i>0.1460</i>	<i>0.61</i>	<i>0.0057</i>	<i>0.61</i>	56	5	NA
LI	8105	82-99	Prerecruits	0.0516	1.00	0.0022	1.00	29	1	7
LI	8204	82-99	Prerecruits	0.0000	.	0.0000	.	30	0	7
LI	8305	82-99	Prerecruits	0.0330	1.00	0.0012	1.00	29	1	7
LI	8403	82-99	Prerecruits	0.1860	0.37	0.0070	0.36	55	7	7
LI	8604	82-99	Prerecruits	0.1878	0.60	0.0067	0.61	29	3	7
LI	8903	82-99	Prerecruits	0.3889	1.00	0.0146	1.00	28	1	7
LI	9203	82-99	Prerecruits	1.6034	0.41	0.0629	0.41	28	7	7
LI	9404	82-99	Prerecruits	1.1167	0.12	0.0441	0.11	32	10	7
LI	9704	82-99	Prerecruits	0.2297	0.38	0.0091	0.37	28	4	7
LI	9903	82-99	Prerecruits	0.1529	0.52	0.0052	0.49	30	3	7
LI	200206	82-99	Prerecruits	0.2958	0.57	0.0101	0.57	29	5	7
LI	7801	100-113	New recruits	0.0203	1.00	0.0012	1.00	46	1	7
LI	7807	100-113	New recruits	0.0768	1.00	0.0048	1.00	23	1	7
LI	<i>78 Mean</i>	100-113	<i>New recruits</i>	<i>0.0486</i>	<i>1.00</i>	<i>0.0030</i>	<i>1.00</i>	69	2	NA
LI	7901	100-113	New recruits	0.1998	0.58	0.0118	0.59	33	3	7
LI	8001	100-113	New recruits	0.0000	.	0.0000	.	28	0	7
LI	8006	100-113	New recruits	0.0419	1.00	0.0021	1.00	28	1	7
LI	<i>80 Mean</i>	100-113	<i>New recruits</i>	<i>0.0209</i>	<i>1.00</i>	<i>0.0011</i>	<i>1.00</i>	56	1	NA
LI	8105	100-113	New recruits	0.0516	1.00	0.0029	1.00	29	1	7
LI	8204	100-113	New recruits	0.0000	.	0.0000	.	30	0	7
LI	8305	100-113	New recruits	0.0000	.	0.0000	.	29	0	7
LI	8403	100-113	New recruits	0.0622	0.56	0.0038	0.59	55	2	7
LI	8604	100-113	New recruits	0.0694	0.49	0.0041	0.44	29	2	7
LI	8903	100-113	New recruits	0.6813	0.83	0.0404	0.83	28	3	7
LI	9203	100-113	New recruits	2.3791	0.56	0.1457	0.56	28	4	7
LI	9404	100-113	New recruits	1.5826	0.32	0.0939	0.32	32	6	7
LI	9704	100-113	New recruits	0.7820	0.54	0.0455	0.55	28	4	7
LI	9903	100-113	New recruits	0.0882	0.71	0.0052	0.71	30	2	7
LI	200206	100-113	New recruits	0.2034	0.41	0.0121	0.41	29	4	7
LI	7801	114+	Old recruits	2.1478	0.36	0.3382	0.39	46	12	7
LI	7807	114+	Old recruits	6.5628	0.41	1.0222	0.42	23	5	7
LI	<i>78 Mean</i>	114+	<i>Old recruits</i>	<i>4.3553</i>	<i>0.41</i>	<i>0.6802</i>	<i>0.42</i>	69	17	NA
LI	7901	114+	Old recruits	3.4717	0.30	0.5170	0.31	33	5	7
LI	8001	114+	Old recruits	1.7597	0.10	0.2656	0.13	28	5	7
LI	8006	114+	Old recruits	5.2449	0.27	0.7588	0.31	28	7	7
LI	<i>80 Mean</i>	114+	<i>Old recruits</i>	<i>3.5023</i>	<i>0.27</i>	<i>0.5122</i>	<i>0.31</i>	56	12	NA
LI	8105	114+	Old recruits	0.0913	0.71	0.0180	0.71	29	2	7
LI	8204	114+	Old recruits	4.7463	0.51	0.7540	0.52	30	5	7
LI	8305	114+	Old recruits	0.4073	0.72	0.0545	0.72	29	2	7
LI	8403	114+	Old recruits	1.7534	0.32	0.2603	0.33	55	7	7
LI	8604	114+	Old recruits	1.7845	0.58	0.2902	0.60	29	3	7
LI	8903	114+	Old recruits	3.6611	0.73	0.4882	0.74	28	4	7
LI	9203	114+	Old recruits	3.6113	0.36	0.3530	0.34	28	7	7
LI	9404	114+	Old recruits	8.2497	0.19	0.9869	0.21	32	8	7
LI	9704	114+	Old recruits	4.5178	0.63	0.5880	0.62	28	4	7
LI	9903	114+	Old recruits	10.8701	0.64	1.4445	0.60	30	5	7
LI	200206	114+	Old recruits	2.0229	0.66	0.3102	0.67	29	5	7

Table C23 (cont) (p.6 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
SNE	7801	77-99	Prerecruits	1.0488	1.00	0.0323	1.00	15	1	5
SNE	7807	77-99	Prerecruits	1.2051	0.88	0.0380	0.86	17	2	5
SNE	<i>78 Mean</i>	77-99	<i>Prerecruits</i>	<i>1.1269</i>	<i>1.00</i>	<i>0.0352</i>	<i>1.00</i>	32	3	NA
SNE	7901	77-99	Prerecruits	0.9329	0.00	0.0341	0.00	9	1	4
SNE	8001	77-99	Prerecruits	0.2650	1.00	0.0069	1.00	20	1	6
SNE	8006	77-99	Prerecruits	0.2094	0.71	0.0082	0.71	14	2	5
SNE	<i>80 Mean</i>	77-99	<i>Prerecruits</i>	<i>0.2372</i>	<i>1.00</i>	<i>0.0076</i>	<i>1.00</i>	34	3	NA
SNE	8105	77-99	Prerecruits	1.4509	0.31	0.0490	0.36	27	8	8
SNE	8105	77-99	Prerecruits	2.5254	0.33	0.0883	0.38	10	6	4
SNE	8204	77-99	Prerecruits	1.2480	0.29	0.0435	0.34	42	11	9
SNE	8305	77-99	Prerecruits	0.2987	0.39	0.0111	0.39	54	15	9
SNE	8403	77-99	Prerecruits	0.1886	0.48	0.0061	0.49	63	7	9
SNE	8604	77-99	Prerecruits	0.1591	0.64	0.0047	0.66	25	3	8
SNE	8903	77-99	Prerecruits	0.7398	0.53	0.0257	0.52	23	6	8
SNE	9203	77-99	Prerecruits	0.4947	0.53	0.0172	0.52	31	7	9
SNE	9404	77-99	Prerecruits	0.4591	0.39	0.0159	0.40	38	9	9
SNE	9704	77-99	Prerecruits	1.2177	0.36	0.0441	0.38	34	10	9
SNE	9903	77-99	Prerecruits	1.2746	0.50	0.0482	0.54	34	10	9
SNE	200206	77-99	Prerecruits	0.2023	0.71	0.0080	0.75	24	3	8
SNE	7801	100-116	New recruits	1.1986	1.00	0.0729	1.00	15	1	5
SNE	7807	100-116	New recruits	1.1986	1.00	0.0729	1.00	17	1	5
SNE	<i>78 Mean</i>	100-116	<i>New recruits</i>	<i>1.1986</i>	<i>1.00</i>	<i>0.0729</i>	<i>1.00</i>	32	2	NA
SNE	7901	100-116	New recruits	0.3110	0.82	0.0175	0.84	9	2	4
SNE	8001	100-116	New recruits	0.1451	0.82	0.0082	0.84	20	2	6
SNE	8006	100-116	New recruits	0.1228	0.53	0.0074	0.54	14	3	5
SNE	<i>80 Mean</i>	100-116	<i>New recruits</i>	<i>0.1340</i>	<i>0.82</i>	<i>0.0078</i>	<i>0.84</i>	34	5	NA
SNE	8105	100-116	New recruits	0.8340	0.38	0.0488	0.34	27	2	8
SNE	8105	100-116	New recruits	1.7103	0.38	0.1001	0.34	10	2	4
SNE	8204	100-116	New recruits	0.8673	0.34	0.0504	0.31	42	5	9
SNE	8305	100-116	New recruits	0.3420	0.46	0.0206	0.46	54	13	9
SNE	8403	100-116	New recruits	0.3098	0.47	0.0179	0.46	63	8	9
SNE	8604	100-116	New recruits	0.1593	0.57	0.0088	0.58	25	4	8
SNE	8903	100-116	New recruits	0.3004	0.46	0.0176	0.47	23	5	8
SNE	9203	100-116	New recruits	0.0498	0.71	0.0028	0.71	31	2	9
SNE	9404	100-116	New recruits	0.6643	0.72	0.0409	0.72	38	4	9
SNE	9704	100-116	New recruits	1.0424	0.38	0.0627	0.38	34	8	9
SNE	9903	100-116	New recruits	0.2349	0.47	0.0136	0.48	34	5	9
SNE	200206	100-116	New recruits	0.7284	0.72	0.0464	0.72	24	4	8
SNE	7801	117+	Old recruits	26.2199	1.00	3.7305	1.00	15	1	5
SNE	7807	117+	Old recruits	26.2199	1.00	3.7305	1.00	17	1	5
SNE	<i>78 Mean</i>	117+	<i>Old recruits</i>	<i>26.2199</i>	<i>1.00</i>	<i>3.7305</i>	<i>1.00</i>	32	2	NA
SNE	7901	117+	Old recruits	12.5657	0.42	1.8324	0.42	9	4	4
SNE	8001	117+	Old recruits	5.8631	0.42	0.8550	0.42	20	4	6
SNE	8006	117+	Old recruits	1.7757	0.56	0.2617	0.57	14	4	5
SNE	<i>80 Mean</i>	117+	<i>Old recruits</i>	<i>3.8194</i>	<i>0.56</i>	<i>0.5584</i>	<i>0.57</i>	34	8	NA
SNE	8105	117+	Old recruits	10.9687	0.48	1.4624	0.48	27	9	8
SNE	8105	117+	Old recruits	16.9081	0.56	2.2296	0.57	10	4	4
SNE	8204	117+	Old recruits	12.5824	0.40	1.7896	0.41	42	11	9
SNE	8305	117+	Old recruits	8.0424	0.39	1.2844	0.39	54	20	9
SNE	8403	117+	Old recruits	10.9240	0.34	1.6826	0.34	63	18	9
SNE	8604	117+	Old recruits	4.1245	0.68	0.6436	0.69	25	7	8
SNE	8903	117+	Old recruits	5.7642	0.31	0.8650	0.31	23	7	8
SNE	9203	117+	Old recruits	2.5171	0.57	0.4011	0.58	31	3	9
SNE	9404	117+	Old recruits	1.7225	0.53	0.2674	0.54	38	6	9
SNE	9704	117+	Old recruits	12.3193	0.30	1.9161	0.30	34	9	9
SNE	9903	117+	Old recruits	4.4130	0.65	0.7338	0.65	34	7	9
SNE	200206	117+	Old recruits	3.8853	0.27	0.6039	0.22	24	7	8

Table C23 (cont) (p.7 of 7)

Region	Cruise	Length Bin	Group Name	N/Tow	CV	Kg/Tow	CV	Number Tows	Number PositiveTows	Number Strata Sampled
GBK	8001	85-99	Prerecruits	0.5911	0.00	0.0230	0.00	9	1	3
GBK	8006	85-99	Prerecruits	0.5911	0.00	0.0230	0.00	9	1	3
GBK	<i>80 Mean</i>	85-99	<i>Prerecruits</i>	<i>0.5911</i>	<i>0.00</i>	<i>0.0230</i>	<i>0.00</i>	<i>18</i>	<i>2</i>	<i>NA</i>
GBK	8105	85-99	Prerecruits	0.9919	0.22	0.0430	0.23	31	5	10
GBK	8105	85-99	Prerecruits	0.8700	0.25	0.0384	0.27	22	4	9
GBK	<i>81 Mean</i>	85-99	<i>Prerecruits</i>	<i>0.9310</i>	<i>0.25</i>	<i>0.0407</i>	<i>0.27</i>	<i>53</i>	<i>9</i>	<i>NA</i>
GBK	8204	85-99	Prerecruits	0.8700	0.25	0.0384	0.27	22	4	9
GBK	8305	85-99	Prerecruits	0.9310	0.33	0.0386	0.34	44	15	11
GBK	8403	85-99	Prerecruits	1.3811	0.31	0.0566	0.31	29	11	7
GBK	8604	85-99	Prerecruits	4.4127	0.80	0.1812	0.80	45	10	14
GBK	8903	85-99	Prerecruits	0.7516	0.28	0.0314	0.28	76	19	14
GBK	9203	85-99	Prerecruits	4.7721	0.46	0.2006	0.47	66	29	14
GBK	9404	85-99	Prerecruits	8.4210	0.36	0.3590	0.36	68	36	14
GBK	9704	85-99	Prerecruits	17.2458	0.32	0.7204	0.32	65	33	14
GBK	9903	85-99	Prerecruits	5.6447	0.49	0.2369	0.49	58	17	14
GBK	200206	85-99	Prerecruits	5.5683	0.58	0.2338	0.58	42	17	11
GBK	8001	100-111	Prerecruits	0.1478	0.00	0.0077	0.00	9	1	3
GBK	8006	100-111	Prerecruits	0.1478	0.00	0.0077	0.00	9	1	3
GBK	<i>80 Mean</i>	100-111	<i>Prerecruits</i>	<i>0.1478</i>	<i>0.00</i>	<i>0.0077</i>	<i>0.00</i>	<i>18</i>	<i>2</i>	<i>NA</i>
GBK	8105	100-111	Prerecruits	0.2439	0.43	0.0132	0.43	31	3	10
GBK	8105	100-111	Prerecruits	0.2132	0.51	0.0117	0.50	22	2	9
GBK	<i>81 Mean</i>	100-111	<i>Prerecruits</i>	<i>0.2286</i>	<i>0.51</i>	<i>0.0124</i>	<i>0.50</i>	<i>53</i>	<i>5</i>	<i>NA</i>
GBK	8204	100-111	New recruits	0.2132	0.51	0.0117	0.50	22	2	9
GBK	8305	100-111	New recruits	0.3912	0.46	0.0232	0.46	44	7	11
GBK	8403	100-111	New recruits	0.9156	0.19	0.0536	0.20	29	8	7
GBK	8604	100-111	New recruits	2.6033	0.73	0.1519	0.73	45	10	14
GBK	8903	100-111	New recruits	1.5841	0.43	0.0999	0.45	76	22	14
GBK	9203	100-111	New recruits	5.1266	0.53	0.3055	0.52	66	22	14
GBK	9404	100-111	New recruits	9.6806	0.39	0.5820	0.39	68	30	14
GBK	9704	100-111	New recruits	18.0554	0.36	1.0752	0.36	65	31	14
GBK	9903	100-111	New recruits	8.0000	0.50	0.4874	0.49	58	17	14
GBK	200206	100-111	New recruits	7.3069	0.63	0.4424	0.63	42	13	11
GBK	8001	112+	Old recruits	0.1478	0.00	0.0106	0.00	9	1	3
GBK	8006	112+	Old recruits	0.1478	0.00	0.0106	0.00	9	1	3
GBK	<i>80 Mean</i>	112+	<i>Old recruits</i>	<i>0.1478</i>	<i>0.00</i>	<i>0.0106</i>	<i>0.00</i>	<i>18</i>	<i>2</i>	<i>NA</i>
GBK	8105	112+	Old recruits	0.6260	0.01	0.0696	0.00	31	4	10
GBK	8105	112+	Old recruits	0.6095	0.01	0.0693	0.00	22	3	9
GBK	<i>81 Mean</i>	112+	<i>Old recruits</i>	<i>0.6177</i>	<i>0.01</i>	<i>0.0694</i>	<i>0.00</i>	<i>53</i>	<i>7</i>	<i>NA</i>
GBK	8204	112+	Old recruits	0.6095	0.01	0.0693	0.00	22	3	9
GBK	8305	112+	Old recruits	3.9641	0.58	0.5867	0.66	44	12	11
GBK	8403	112+	Old recruits	8.0097	0.61	1.2074	0.68	29	8	7
GBK	8604	112+	Old recruits	7.4371	0.53	0.8927	0.52	45	6	14
GBK	8903	112+	Old recruits	26.5323	0.72	3.1317	0.73	76	20	14
GBK	9203	112+	Old recruits	10.5515	0.31	1.1874	0.31	66	25	14
GBK	9404	112+	Old recruits	53.5769	0.36	6.4436	0.39	68	25	14
GBK	9704	112+	Old recruits	35.8057	0.27	3.6609	0.25	65	28	14
GBK	9903	112+	Old recruits	36.8253	0.31	3.9445	0.30	58	23	14
GBK	200206	112+	Old recruits	32.4079	0.43	3.6658	0.41	42	17	11

Table C24. Database parameters for surfclam survey data used in this assessment and for data similar to data used by NEFSC (2000). Parameters for survey trends in NNJ and SNJ are shown as examples; length boundary parameters for other areas are given in Table C25. Database extractions for swept area biomass calculations used a lower length bound of 120 mm (NNJ and SNJ) or 100 mm (all other areas). Negative parameter values are ignored in database calculations.

Database Parameter	For comparison to N/Tow for various sizegroups in SARC 30 (Table E15)	For comparison to "KG/Tow All Sizes" in SARC 30 (Table E15)	Trends in NNJ and SNJ surfclam prior to 1982	Trends in NNJ and SNJ surfclam 1982 and later	Survey data for swept area biomass calculations
DISTANCE_TYPE	TREND	TREND	TREND	TREND	SENDIST_NEG1
LENGTH_BIN_SIZE_MM	10	10000	1000	1000	1000
FIRST_LENGTH_MM	0	0	107 or 120 or 130	107 or 120 or 130	100 or 120
FIRST_BIN_IS_PLUSGROUP	-1	-1	-1	-1	-1
LAST_LENGTH_MM	250	250	119 or 129 or 250	119 or 129 or 250	250
LAST_BIN_IS_PLUSGROUP	-1	-1	-1	-1	-1
SVSPP_TO_USE	403	403	403	403	403
AREAKIND	OLD	OLD	GIS	GIS	GIS
REV_DATE_FOR_AREAS	2002	2002	2002	2002	2002
REV_DATE_FOR_LW	0	0	1999	1999	1999
FIRST_JWSTCODE	-1	-1	-1	-1	-1
LAST_JWSTCODE	-1	-1	-1	-1	-1
FIRST_RANDLIKE	1	1	1	1	1
LAST_RANDLIKE	2	2	2	2	2
FIRST_STATION	-1	-1	-1	-1	-1
LAST_STATION	-1	-1	-1	-1	-1
FIRST_HAUL	1	1	-1	1	1
LAST_HAUL	3	3	-3	3	3
FIRST_GEARCOND	6	1	-1	1	1
LAST_GEARCOND	6	6	-6	6	6
FIRST_STRATUM	1	1	1	1	1
LAST_STRATUM	96	96	96	96	96
FIRST_REGION_CODE	1	1	3	3	1
LAST_REGION_CODE	7	7	4	4	7
WRITE_TOW_DATA	1	1	-1	-1	-1
WRITE_STRATUM_DATA	1	1	-1	-1	-1
FIRST_CRUISE	-9700	-9700	-7000	-7000	9700
LAST_CRUISE	-9800	-9800	8200	-8200	-9800
NOMINAL_TOW_DISTANCE_NM	0.15	0.15	0.15	0.15	0.15
FILLHOLZ	-1	-1	1	1	1



Table C25. Surfclam growth model (length at age) parameters (Weinberg and Helser 1996) and length groups for pre-recruit, recruit and old recruit survey data.

Stock	New Jersey (NNJ and SNJ)			Delmarva and SVA			Long Island (LI)	Southern New England (SNE)	Georges Bank (GBK)
	1980	1989-1992	Average	1980	1989-1992	Average	All	All	All
Time Period	1980	1989-1992	Average	1980	1989-1992	Average	All	All	All
$L_{max}$ (mm)	170.8	163.7		171.0	164.0		161.8	164.7	154.1
$K$ ( $y^{-1}$ )	0.254	0.217		0.256	0.177		0.251	0.300	0.242
$t_o$ (y)	0.010	-0.214		0.132	-1.125		-0.443	0.319	0.203
Age at recruitment ( $k$ ) in years	4.8	5.9	5.3	3.6	4.2	3.9	3.4	3.4	4.5
Length at age $k-1$	105	109	107	79	88	83	82	77	85
Length at age $k$	120	120	120	100	100	100	100	100	100
Length at age $k+1$	131	129	130	116	110	113	114	117	112

Table C26. Growth model parameters (meat weight at age) used in the KLAMZ model for surfclam (NEFSC 2000).

Area	Years	$\rho$	$J_t$
New Jersey (NNJ and SNJ)	< 1981	0.8392	0.6841
	1981-1988	0.8392	By interpolation
	>1988	0.8392	0.7569
Delmarva	< 1981	0.8621	0.5079
	1981-1988	0.8621	By interpolation
	>1988	0.8621	0.5553
Long Island (LI)	All	0.8278	0.5232
Southern New England (SNE)	All	0.8023	0.4346
Georges Bank (GBK)	All	0.8456	0.6588

Table C27. KLAMZ model results for DMV surfclam. CV's for biomass and recruitment are from a bootstrap analysis (1000 iterations). CV's for fishing mortality rates are by the delta method.

Year	Biomass (1000 mt)	CV	Recruitment (1000 mt)	CV	Fishing Mortality (y <sup>-1</sup> )	CV	Surplus Production (1000 mt)	Instantaneous Surplus Production Rate (y <sup>-1</sup> )
1977	79	800%	NA	NA	0.042	82%	29	0.318
1978	105	160%	26	0.043846	0.031	66%	37	0.298
1979	138	105%	31	0.508006	0.018	58%	59	0.355
1980	194	71%	52	0.501089	0.013	53%	87	0.369
1981	279	46%	76	0.404296	0.000	50%	93	0.289
1982	372	33%	77	0.286368	0.027	50%	57	0.143
1983	419	26%	41	0.168609	0.021	50%	26	0.061
1984	436	24%	21	0.278116	0.019	50%	20	0.045
1985	448	24%	27	0.368931	0.021	50%	8	0.019
1986	447	23%	22	0.229895	0.007	50%	-4	-0.009
1987	440	22%	15	0.358235	0.005	50%	-12	-0.027
1988	427	21%	13	0.359718	0.003	50%	-17	-0.041
1989	408	21%	11	0.417193	0.010	50%	-22	-0.055
1990	383	20%	8	0.563822	0.011	50%	-24	-0.065
1991	355	19%	7	0.728656	0.005	50%	-25	-0.073
1992	328	19%	6	0.913564	0.004	50%	-23	-0.072
1993	304	20%	7	1.201202	0.013	50%	-16	-0.055
1994	284	20%	12	0.834815	0.014	50%	-6	-0.023
1995	274	21%	19	0.421947	0.012	50%	5	0.017
1996	276	21%	26	0.268422	0.009	50%	14	0.051
1997	288	20%	32	0.309467	0.006	50%	21	0.071
1998	307	19%	35	0.618812	0.001	50%	5	0.016
1999	312	18%	17	0.156186	0.002	50%	-7	-0.023
2000	304	18%	8	0.439081	0.008	50%	-12	-0.040
2001	290	18%	7	0.798677	0.013	51%	-15	-0.052
2002	272	19%	6	0.936476	0.019	51%	NA	NA

Table C28. Projected biomass, catch and fishing mortality for surfclam during 2002-2003. Projections are uncertain, may be overly pessimistic, and should be interpreted with care (see text for additional details).

Table PROJ-1. Projected biomass, catch and fishing mortality for surfclam during 2002-2003. Projections assume a constant instantaneous rate of surplus production during 2002-2005, use actual catches in 2002 and use catches during 2003-2005 equal to the quota + 12% incidental mortality allowance, prorated by region based on average catches during 1999-2002. Total biomass for 2002 is from a regression model used to smooth original efficiency corrected swept area biomass (ESB) estimates. The biomass in each region during 2002 was calculated by prorating the total based on average ESB in each region during 1997-2002. See text for additional details.

Surplus production rate $p$ ( $y^{-1}$ )	-0.051
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	Northern New Jersey (NNJ)	Southern New Jersey (SNJ)	Delmarva (DMV)	S. Virginia and N. Carolina (SVA)	Long Island (LI)	Southern New England (SNE)	Georges Bank (GBK)	Total
<b>Average ESB 1997-2002 (1000 mt)</b>	429	65	251	11	38	58	284	1,136
<b>% Average ESB 1997-2002</b>	38%	6%	22%	1%	3%	5%	25%	100%
<b>Average Catch 1997-2002 (1000 mt)</b>	16.21	3.76	2.49	0.03	0.52	0.05	0.00	23.06
<b>% Average Catch 1997-2002</b>	70%	16%	11%	0%	2%	0%	0%	100%
<b>Biomass on 1 January (1000 mt)</b>								
2002	348	53	203	9	31	47	230	921
2003	314	47	188	9	28	45	219	849
2004	279	40	176	8	26	42	208	780
2005	246	34	164	8	24	40	198	714
2006	215	28	153	7	22	38	188	651
<b>Percent Change in Biomass</b>								
2002	0%	0%	0%	0%	0%	0%	0%	0%
2003	-10%	-11%	-7%	-6%	-9%	-5%	-5%	-8%
2004	-20%	-24%	-13%	-11%	-16%	-10%	-10%	-15%
2005	-29%	-36%	-19%	-16%	-22%	-15%	-14%	-23%
2006	-38%	-47%	-25%	-20%	-28%	-19%	-18%	-29%
<b>Catch = Landings + 12% (1000 mt)</b>								
2002	16.73	3.19	4.98	0.09	1.30	0.14	0.00	26.43
2003	19.74	4.57	3.03	0.04	0.63	0.06	0.00	28.07
2004	19.74	4.57	3.03	0.04	0.63	0.06	0.00	28.07
2005	19.74	4.57	3.03	0.04	0.63	0.06	0.00	28.07
<b>Fishing Mortality (<math>y^{-1}</math>)</b>								
2002	0.051	0.064	0.026	0.010	0.044	0.003	0.000	0.030
2003	0.067	0.105	0.017	0.005	0.023	0.001	0.000	0.034
2004	0.075	0.123	0.018	0.005	0.025	0.002	0.000	0.038
2005	0.086	0.149	0.019	0.005	0.027	0.002	0.000	0.041

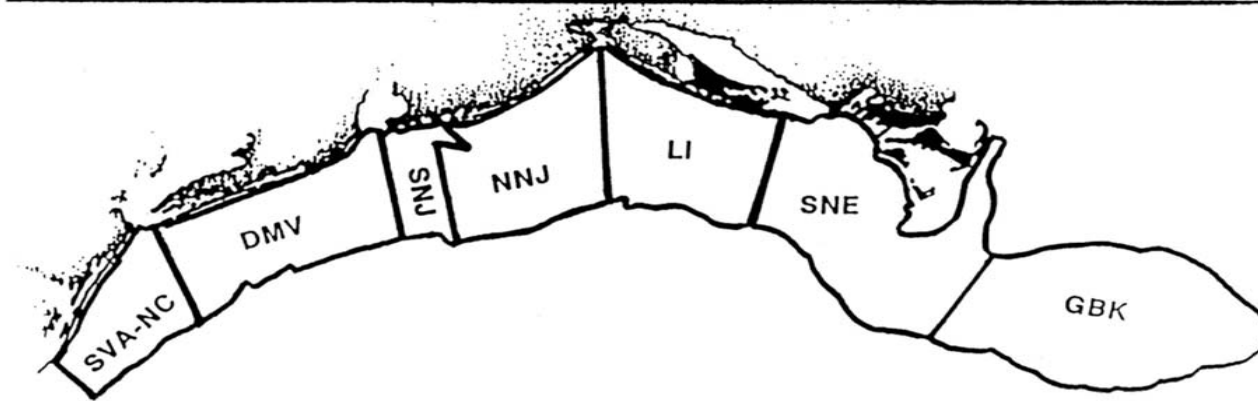
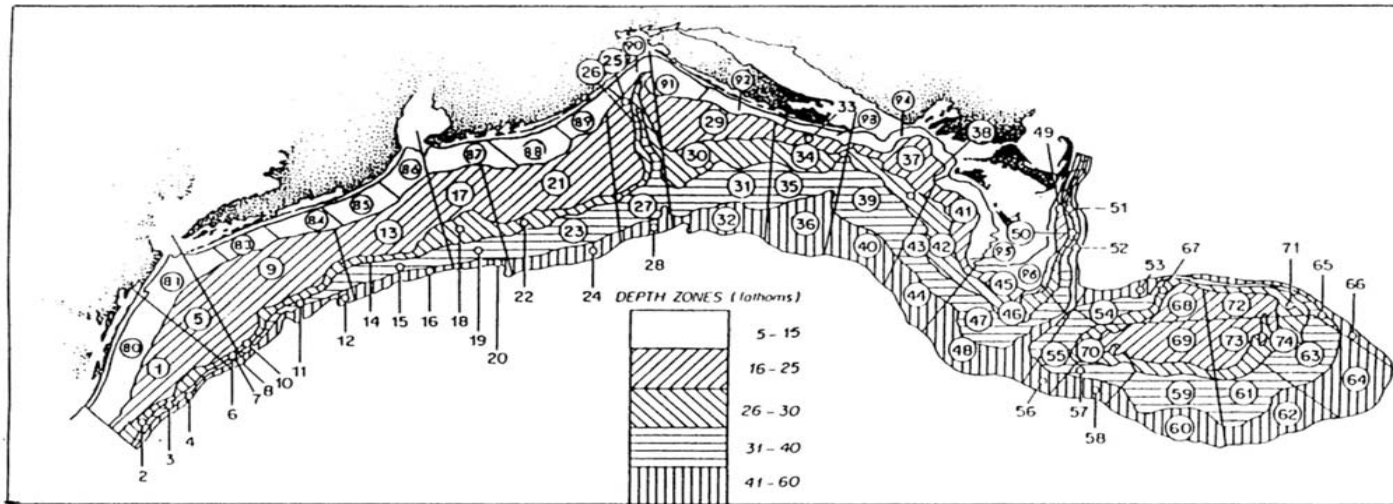


Figure C1. Clam strata and regions.

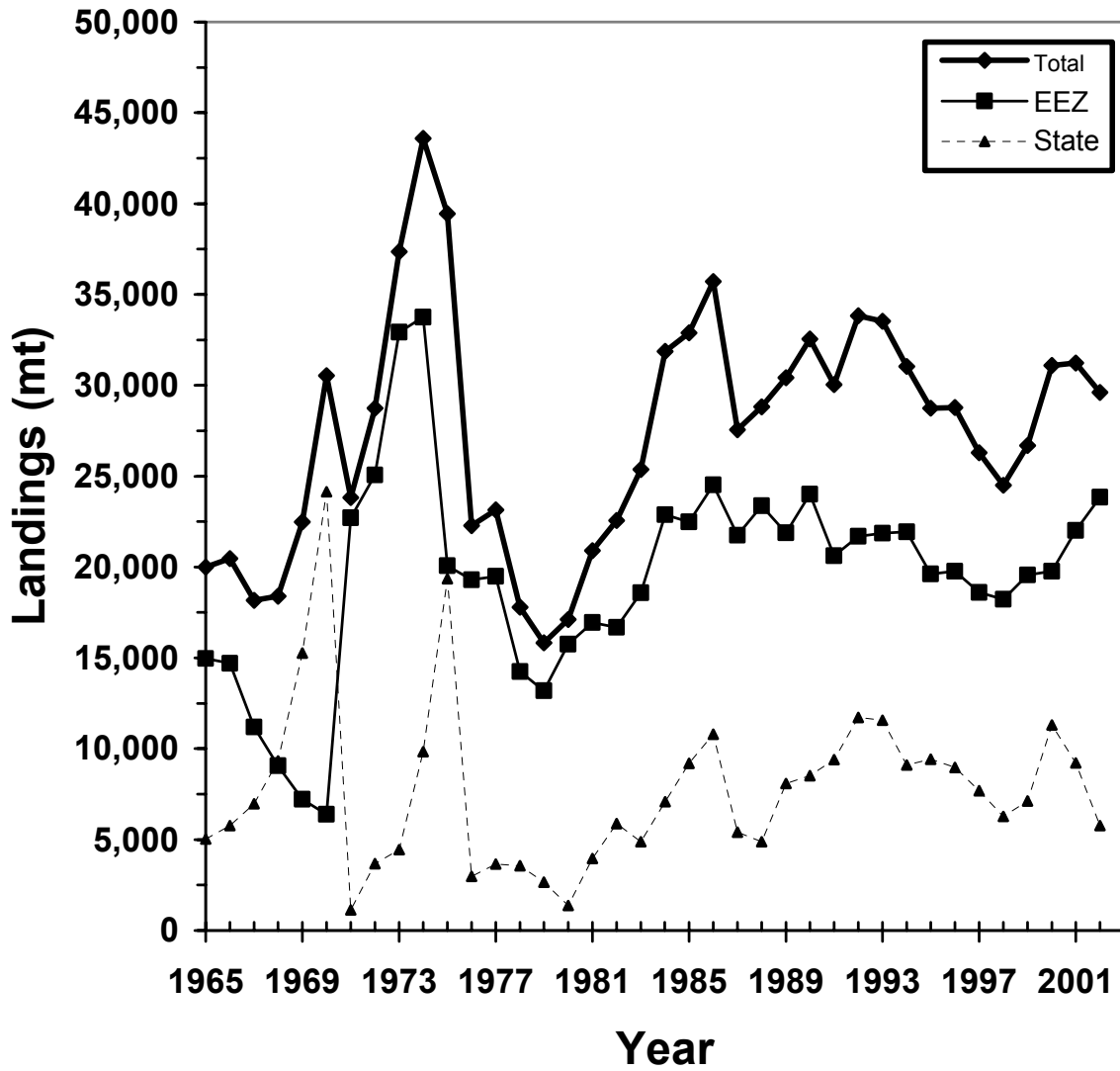


Figure C2. Landings of surfclams, 1965 - 2002. Data are for all areas (total), Exclusive Economic Zone (EEZ, 3 - 200 miles from the coast, and state (inshore) waters. EEZ data source: Logbooks.

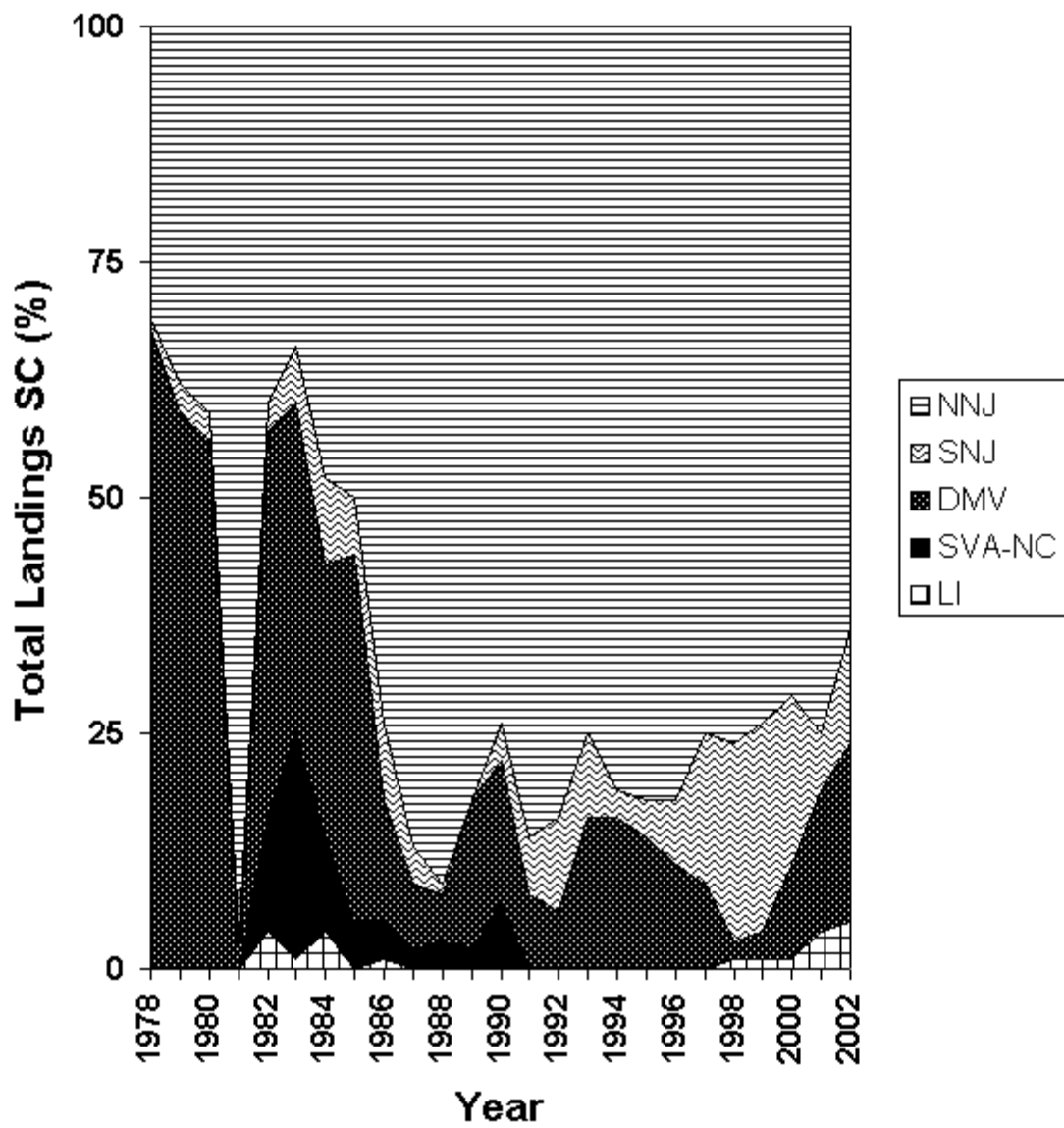


Figure C3. Proportion of surfclam landings in the Mid-Atlantic region, by area and year, 1978- 2002.

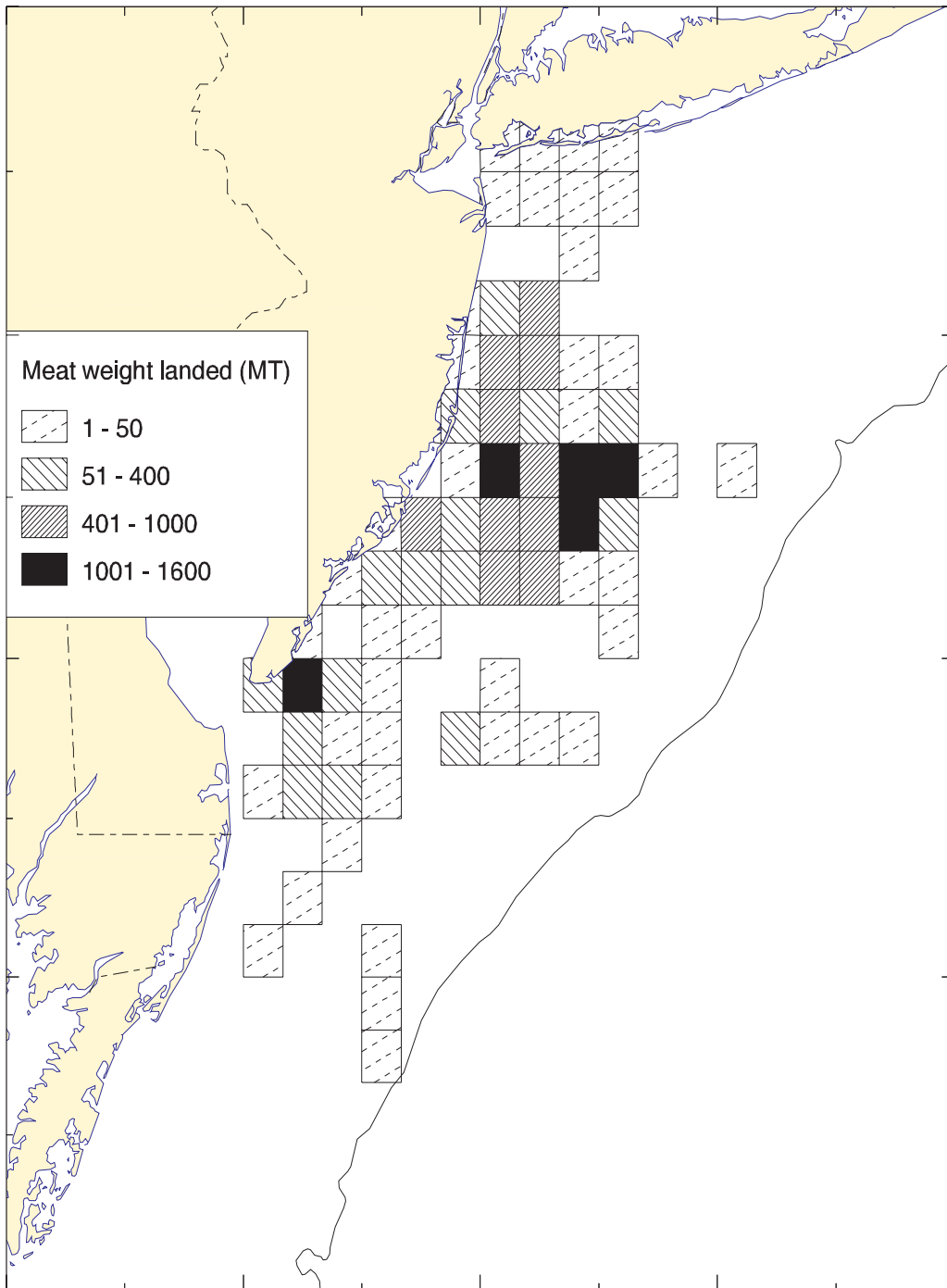


Figure C4. Distribution of surfclam landings during 1999(scInd832002b) by ten-minute square.

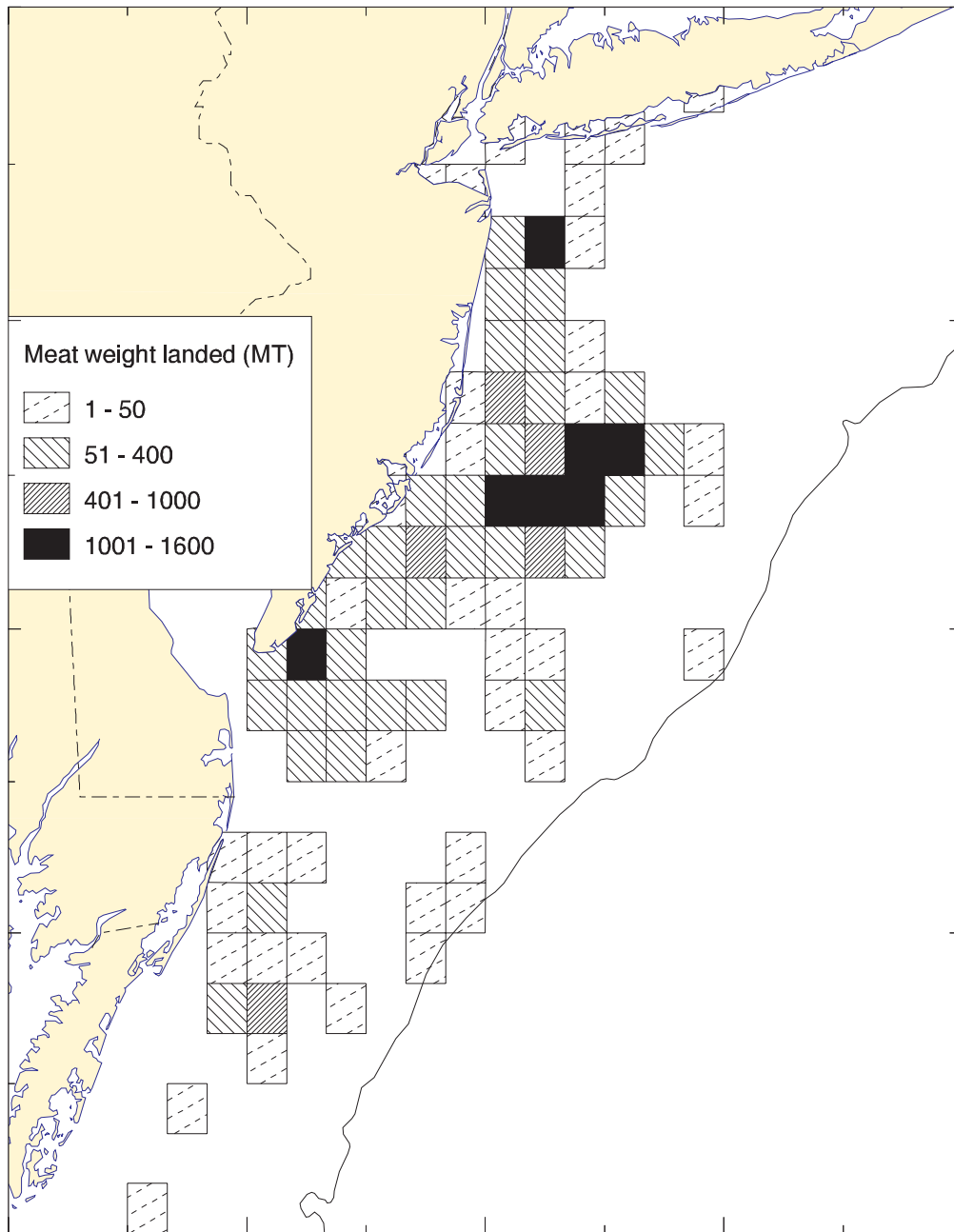


Figure C5. Distribution of surfclam landings during 2000(scIn832002b) by ten-minute square.



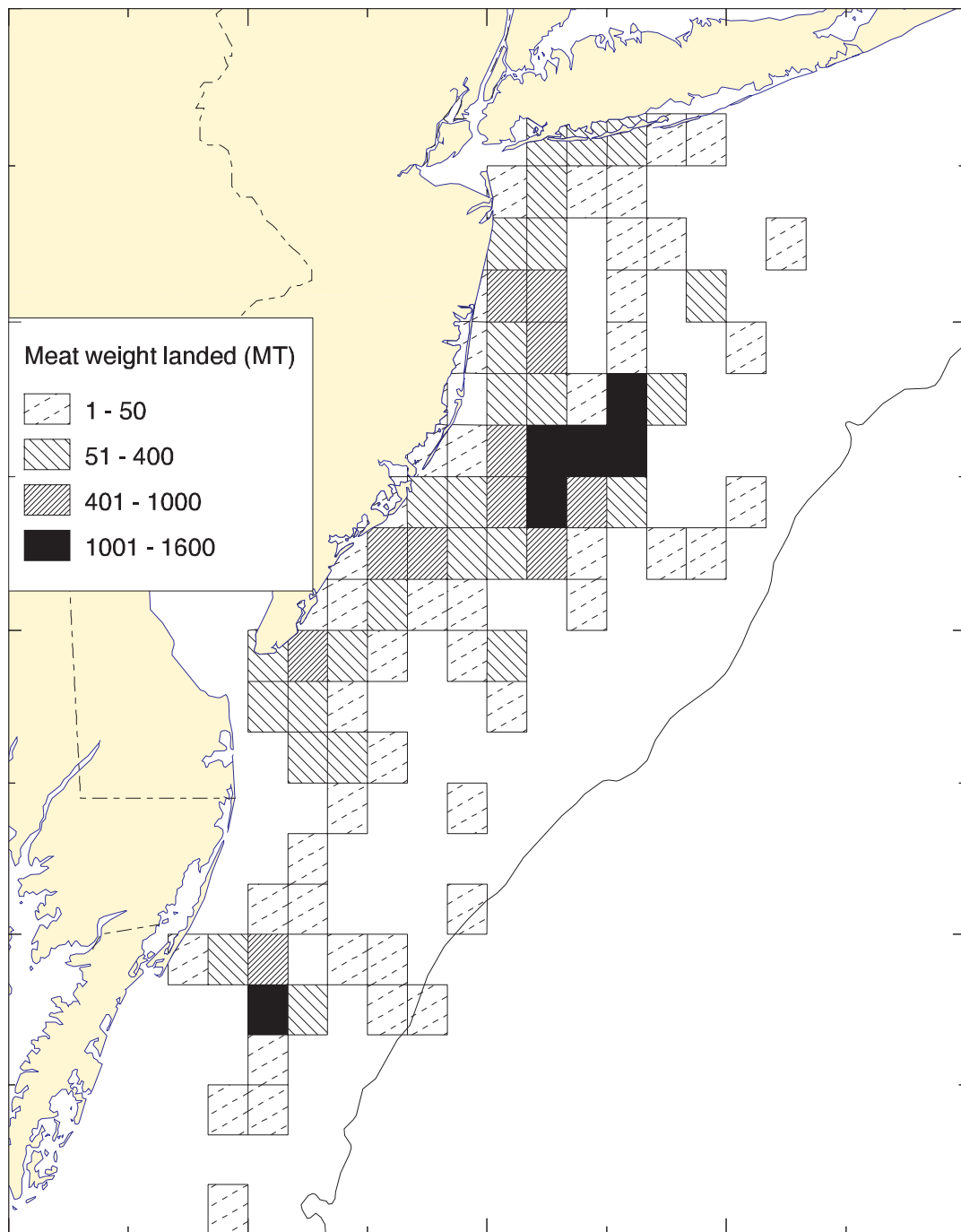


Figure C6. Distribution of surfclam landings during 2001(scInd832002b) by ten-minute square.

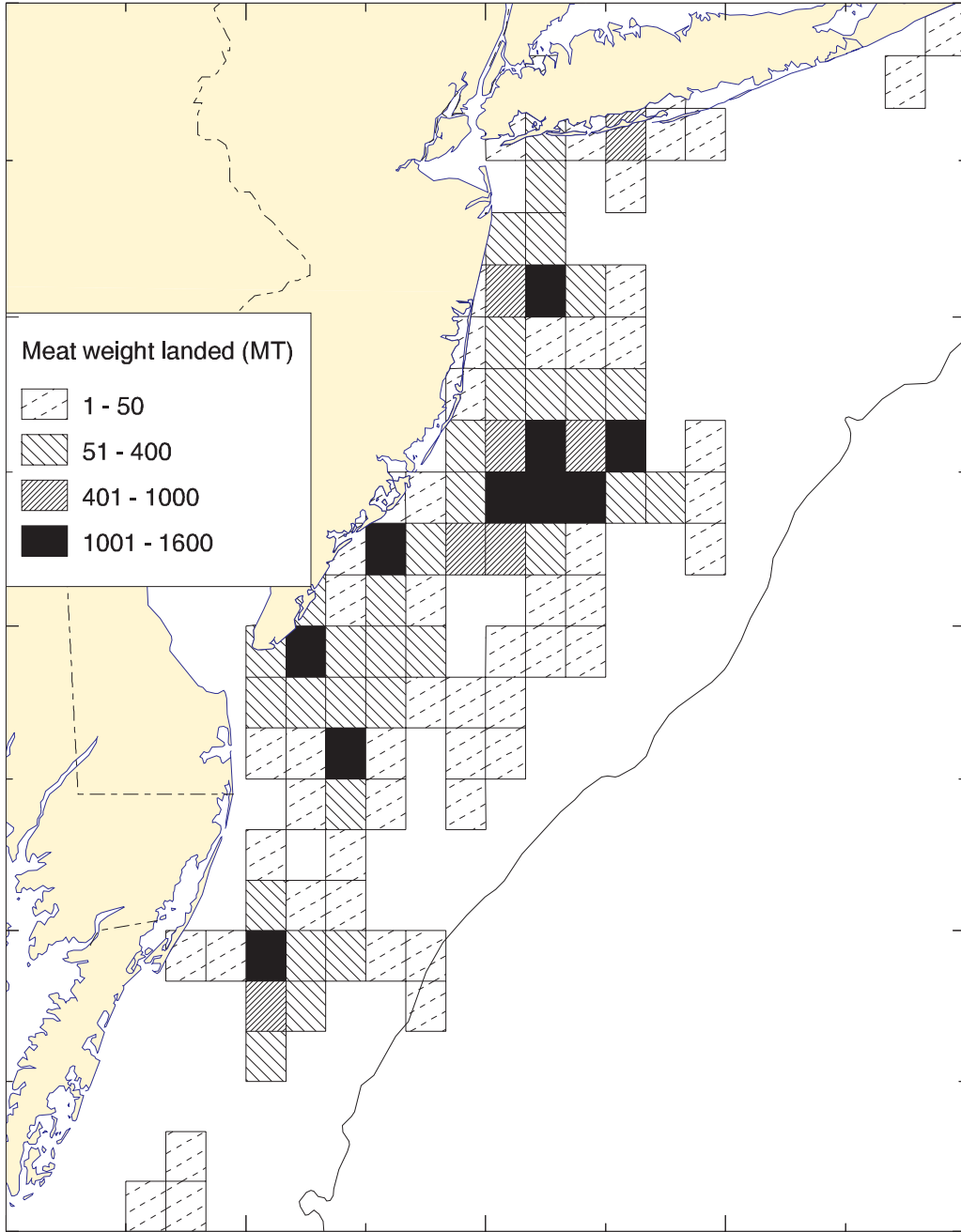


Figure C7. Distribution of surfclam landings during 2002(scInd832002b) by ten-minute square.

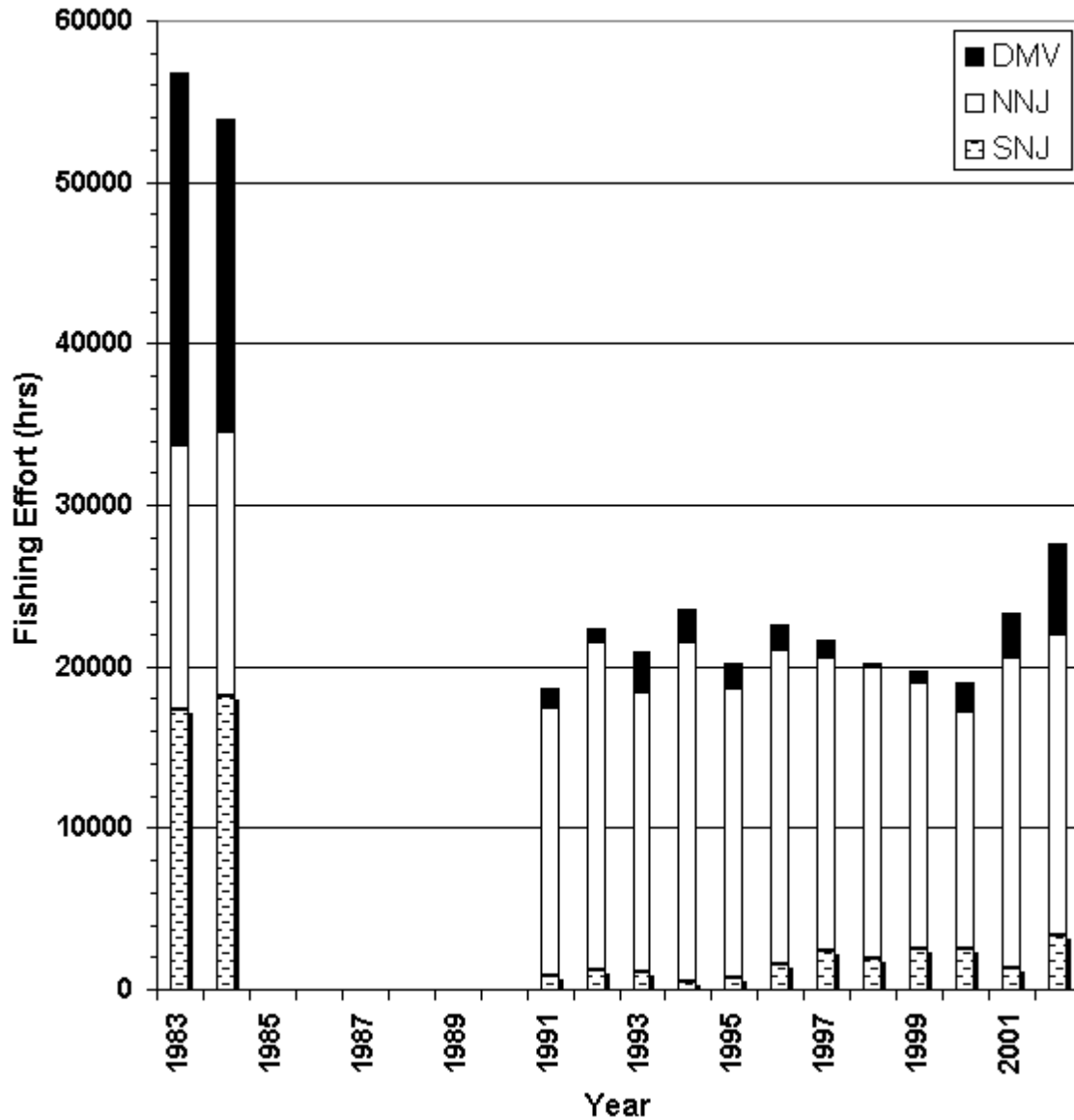
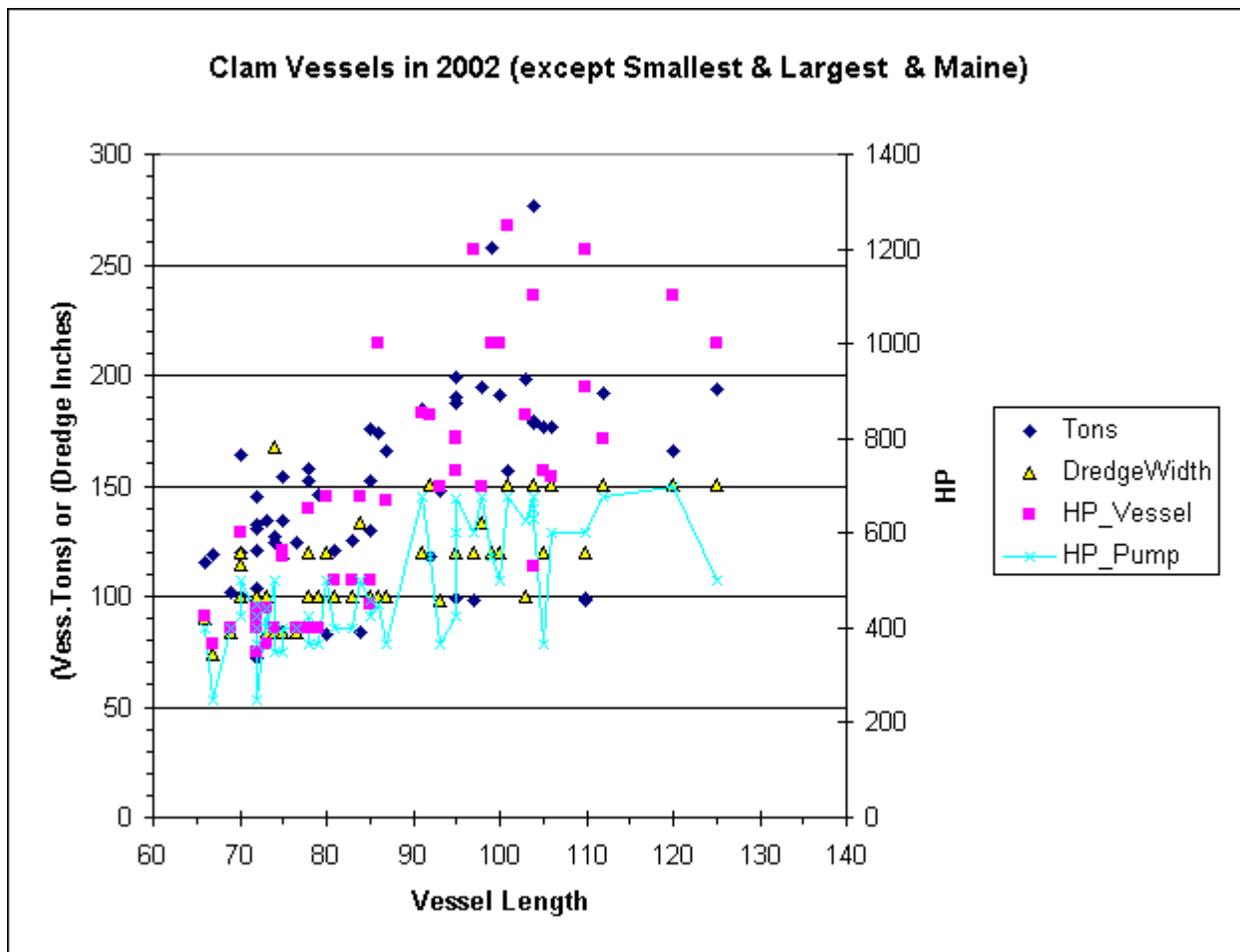


Figure C8. Total reported hours fishing during surfclam trips, by region year. Effort was not reported accurately from 1985 - 1990.



All 2002 Clam Vessels (Except from Maine) :

Var1	Var2	Corr. Coef. (r)	Significance
Length	Tons	0.718	**
HP Vessel	Tons	0.318	*
Dredge W	Tons	0.404	**
HP Pump	Tons	0.439	**

for  $v=n-2$ ;  $n=55$  :

Significance Level	Critical Value
* ( $p=.05$ )	0.26
** ( $p=.01$ )	0.34

Figure C9. Correlations between physical characteristics of commercial clam vessels.

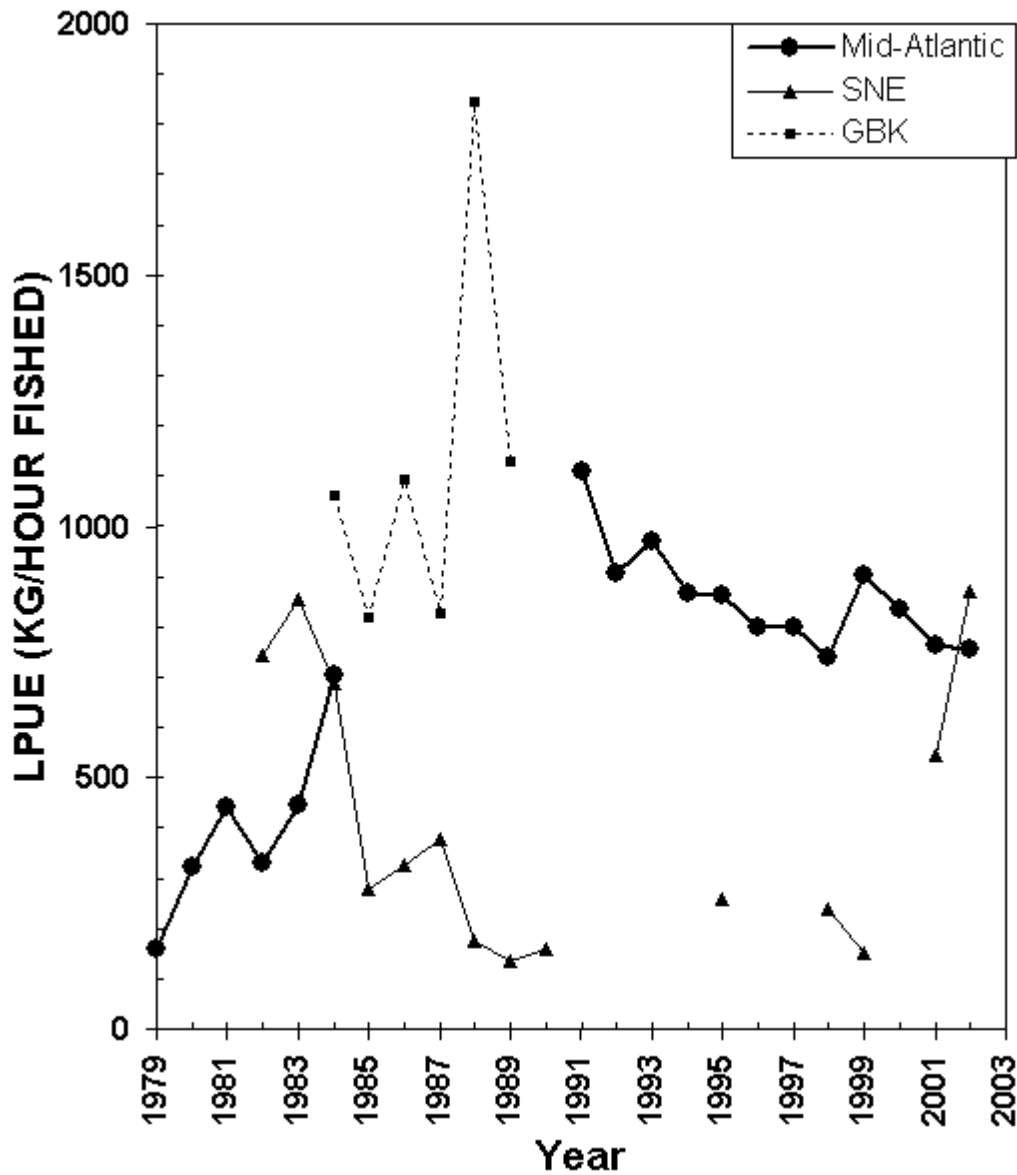


Figure C10. Landings per unit effort of surfclams by Class 3 vessels (105 + GRT) by region, 1979 - 2002. Data source: Logbooks (SfyyyVR).

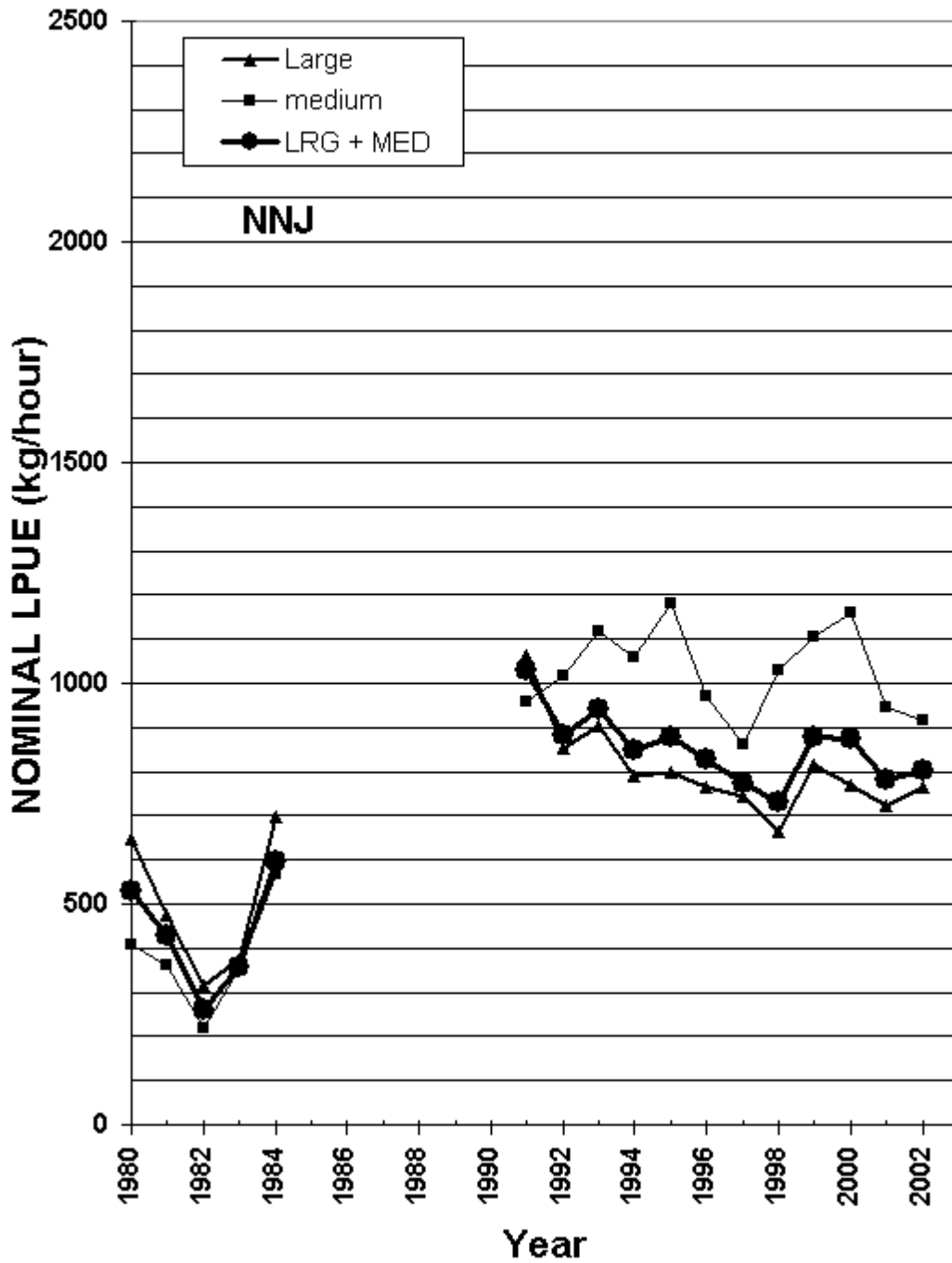


Figure C11. Nominal landings per unit effort for N. New Jersey, by vessel class (Medium: 51-104 GRT; Large: 105 GRT+).

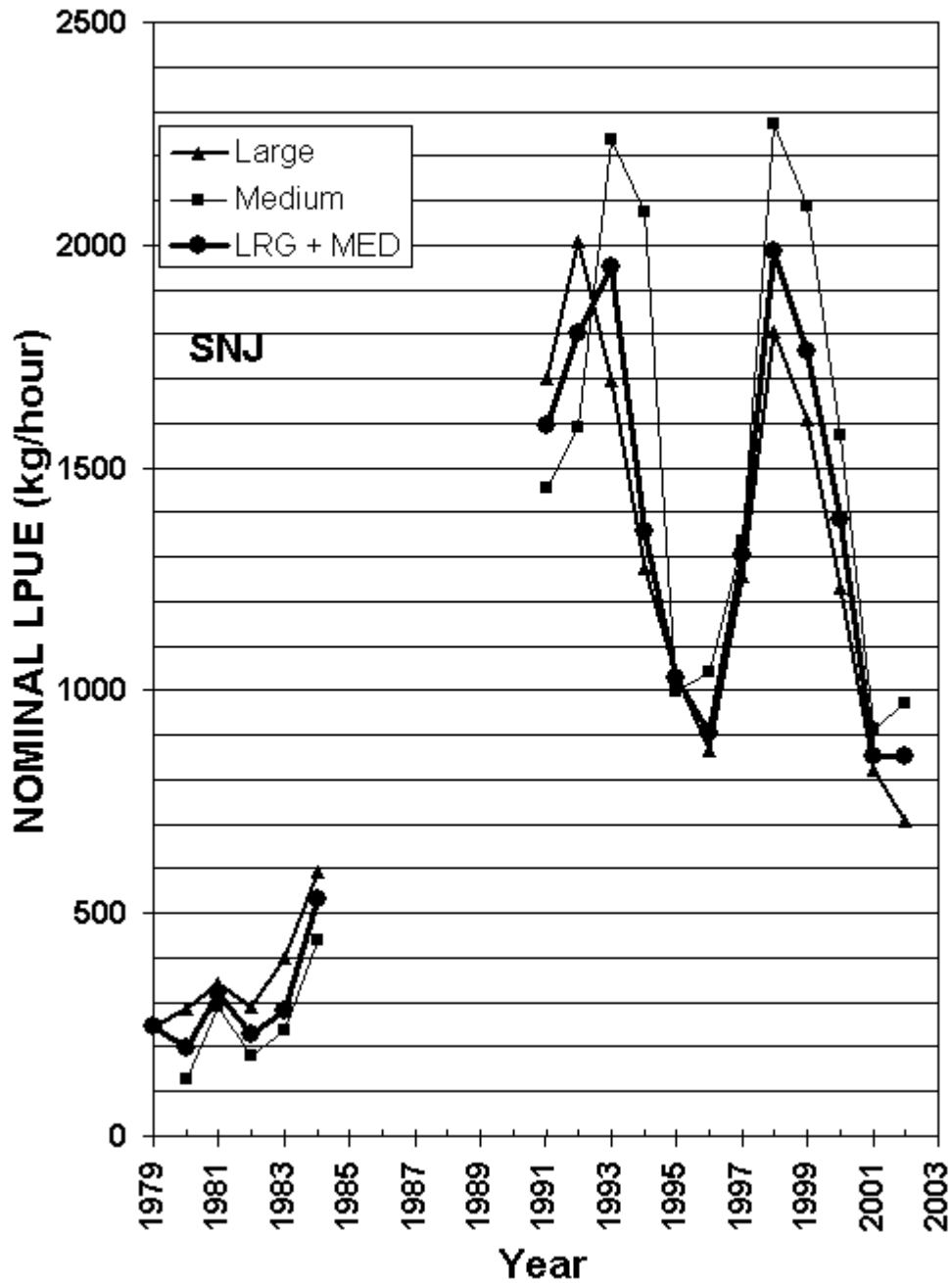


Figure C12. Nominal landings per unit effort for S. New Jersey, by vessel class (Medium: 51-104 GRT; Large: 105 GRT+).

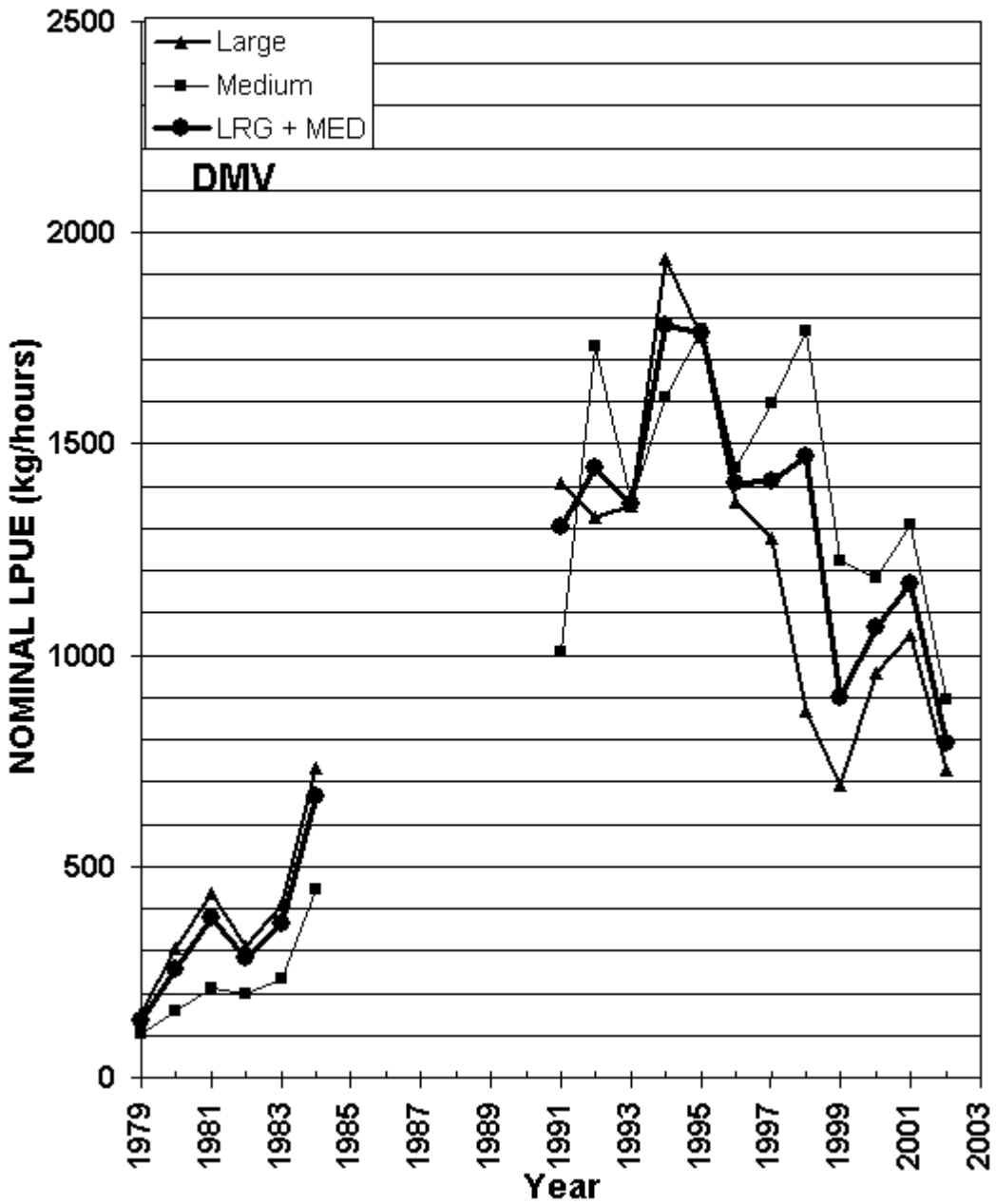


Figure C13. Nominal landings per unit effort for Delmarva, by vessel class (Medium: 51-104 GRT; Large: 105 GRT+).



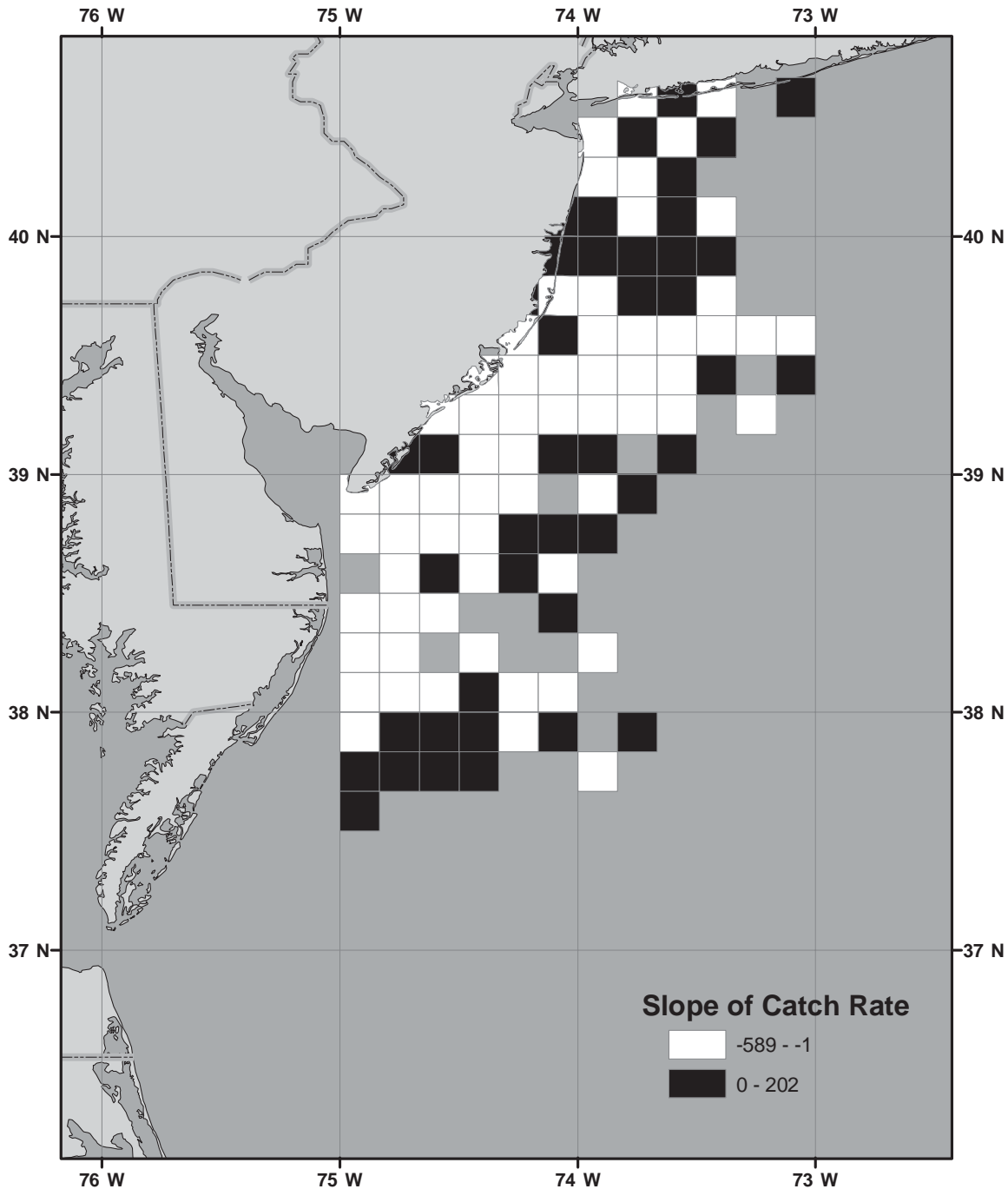


Figure C14. Spatial analysis, by ten minute square (TNMS), of trends in commercial catch rate from 1991-2002. For each TNMS, the slope of LPUE vs time was computed. If the slope was positive the TNMS was filled with black. If the slope was negative, the TNMS was filled with white.

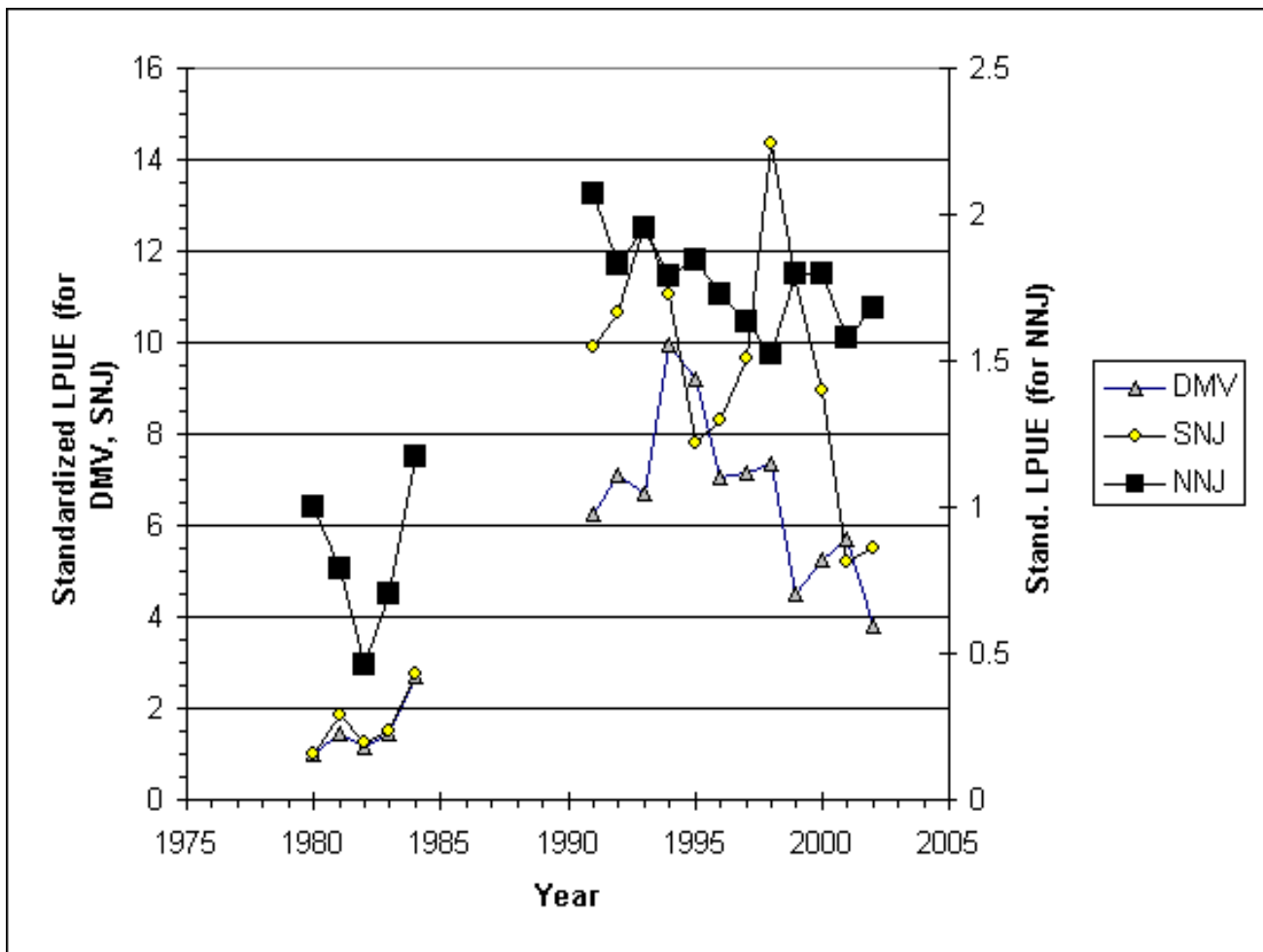


Figure C15. Standardized LPUE for surfclams, analyzed with a general linear model including Year and Subregion. A separate model was run for each region.

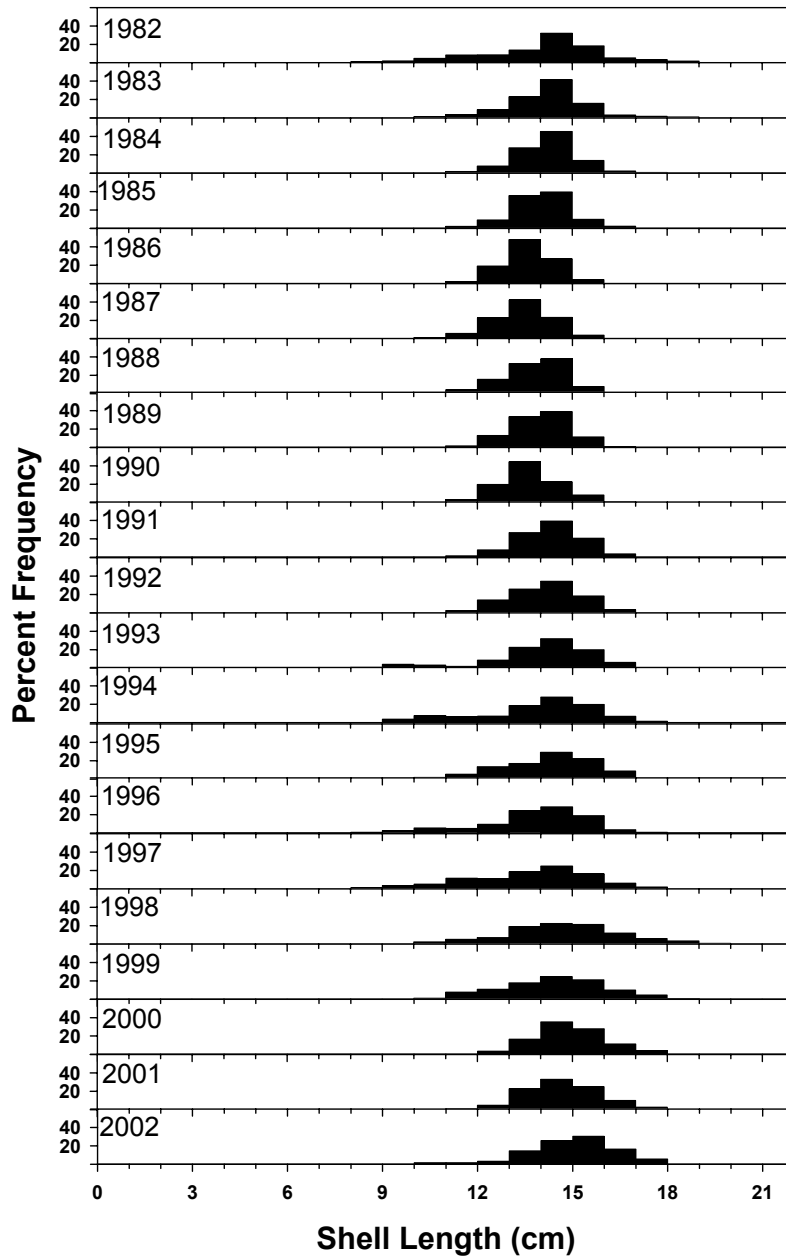


Figure C16. Surfclam commercial length frequency distributions based on port samples.  
 Region : New Jersey.

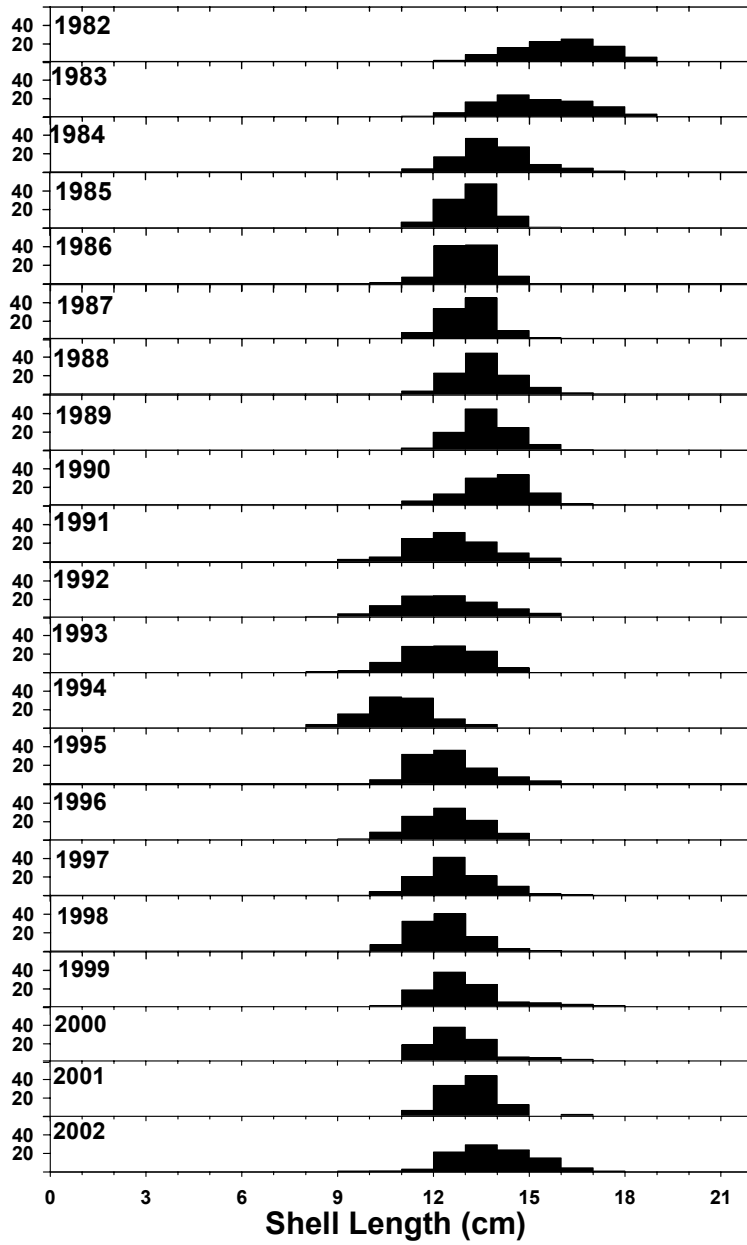
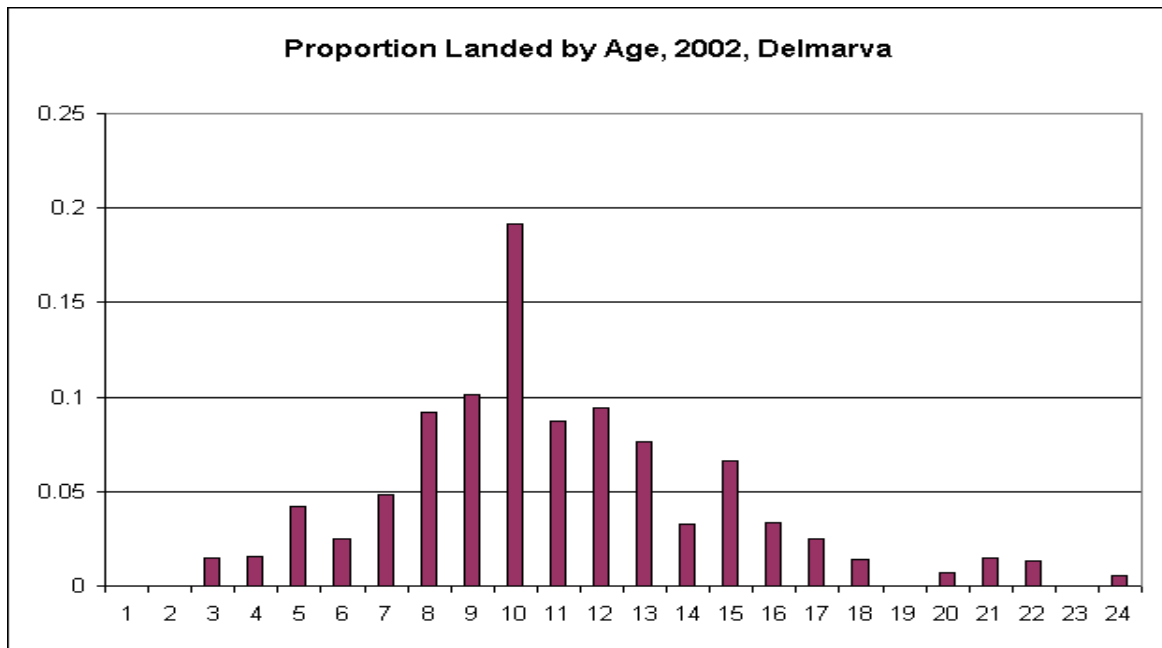
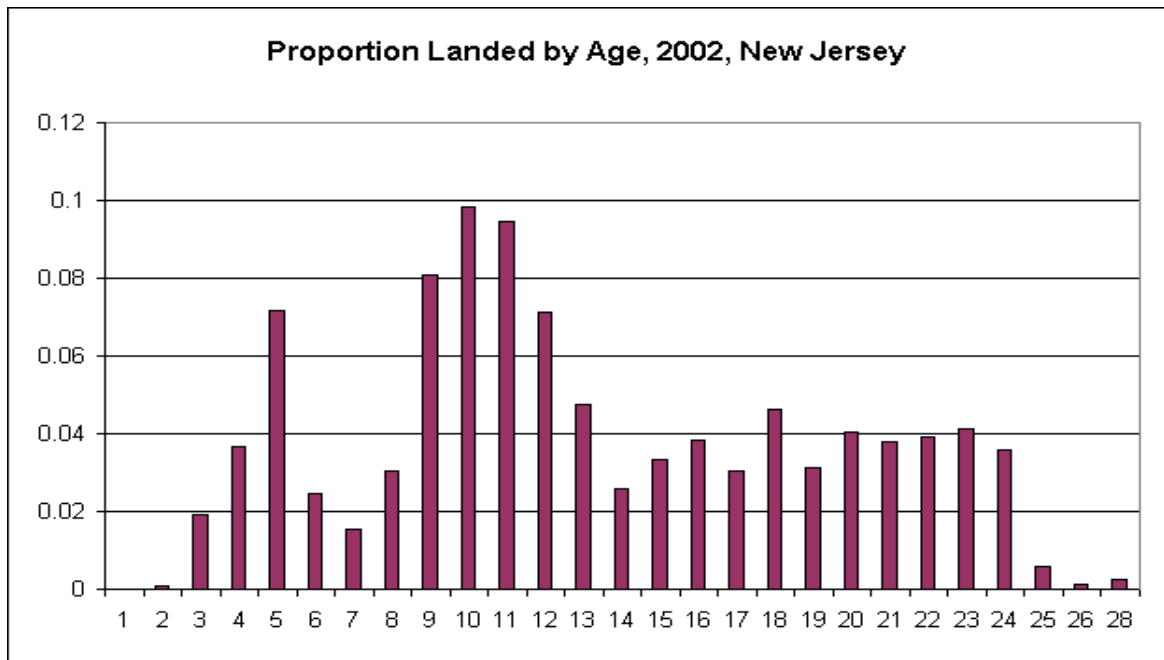


Figure C17. Surfclam commercial length frequency distributions based on port samples.  
 Region : **Delmarva**.



**Figure C18. Proportion of surfclams landed in 2002, by region and age (years). Source data: Commer. Port samples.**

SSP(red=fishing, <=4deg; green=depth), Sta.= 538

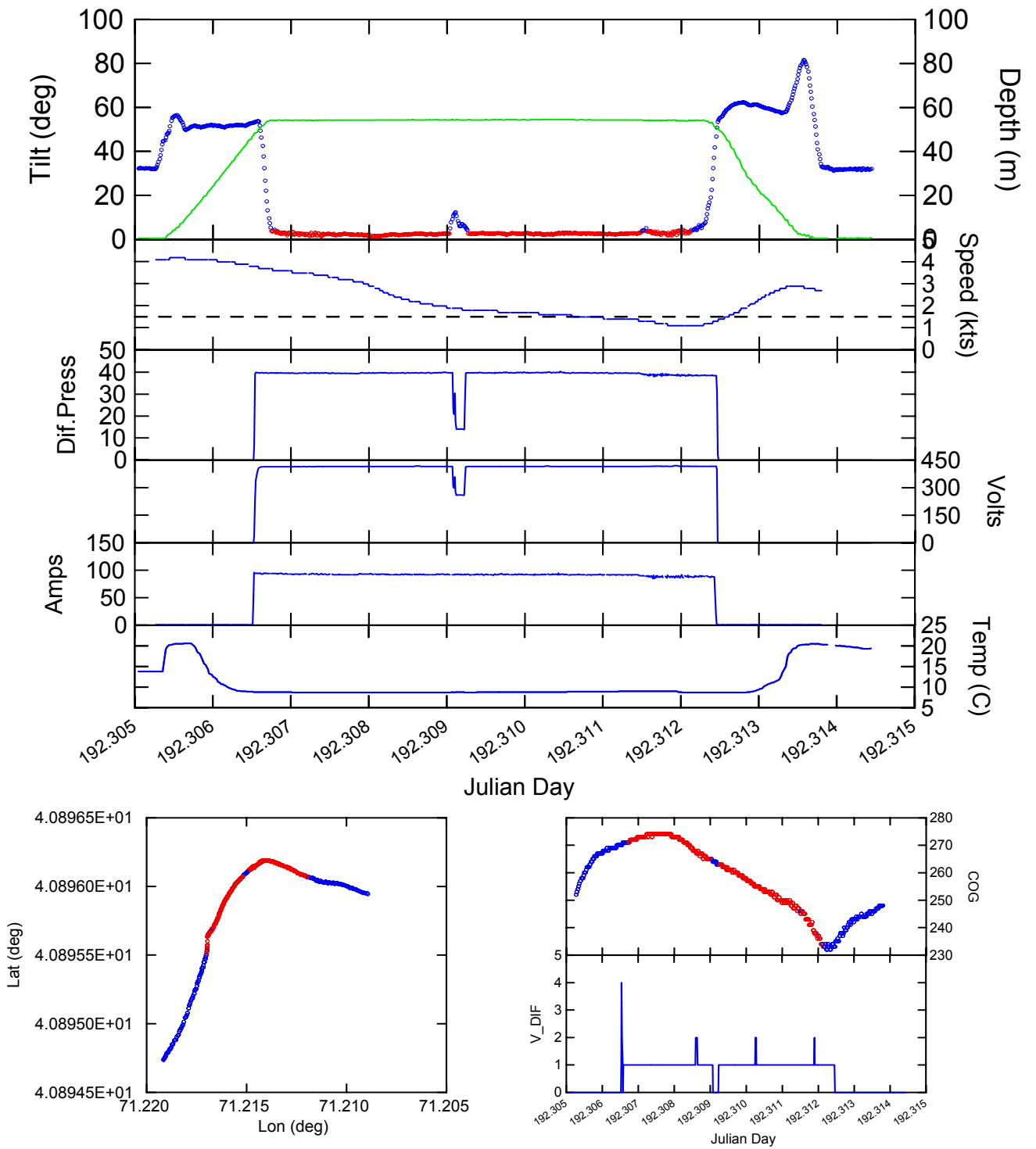
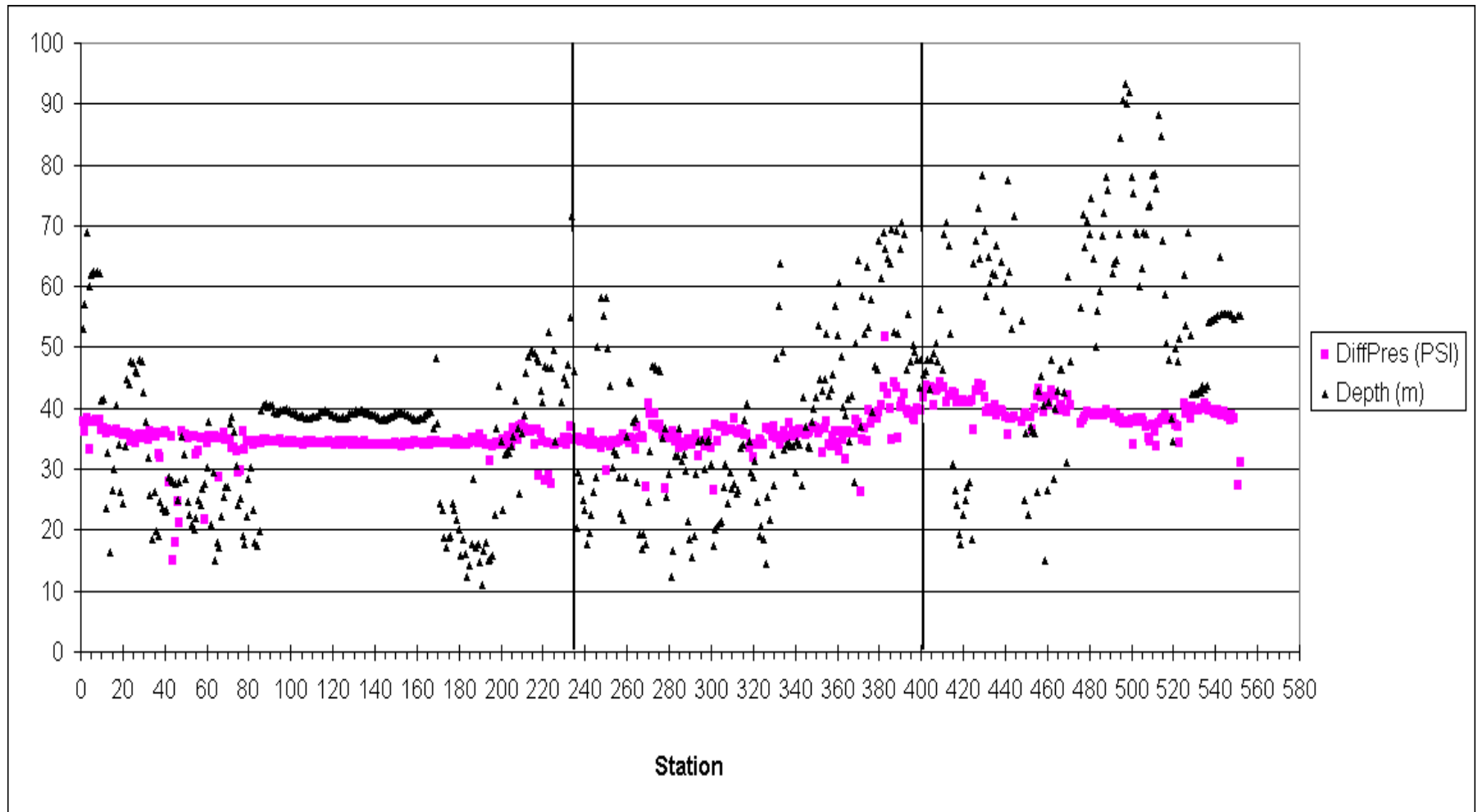


Figure C19. Example of sensor data collected at each DE-II station during the 2002 clam survey.

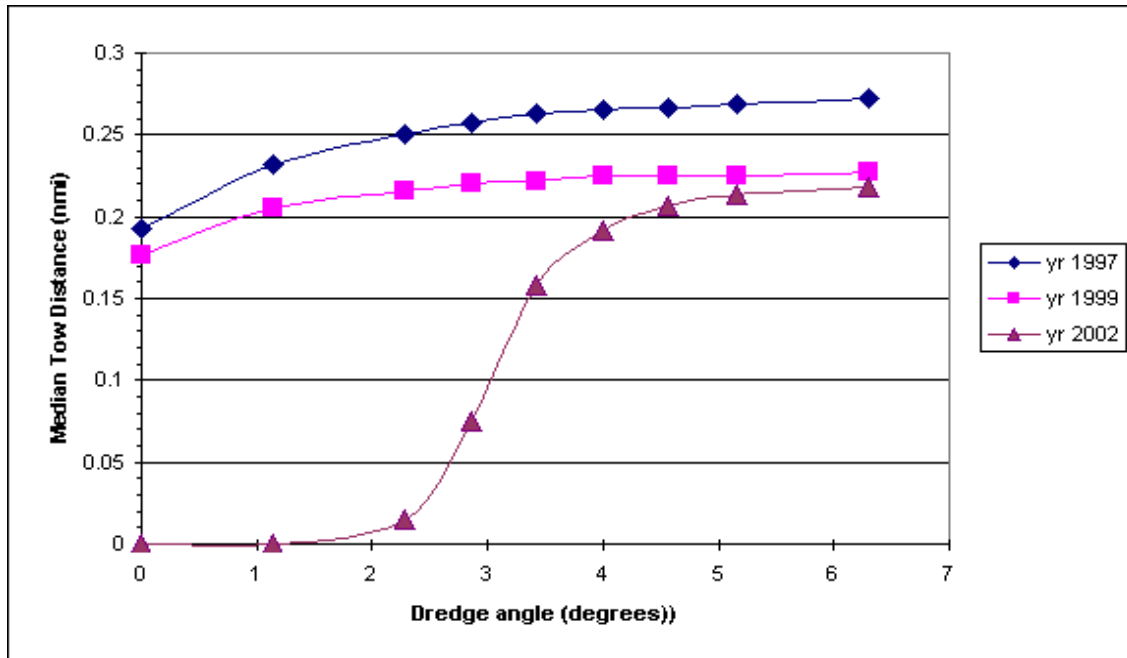


**Figure C20. Delaware II differential pressure (psi) and station depth (m) measured by the Survey Sensor Package, 2002 NMFS Clam Survey, Cruise 200206.**

**Figure C21.**

**Examination of tow distance, computed from sensor data, as a function of dredge angle, in 1997, 1999, and 2002. Calculation includes all good survey tows.**

Dredge Angle (degrees)	Median Tow Distance (nmi)			Fraction of Distance at Asymptote		
	yr 1997	yr 1999	yr 2002	yr <b>1997</b>	yr <b>1999</b>	yr <b>2002</b>
6.3	0.272	0.227	0.218	1.000	1.000	1.000
5.2	0.269	0.225	0.213	0.989	0.991	0.977
4.6	0.267	0.225	0.206	0.982	0.991	0.945
4.0	0.265	0.225	0.191	0.974	0.991	0.876
3.4	0.263	0.222	0.158	0.967	0.978	0.725
2.9	0.257	0.22	0.075	0.945	0.969	0.344
2.3	0.25	0.216	0.015	0.919	0.952	0.069
1.1	0.232	0.205	0	0.853	0.903	0.000
0.0	0.193	0.176	0	0.710	0.775	0.000





	Used	By Drawing	Measured
Knife Pivot Fwd of Dredge End (Inches):	72	71.75	72
Knife Edge Fwd of Pivot (Inches):	32.5	32	32.5
Knife Edge Fwd of Dredge End (Inches):	104.5	103.75	
Knife Edge Below Dredge Runner (Inches):	8	8	
Manifold Center Fwd of Dredge End (Inches):	138.5	138.5	138.5
Manifold Nozzle Aft of Manifold Center (Inches):	3.1	3.1	
Manifold Nozzle Fwd of Dredge End (Inches):	135.4	135.4	
Manifold Nozzle Above Dredge Runner (Inches):	1.5	1.5	
Manifold Nozzle Angle to Runner (Degrees):	45	45	

Dredge Angle To Bottom Deg	Manifold Nozzle Vert Height Above Bottom Inches	Manifold Angle To Bottom Degrees	Water Jet Travel To Bottom Inches
6.00	15.73	51.00	20.24
5.50	14.54	50.50	18.84
5.00	13.35	50.00	17.42
4.50	12.16	49.50	15.99
4.00	10.97	49.00	14.53
3.50	9.78	48.50	13.06
3.00	8.60	48.00	11.57
2.50	7.41	47.50	10.05
2.00	6.23	47.00	8.52
1.50	5.05	46.50	6.96
1.00	3.86	46.00	5.37
0.50	2.68	45.50	3.76
0.00	1.50	45.00	2.12
Dredge Angle	NH	NA	WL
	Nozzle Abv Bttm		Water Jet Travel

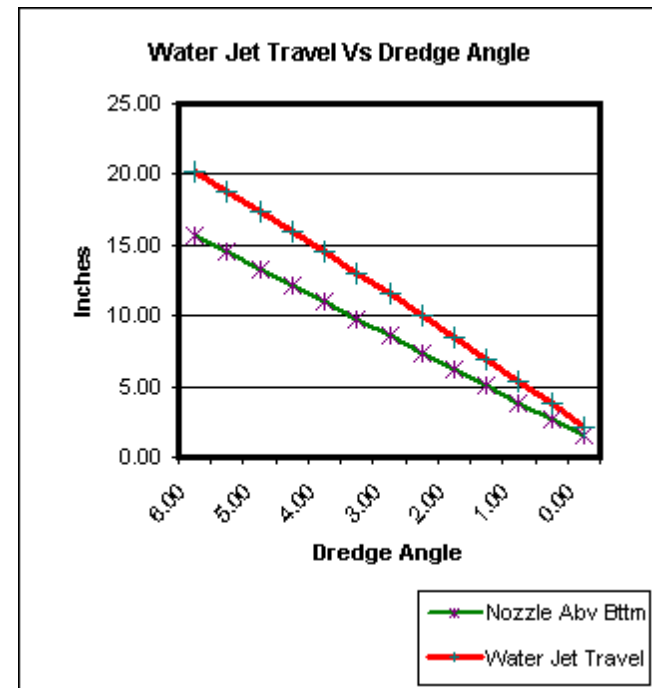


Figure C22.  
Relationship between NMFS clam dredge angle and water jet travel distance to bottom. From J. Womack, 5/2003.

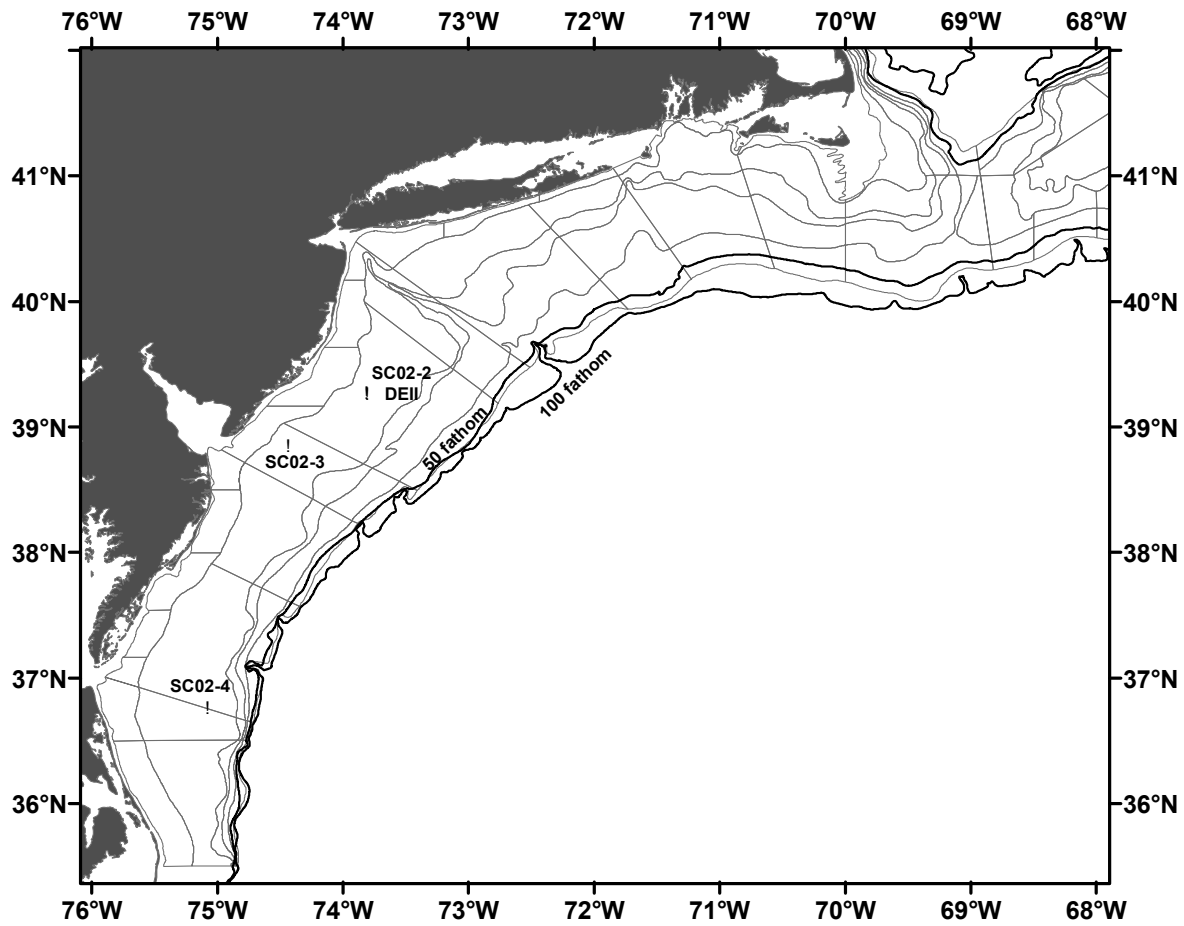


Figure C23. Locations of dredge efficiency experiments with surfclams in 2002.  
 Vessels : R/V Delaware II and F/V Jersey Girl.

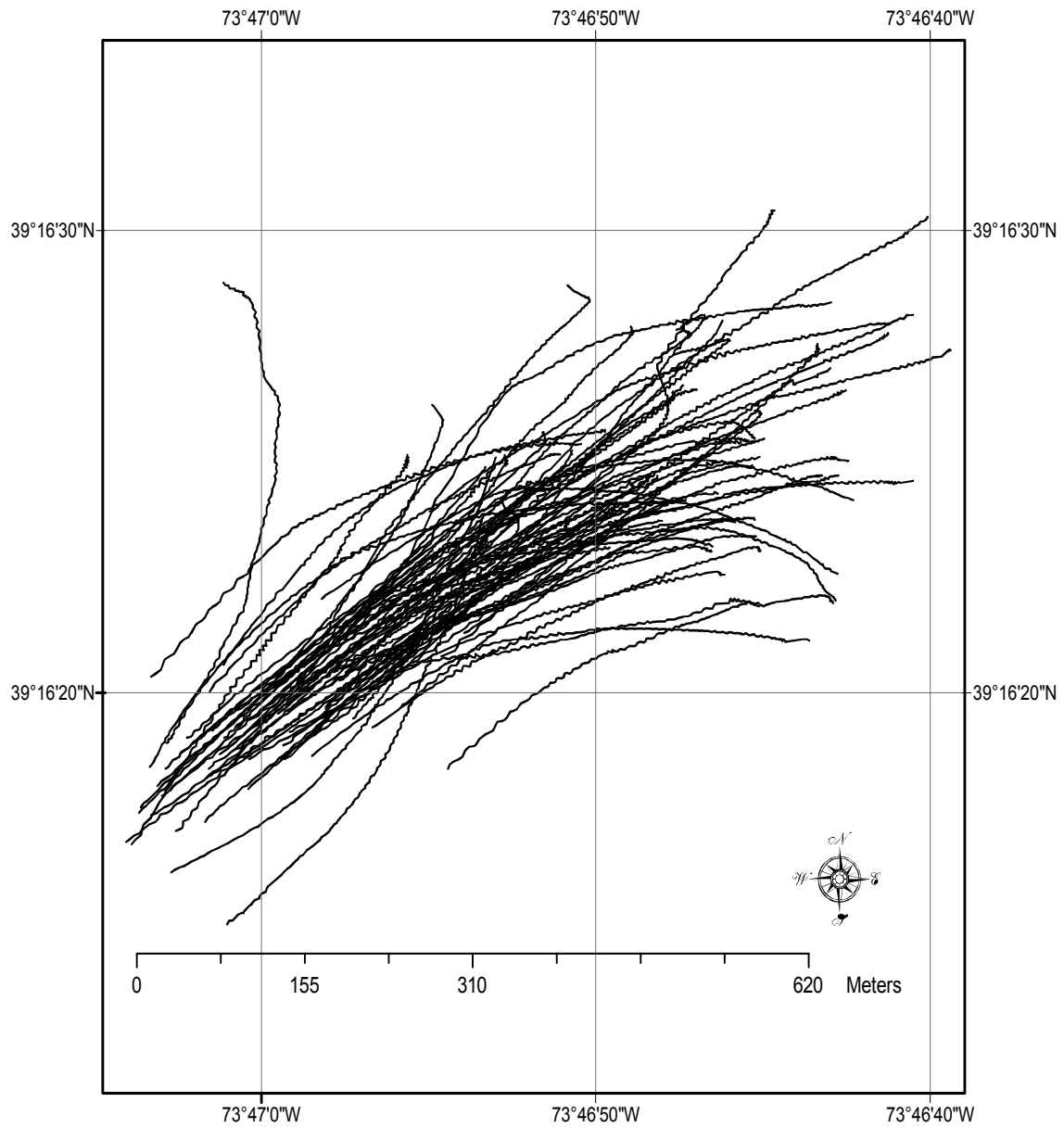


Fig. C24. *R/V Delaware-II* dredge calibration experiment on surfclams off NJ in June, 2002.

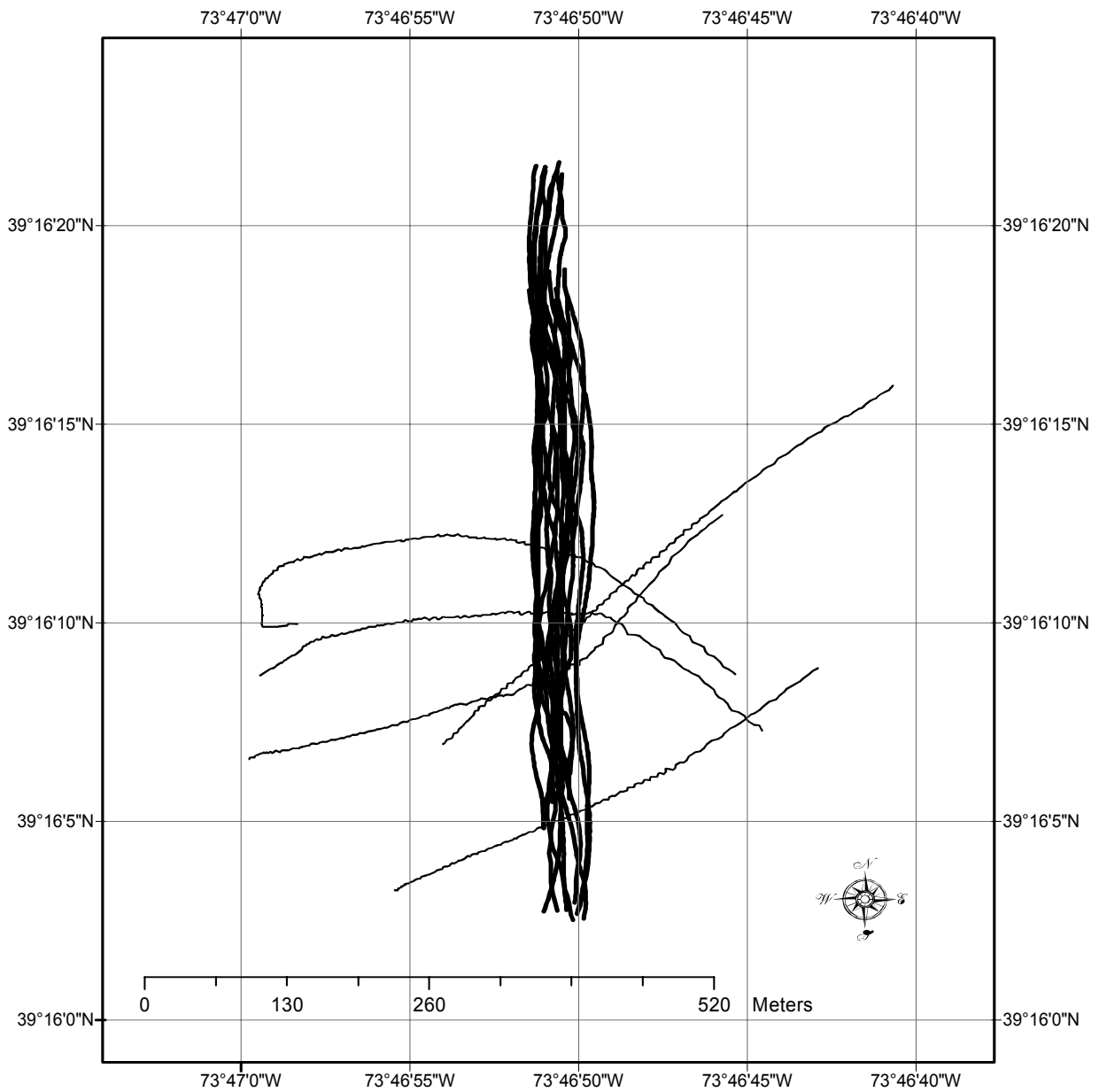


Fig. C25. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Jersey Girl* (darker lines), 2002, off NJ at site: sc02-2.

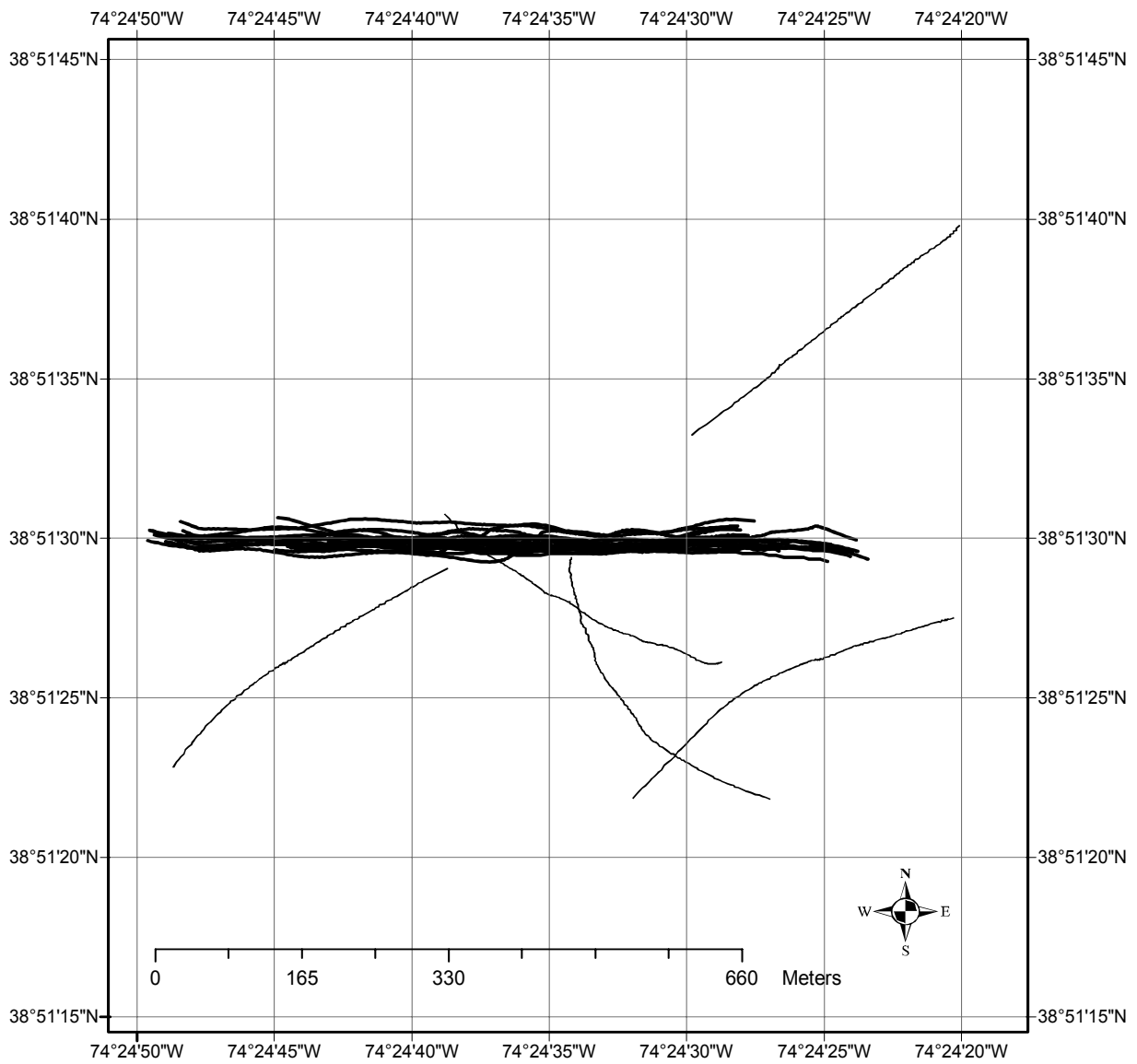


Fig. C26. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Jersey Girl* (darker lines), 2002, off SNJ at site: sc02-3.

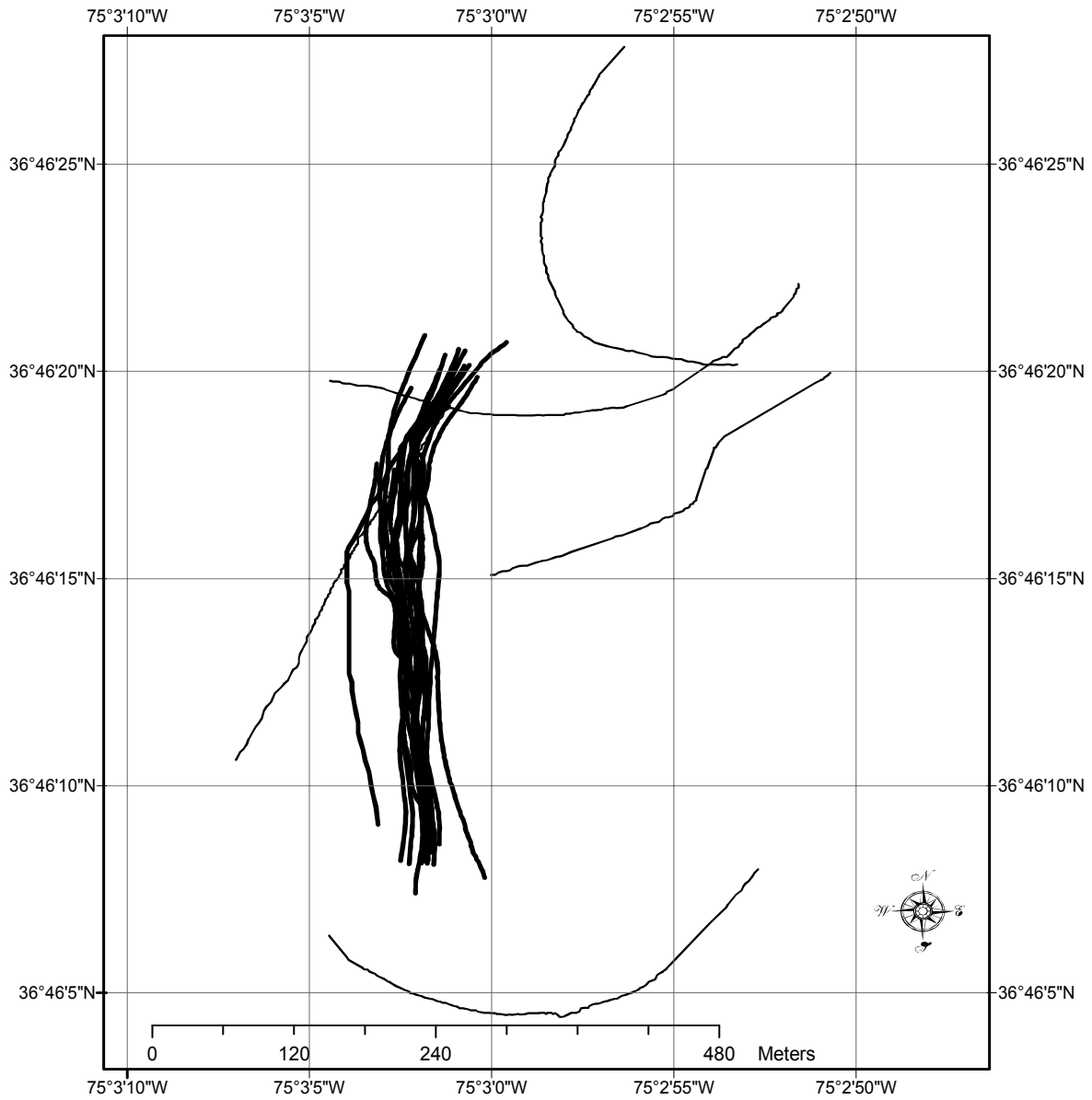
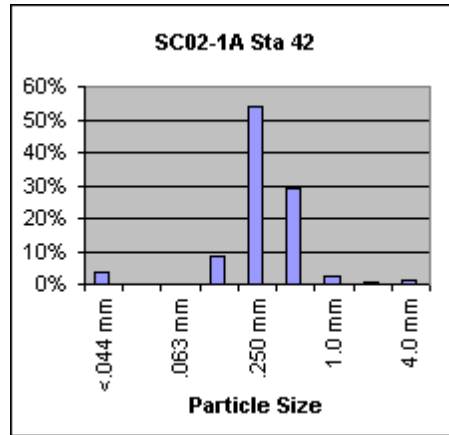
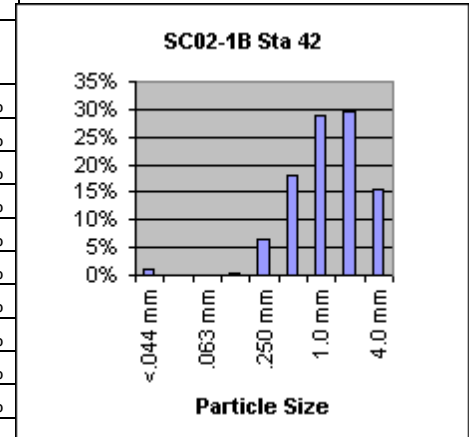


Fig. C27. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Jersey Girl* (darker lines), 2002, off Delmarva at site: sc02-4.

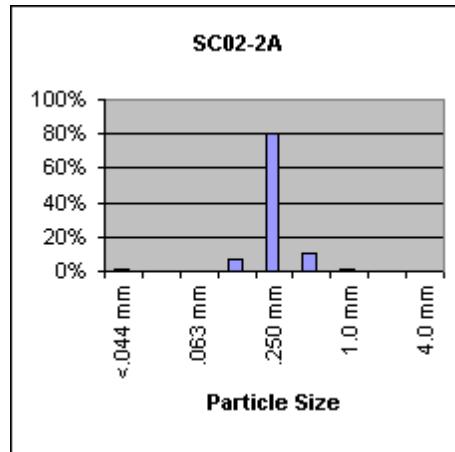
SC02-1A Sta 42		
Particle Size	Mass	Percent
<.044 mm	18.006	3.7%
.044 mm	0.148	0.0%
.063 mm	1.275	0.3%
.125 mm	40.163	8.3%
.250 mm	262.128	54.0%
.500 mm	140.714	29.0%
1.0 mm	10.940	2.3%
2.0 mm	4.341	0.9%
4.0 mm	7.283	1.5%
Total Mass	484.998	100.0%



SC02-1B Sta 42		
Particle Size	Mass	Percent
<.044 mm	4.576	0.9%
.044 mm	0.174	0.0%
.063 mm	0.209	0.0%
.125 mm	2.504	0.5%
.250 mm	31.274	6.4%
.500 mm	87.430	17.9%
1.0 mm	141.734	29.0%
2.0 mm	145.375	29.8%
4.0 mm	75.190	15.4%
Total Mass	488.466	100.0%



SC02-2A		
Particle Size	Mass	Percent
<.044 mm	8.946	1.4%
.044 mm	0.209	0.0%
.063 mm	1.816	0.3%
.125 mm	44.037	6.7%
.250 mm	530.024	80.2%
.500 mm	70.101	10.6%
1.0 mm	4.004	0.6%
2.0 mm	1.611	0.2%
4.0 mm	0.229	0.0%
Total Mass	660.977	100.0%



SC02-2B		
Particle Size	Mass	Percent
<.044 mm	15.037	2.4%
.044 mm	0.171	0.0%
.063 mm	2.495	0.4%
.125 mm	128.341	20.9%
.250 mm	434.518	70.7%
.500 mm	21.290	3.5%
1.0 mm	2.036	0.3%
2.0 mm	0.698	0.1%
4.0 mm	10.294	1.7%
Total Mass	614.880	100.0%

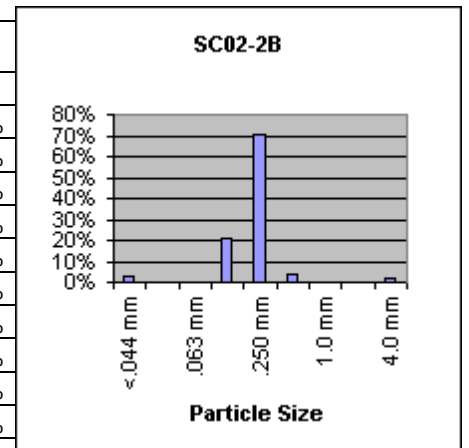
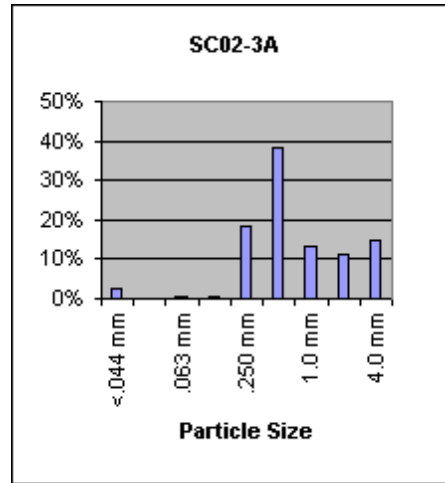


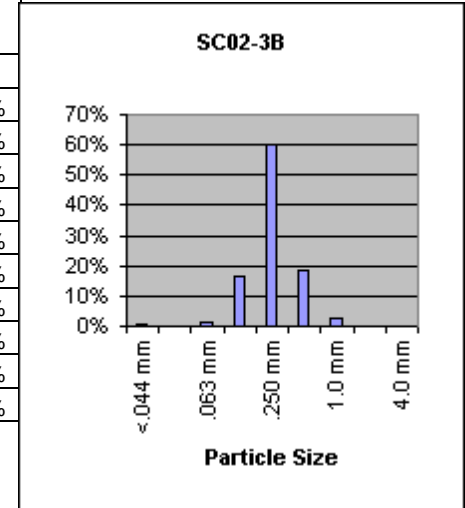
Fig. C28. (1 of 3)

**Figure C28. (2 of 3)**

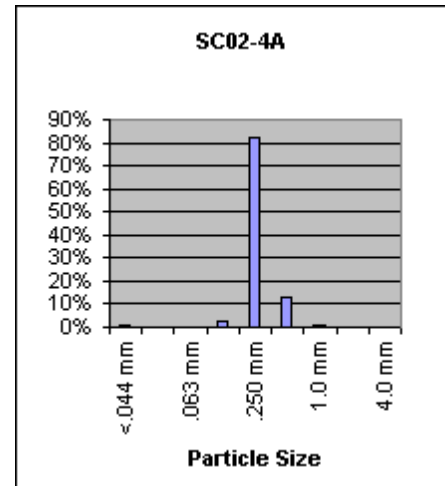
SC02-3A		
Particle Size	Mass	Percent
<.044 mm	14.598	2.8%
.044 mm	0.201	0.0%
.063 mm	2.909	0.6%
.125 mm	2.999	0.6%
.250 mm	97.978	18.6%
.500 mm	200.921	38.2%
1.0 mm	69.133	13.1%
2.0 mm	59.626	11.3%
4.0 mm	77.995	14.8%
Total Mass	526.360	100.0%



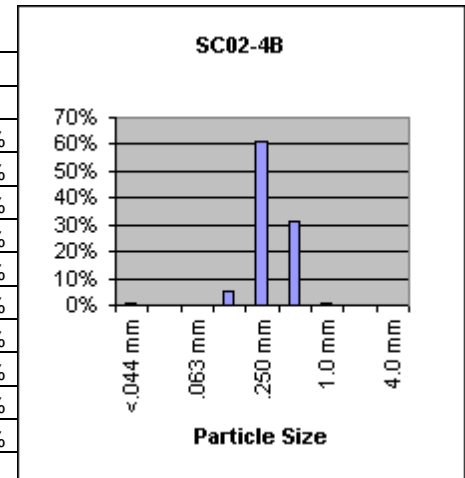
SC02-3B		
Particle Size	Mass	Percent
<.044 mm	3.377	0.6%
.044 mm	0.239	0.0%
.063 mm	6.529	1.1%
.125 mm	92.925	16.4%
.250 mm	342.799	60.4%
.500 mm	105.890	18.6%
1.0 mm	13.707	2.4%
2.0 mm	1.568	0.3%
4.0 mm	0.937	0.2%
Total Mass	567.971	100.0%



SC02-4A		
Particle Size	Mass	Percent
<.044 mm	6.310	1.2%
.044 mm	0.203	0.0%
.063 mm	0.572	0.1%
.125 mm	14.138	2.7%
.250 mm	429.034	81.9%
.500 mm	67.660	12.9%
1.0 mm	2.962	0.6%
2.0 mm	1.149	0.2%
4.0 mm	1.653	0.3%
Total Mass	523.681	100%

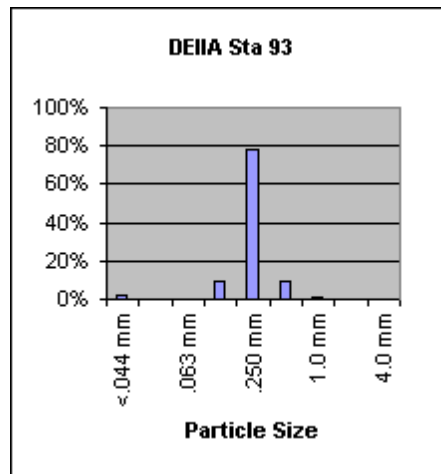


SC02-4B		
Particle Size	Mass	Percent
<.044 mm	3.273	0.8%
.044 mm	0.059	0.0%
.063 mm	0.580	0.1%
.125 mm	22.292	5.2%
.250 mm	263.903	61.4%
.500 mm	135.534	31.5%
1.0 mm	2.354	0.5%
2.0 mm	0.815	0.2%
4.0 mm	1.233	0.3%
Total Mass	430.043	100.0%





<b>DE-IIA Sta 93</b>		
Particle Size	Mass	Percent
<.044 mm	11.636	1.9%
.044 mm	0.368	0.1%
.063 mm	1.684	0.3%
.125 mm	53.740	8.9%
.250 mm	469.458	78.1%
.500 mm	54.801	9.1%
1.0 mm	5.605	0.9%
2.0 mm	2.127	0.4%
4.0 mm	1.483	0.2%
Total Mass	600.902	100.0%



<b>DE-IIB Sta 93</b>		
Particle Size	Mass	Percent
<.044 mm	1.522	0.3%
.044 mm	0.054	0.0%
.063 mm	1.285	0.3%
.125 mm	51.258	11.5%
.250 mm	360.867	80.8%
.500 mm	24.147	5.4%
1.0 mm	1.329	0.3%
2.0 mm	0.322	0.1%
4.0 mm	5.892	1.3%
Total Mass	446.676	100.0%

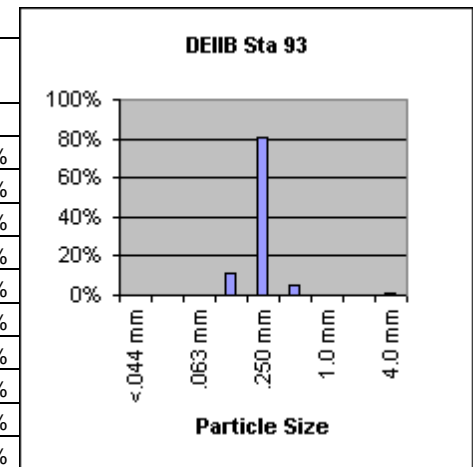
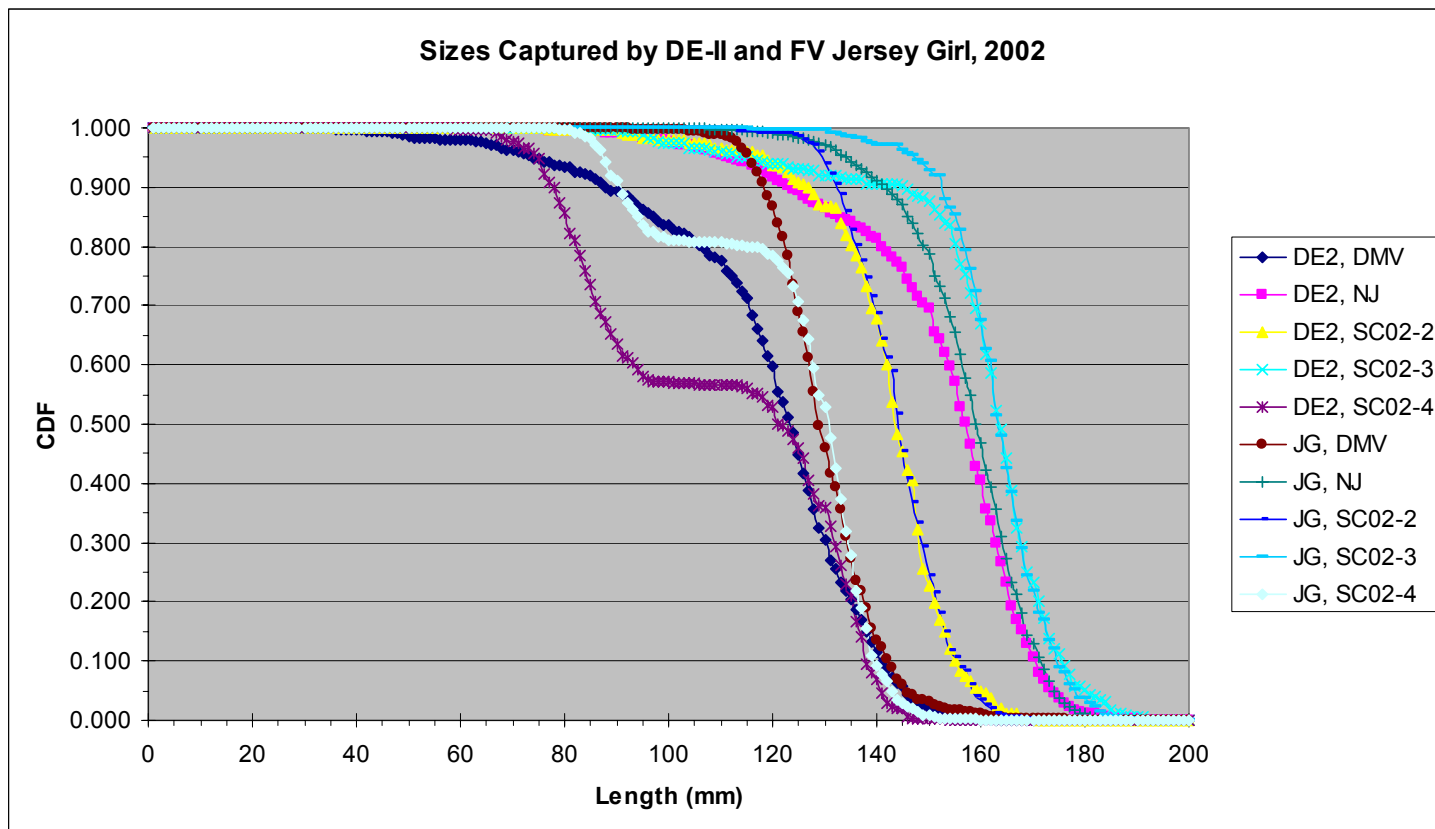


Figure C28 (3 of 3).

Figure C29. Sizes of surfclams captured at several locations by the RV Delaware II and FV Jersey Girl, summer of 2002.



**NJ- Repeats**

model:  $S(L) = 1/(1+\exp(\alpha+\beta * L))$

alpha	beta	L50%ile
10.442	-0.084	124.3

**FV Jersey Girl Relative to RV Delaware-II, Surfclams, Summer 2002**

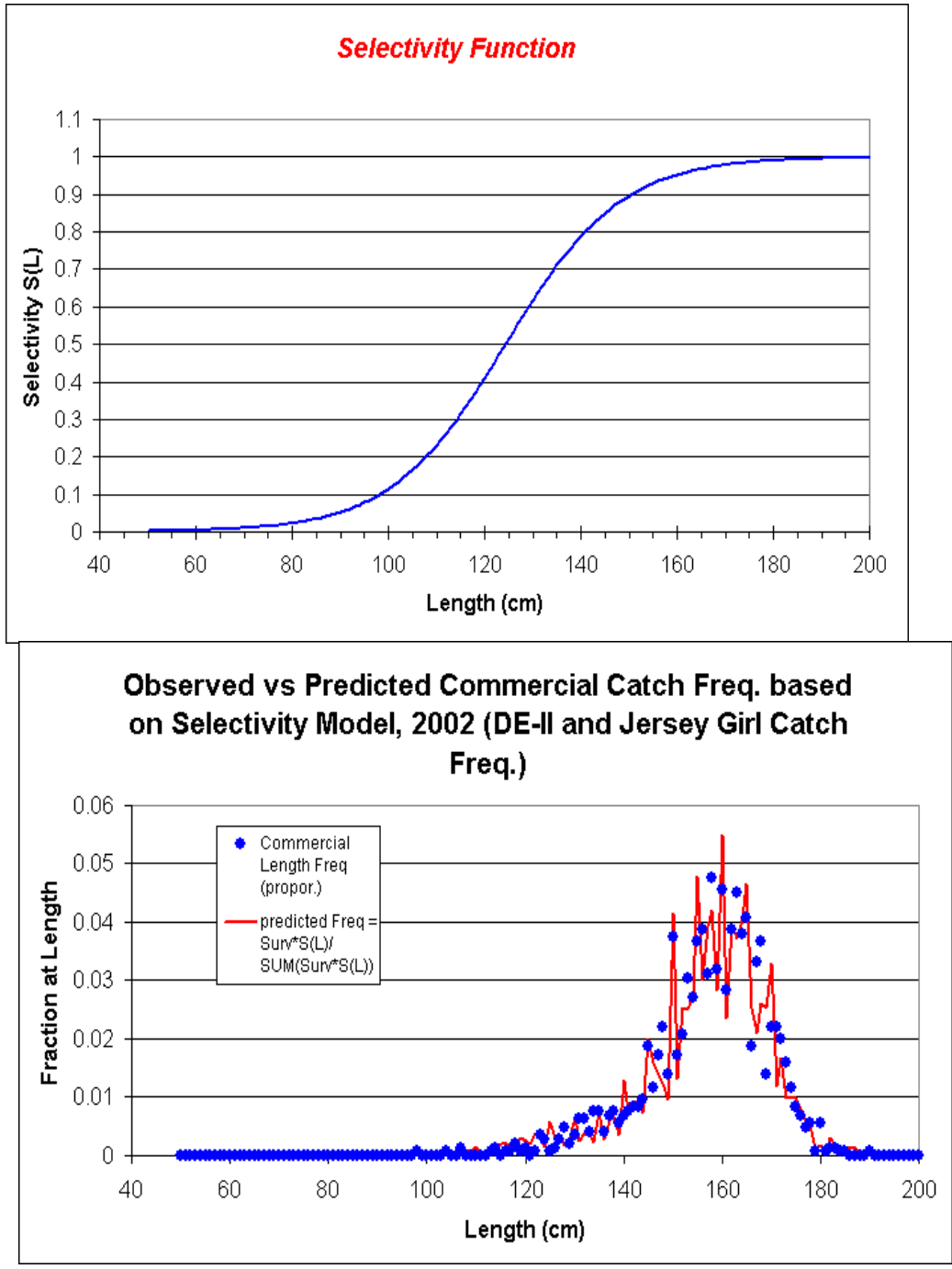


Figure C30. Example of program used to estimate relative selectivity of surfclam lengths between vessels. Data shown are from 9 “repeat” stations off New Jersey, 2002.

Figure C31. Likelihood profile analysis and asymptotic confidence intervals for dredge efficiency and initial density of surfclam in the DE02 depletion study (no indirect effects assumed, 130+ mm).

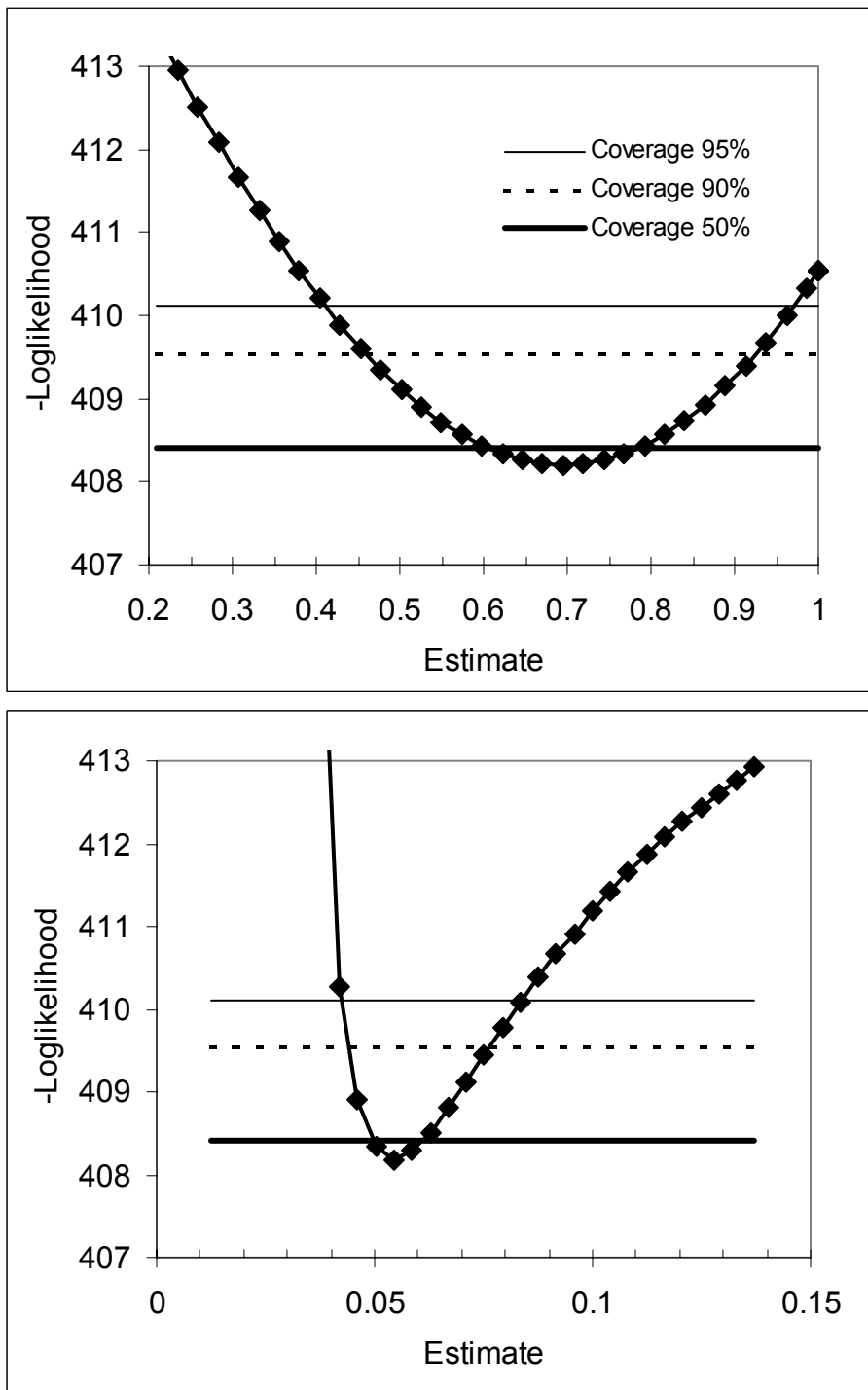


Figure C32. Likelihood profile analysis and asymptotic confidence intervals for dredge efficiency and initial density of surfclam in the JG02 depletion study (no indirect effects assumed, all sizes).

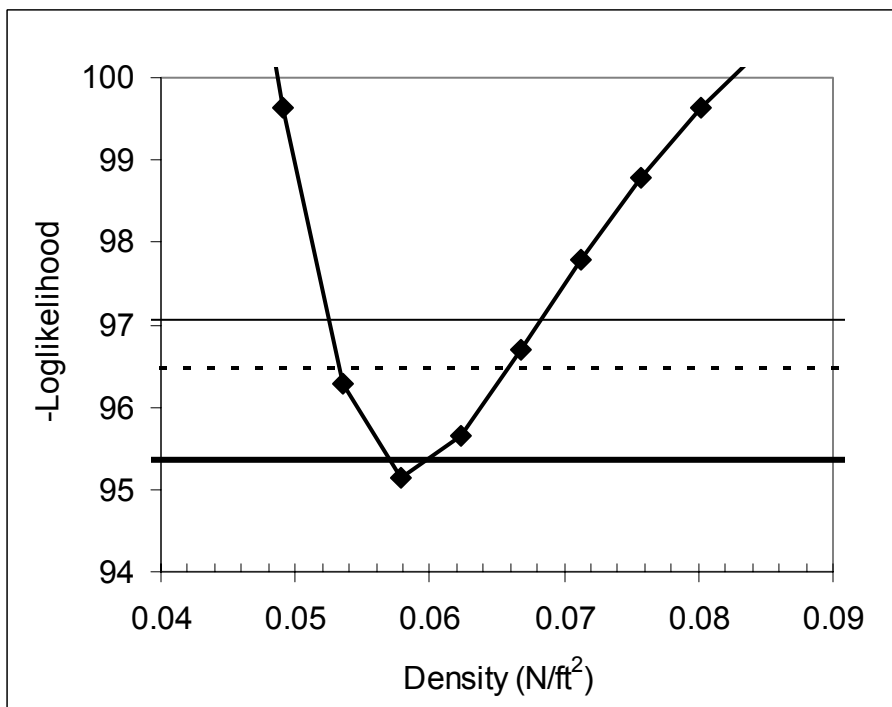
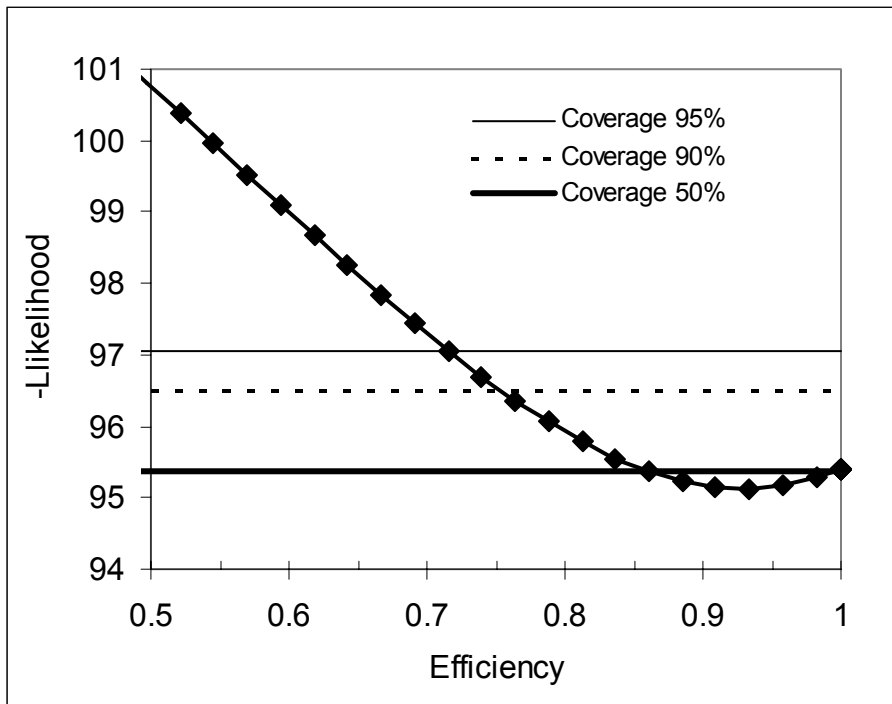


Figure C33. Likelihood profile analysis and asymptotic confidence intervals for dredge efficiency and initial density of surfclam in the JG03 depletion study (no indirect effects assumed, 130+ mm).

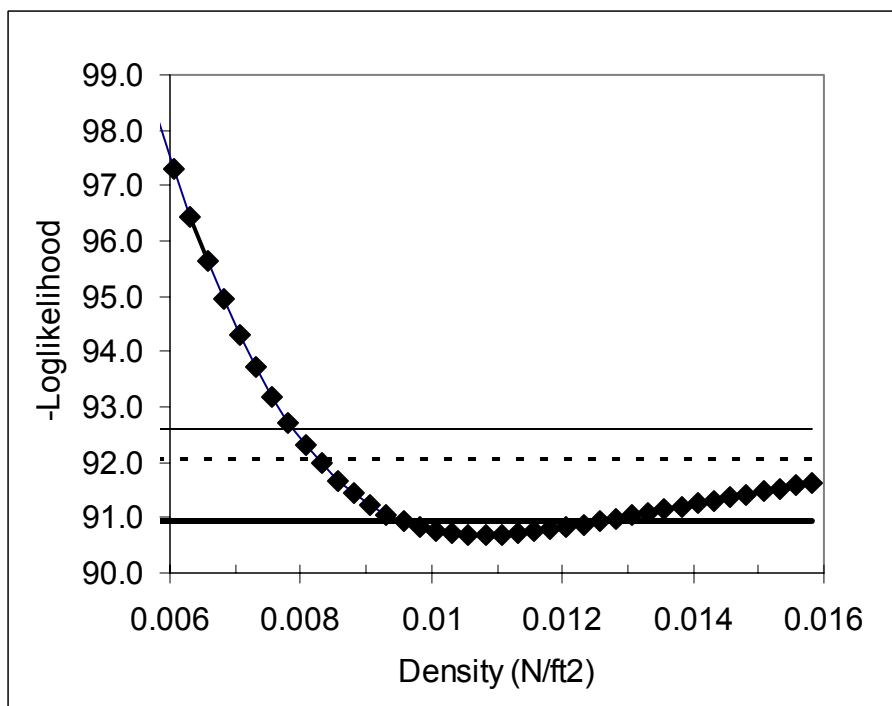
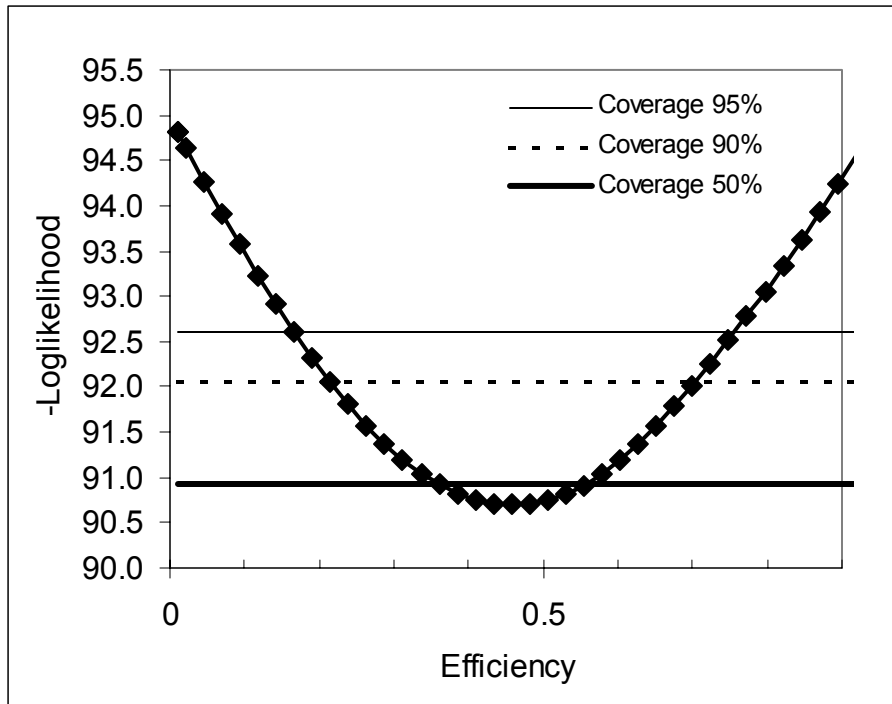
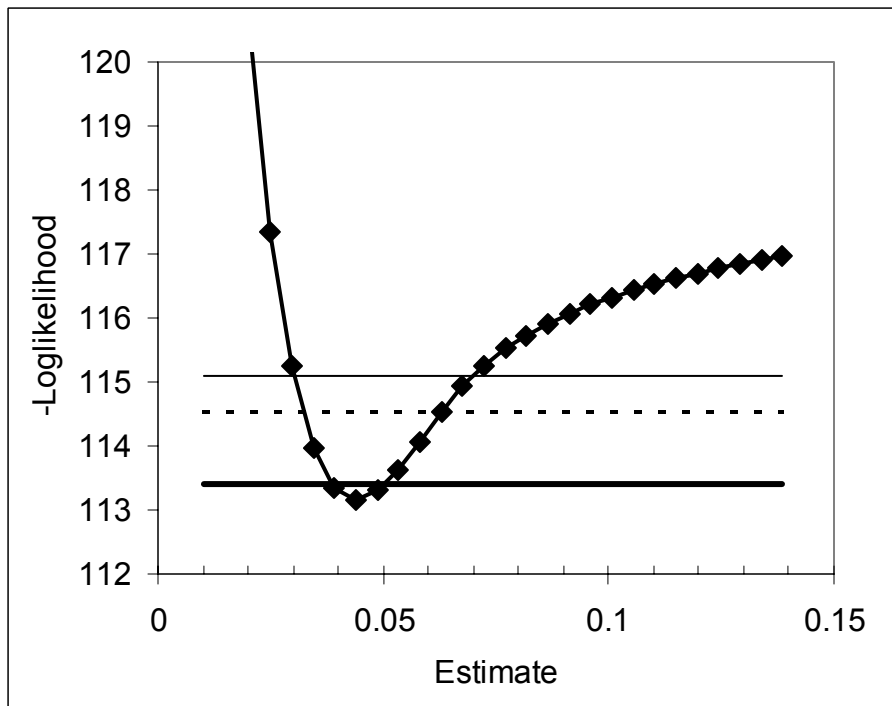
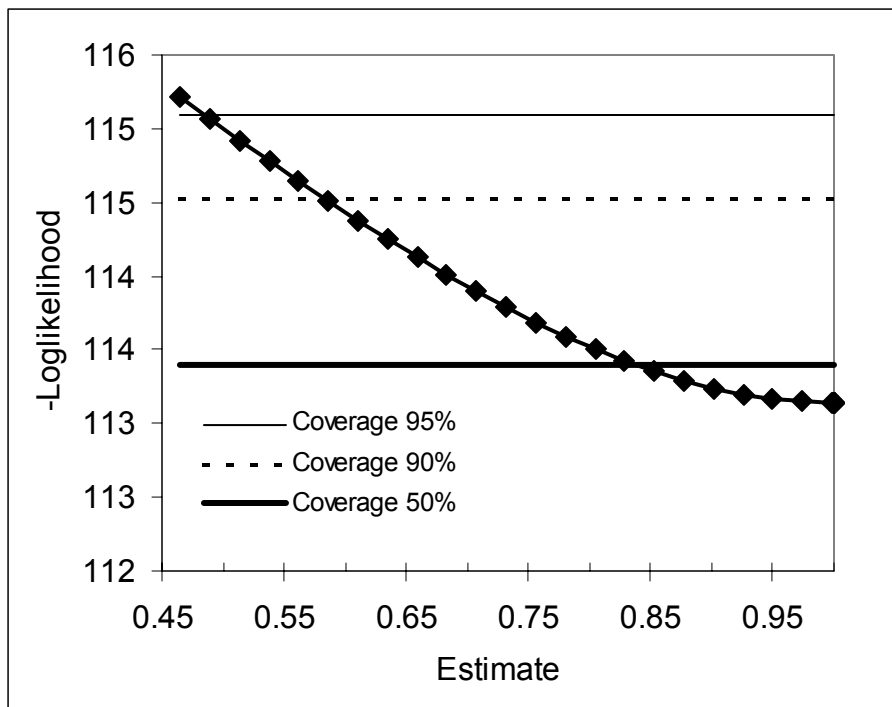


Figure C34. Likelihood profile analysis and asymptotic confidence intervals for dredge efficiency and initial density of surfclam in the JG04 depletion study (no indirect effects assumed, 130+ mm).



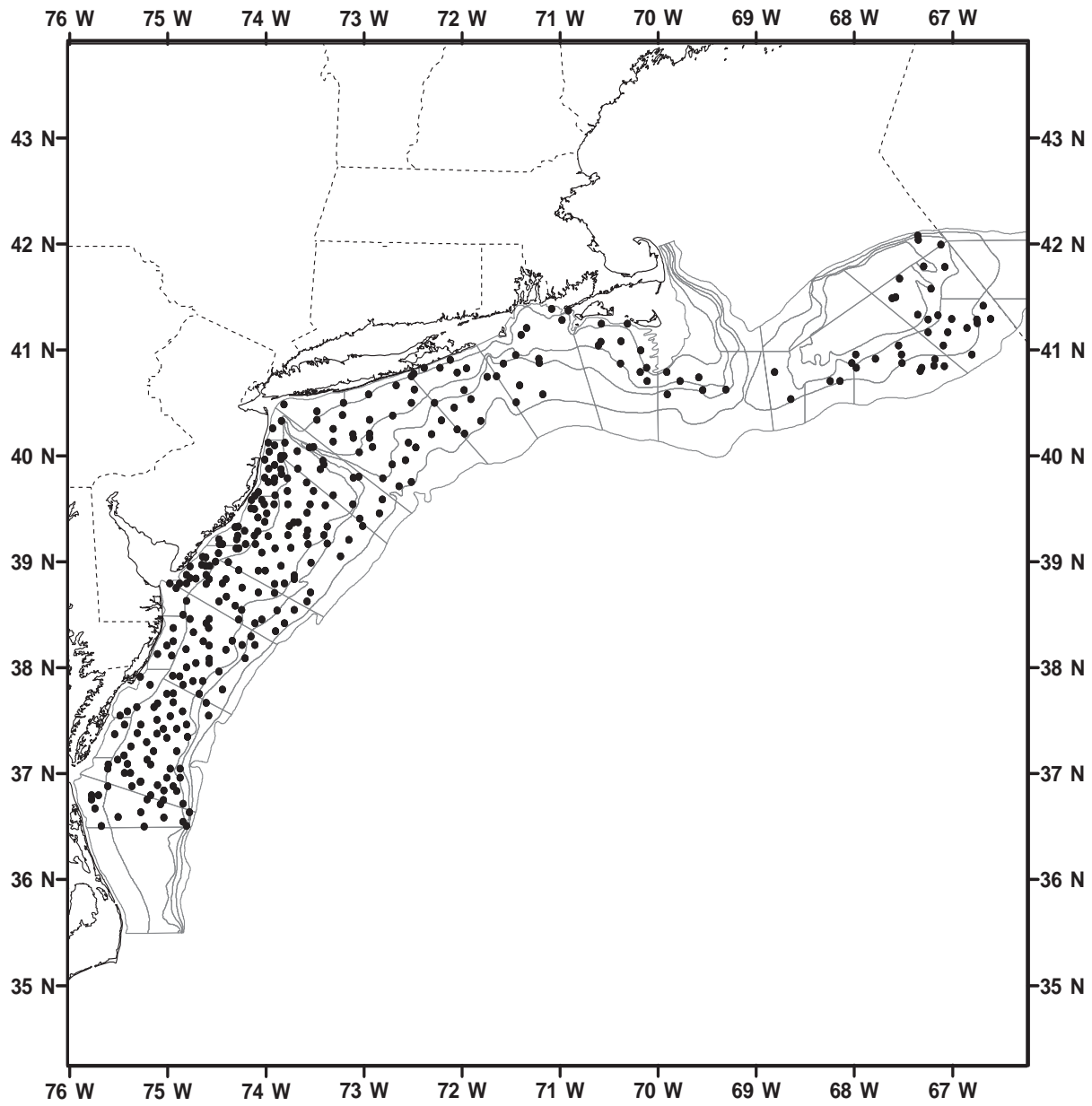


Figure C35.  
Station locations from the 2002 NEFSC surfclam/ocean quahog survey.



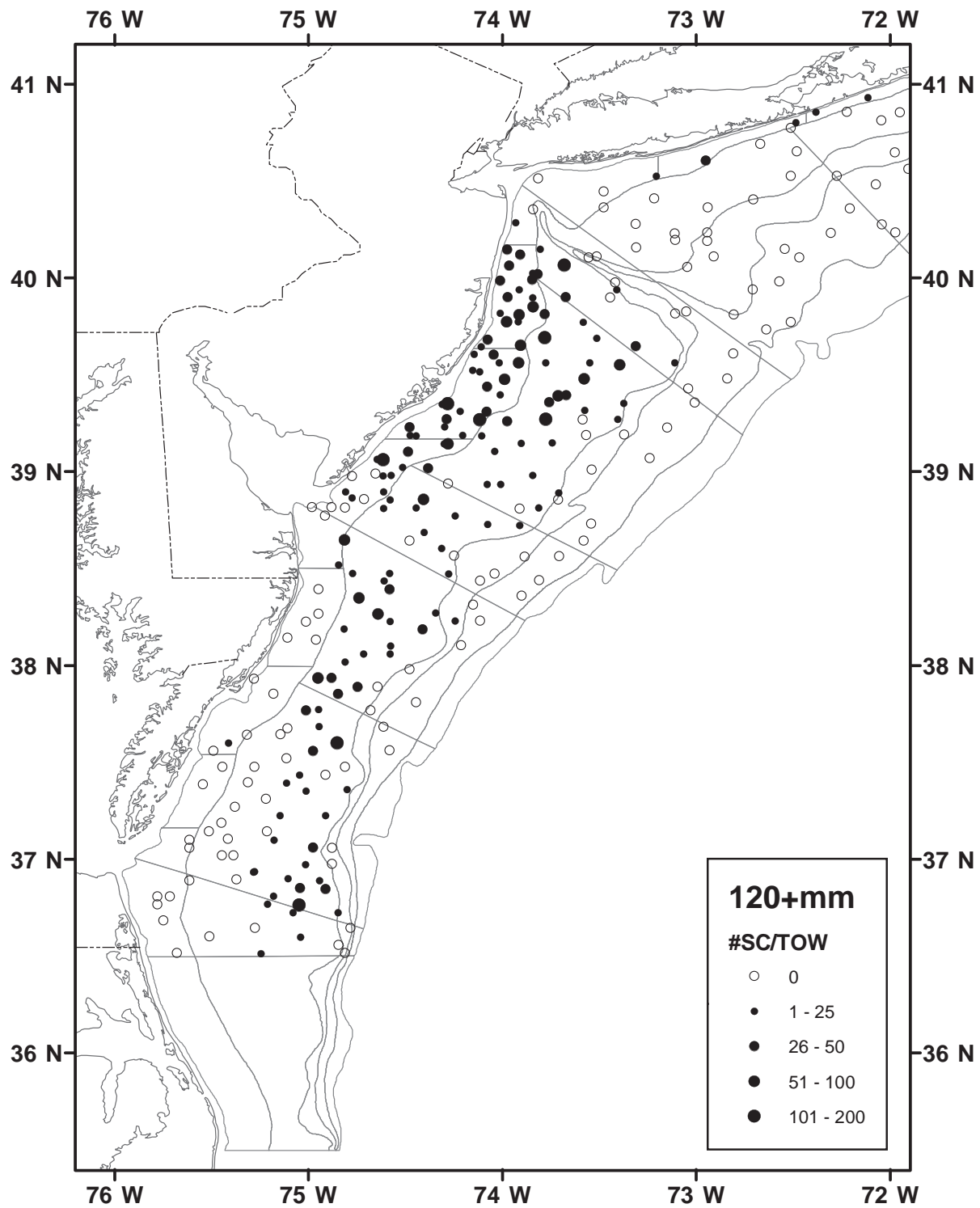


Figure C36.  
 Surfclam abundance per tow ( $\geq 120\text{mm}$ ) adjusted to 0.15 n. mi. tow distance with SSP sensor data, 2002 survey.

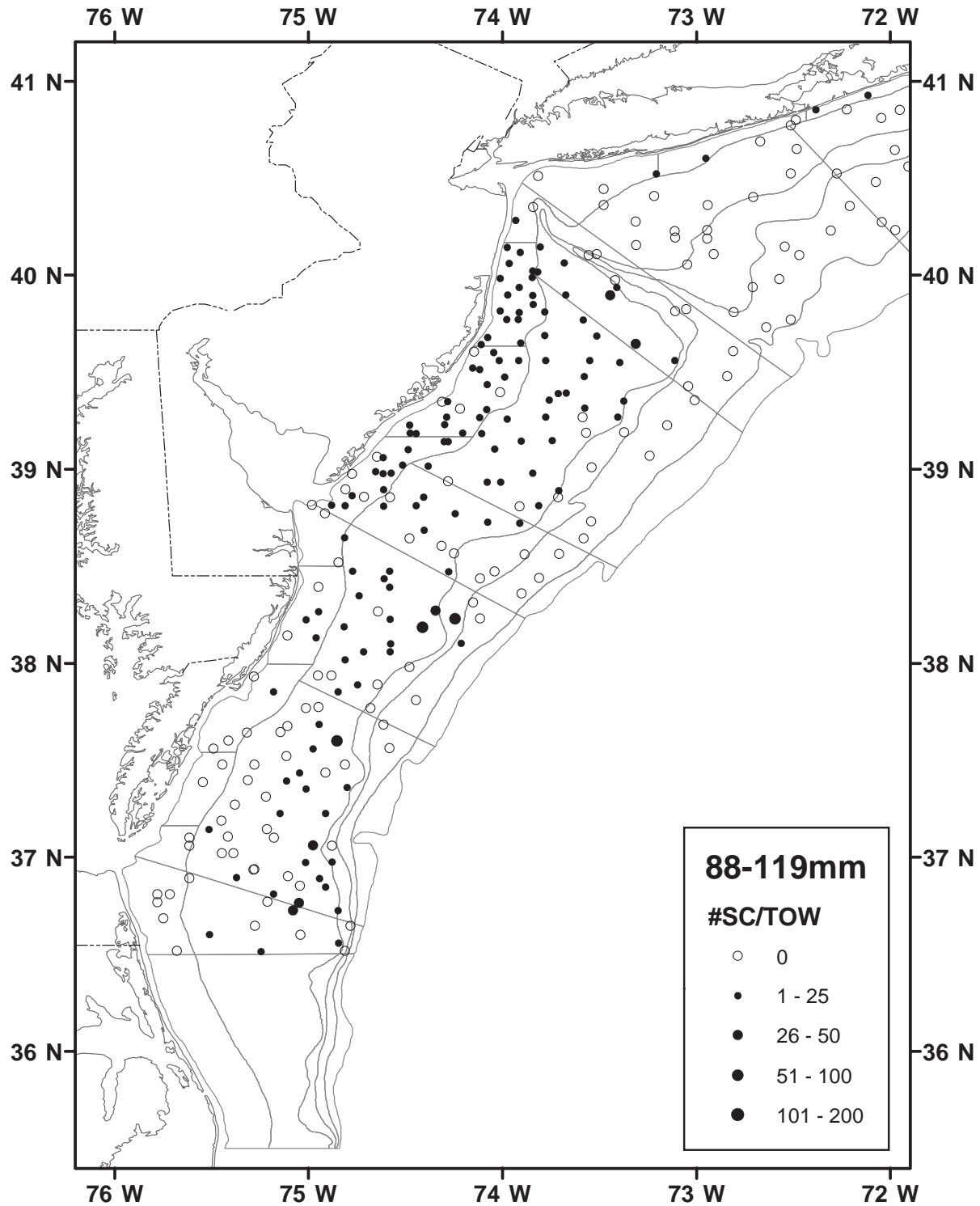


Figure C37.  
 Surfclam abundance per tow (88-119mm) adjusted to 0.15 n. mi. tow distance with  
 SSP sensor data, 2002 survey.

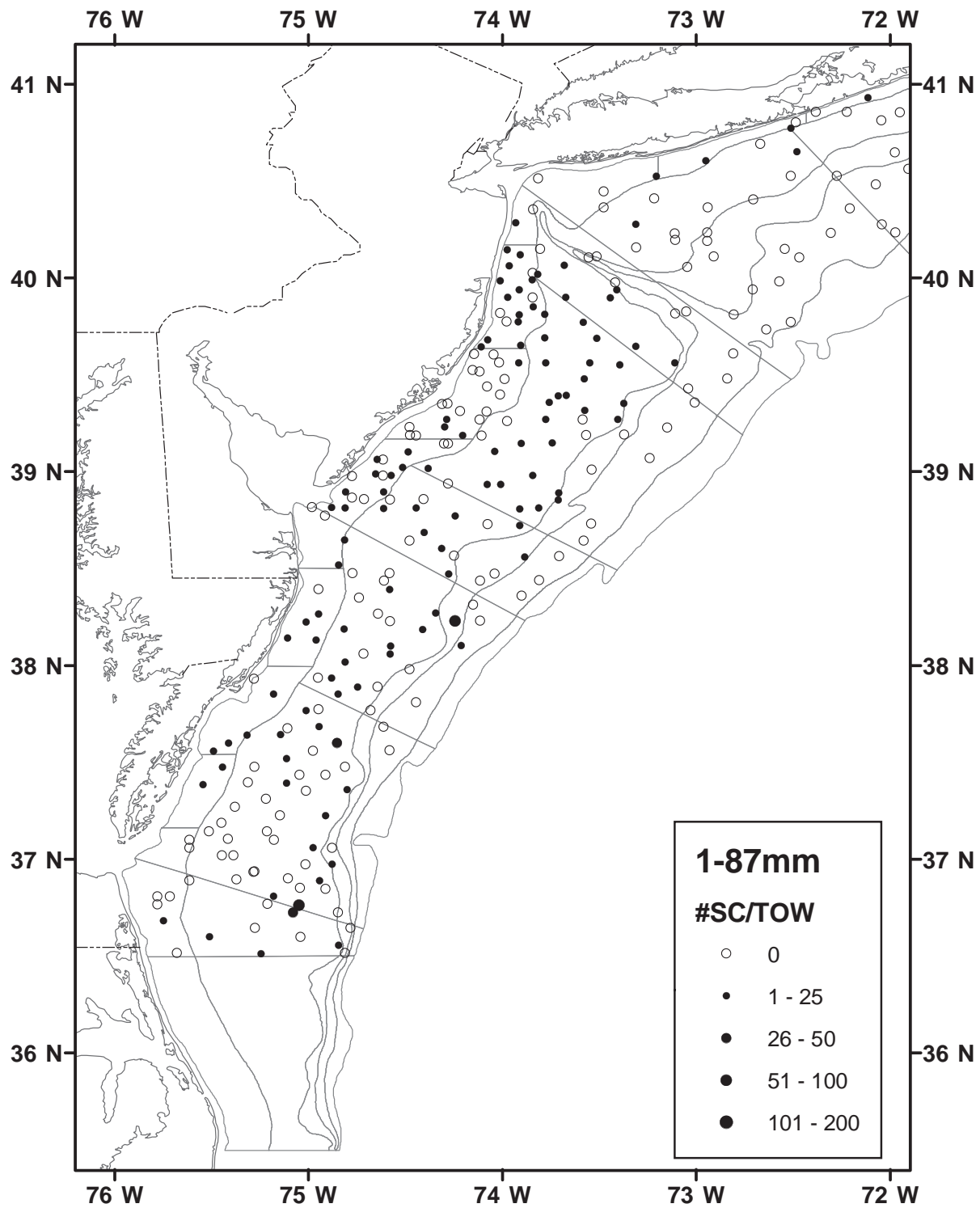


Figure C38.  
Surfclam abundance per tow (1-87mm) adjusted to 0.15 n. mi. tow distance with SSP sensor data, 2002 survey.

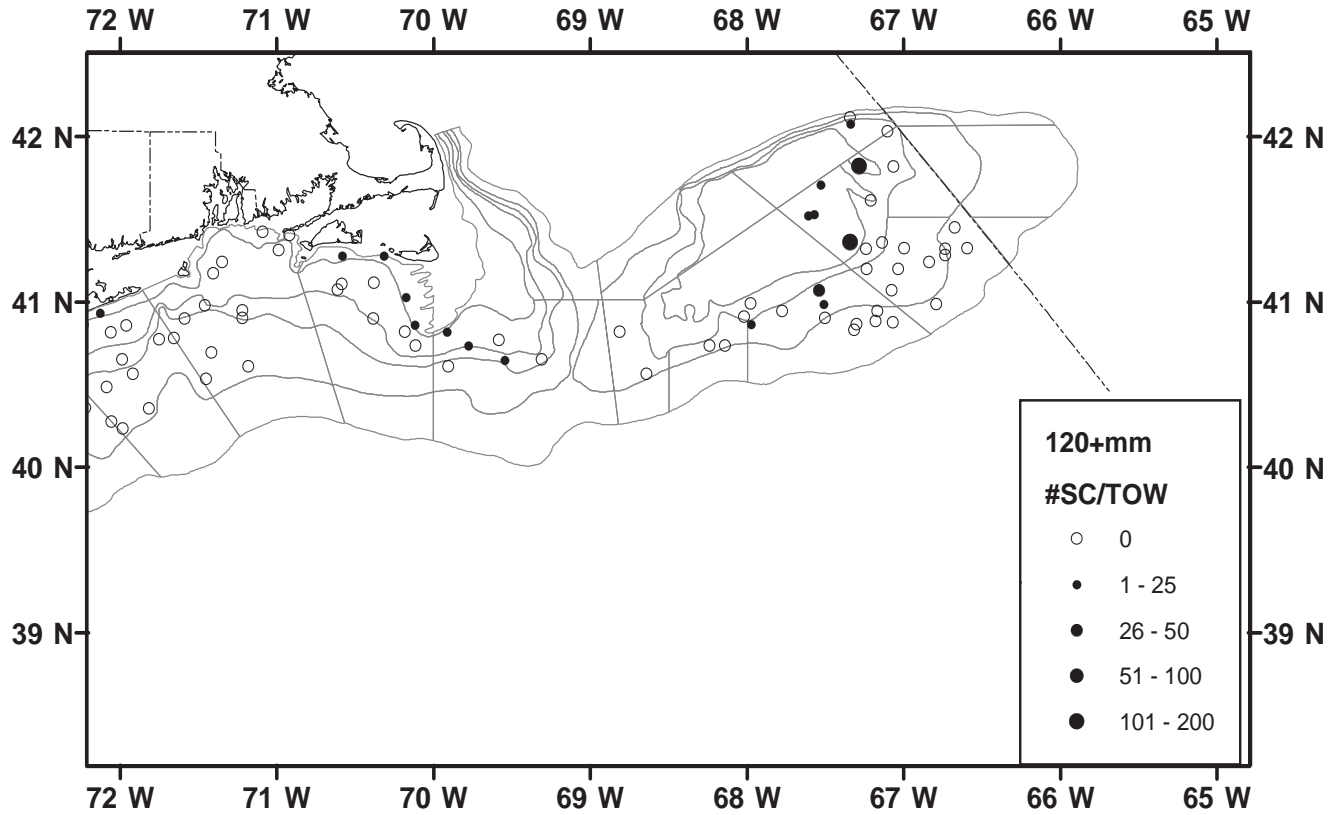


Figure C39.  
 Surfclam abundance per tow ( $\geq 120\text{mm}$ ) adjusted to 0.15 n. mi. tow distance with  
 SSP sensor data, 2002 survey.

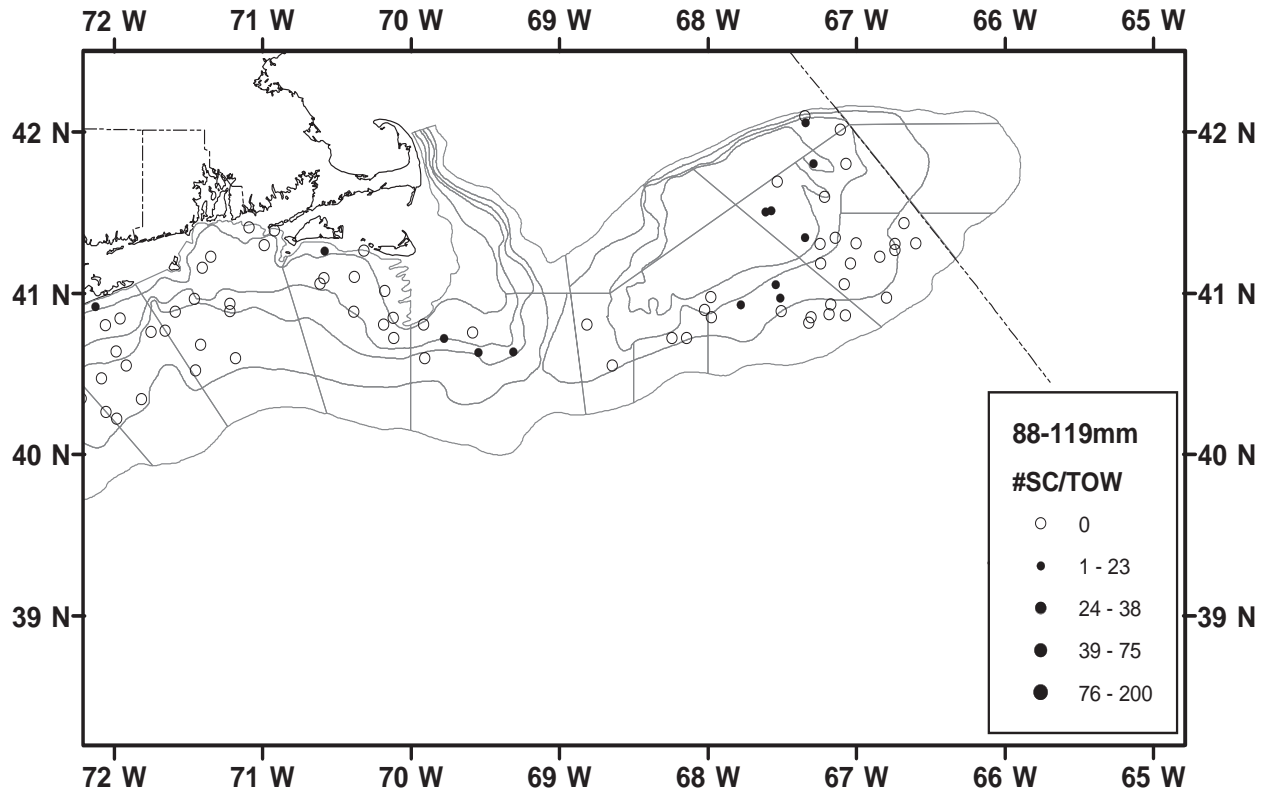


Figure C40.  
 Surfclam abundance per tow (88-119 mm) adjusted to 0.15 n. mi. tow distance with  
 SSP sensor data, 2002 survey.

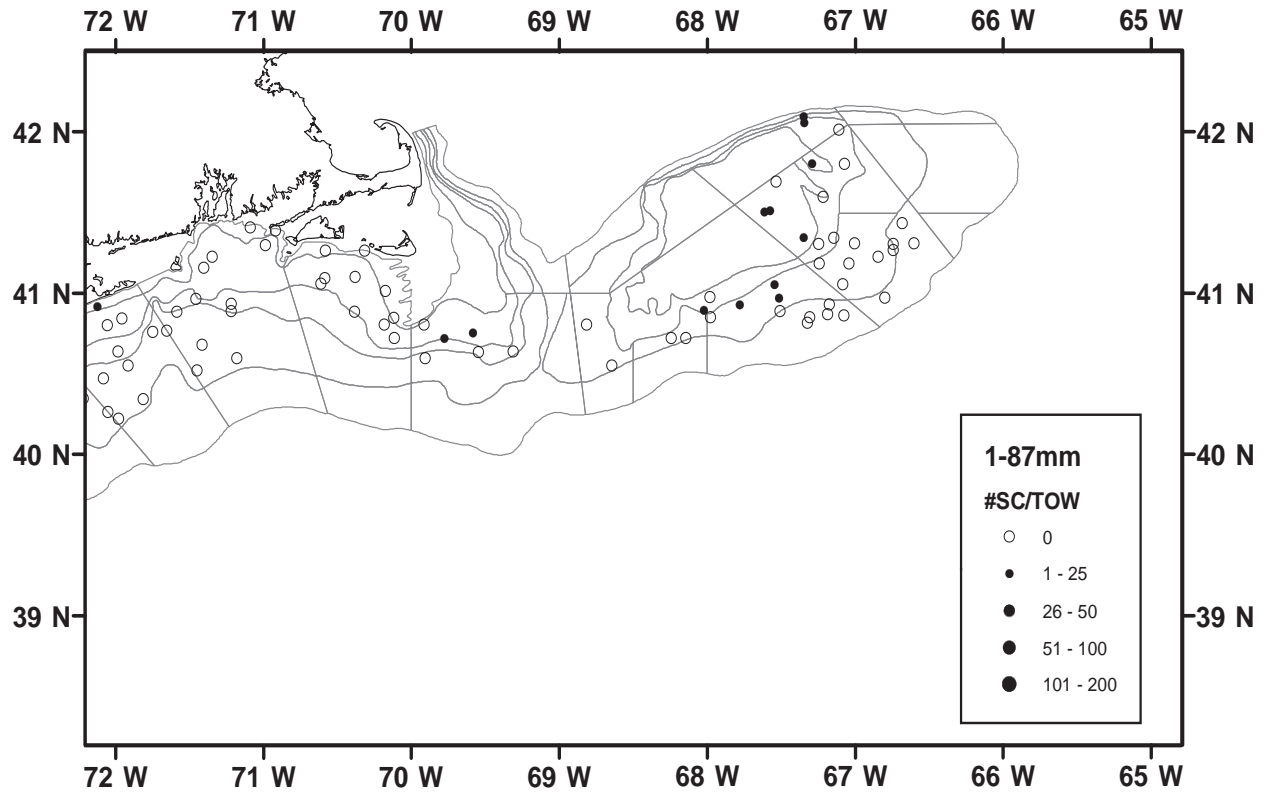


Figure C41.

Surfclam abundance per tow (1-87 mm) adjusted to 0.15 n. mi. tow distance with SSP sensor data, 2002 survey.

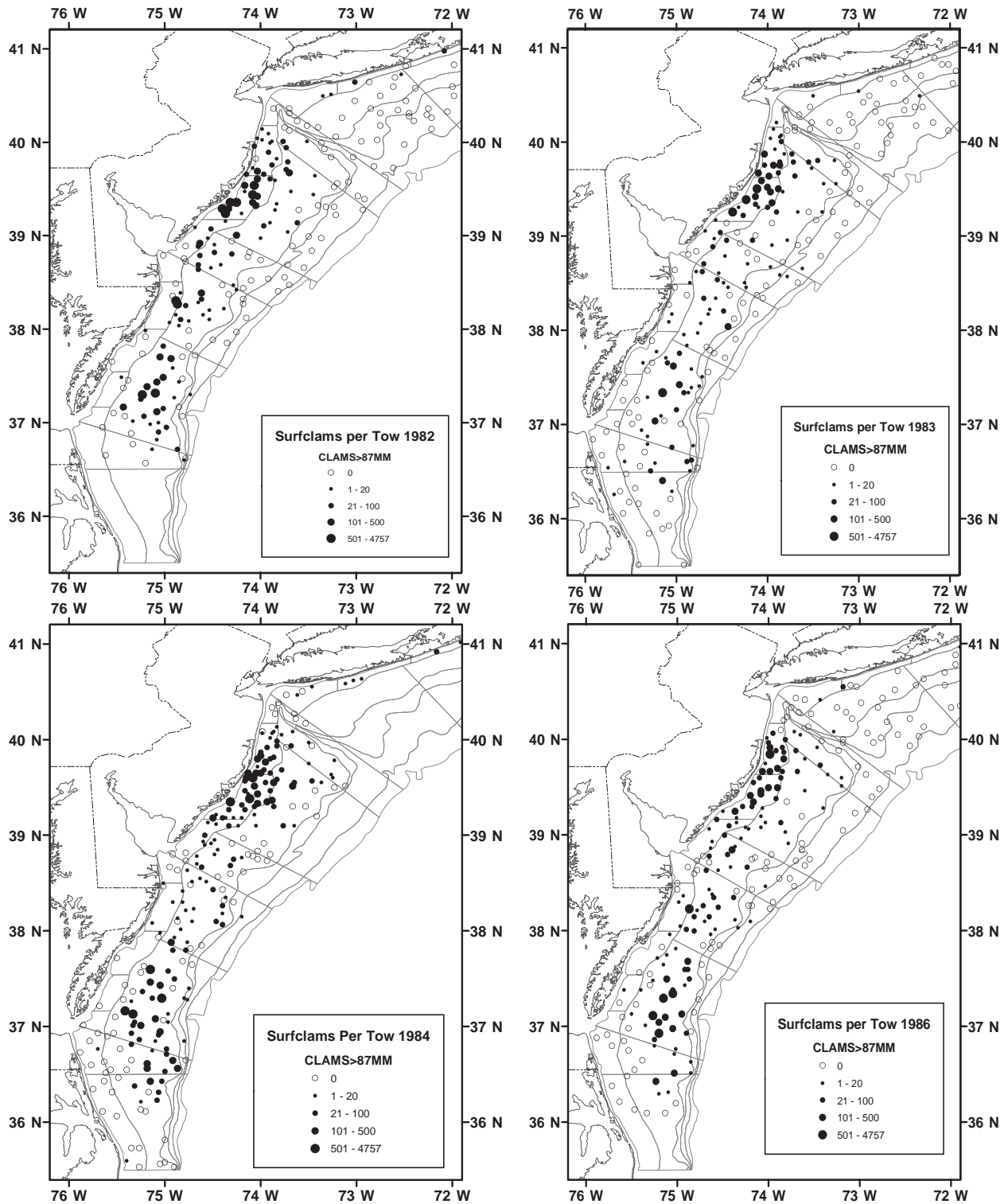


Figure C42.  
 Number of surfclams (88mm+), by station, in NMFS clam surveys, 1982-1986. Catch was not adjusted for distance. Only includes random stations without gear problems.

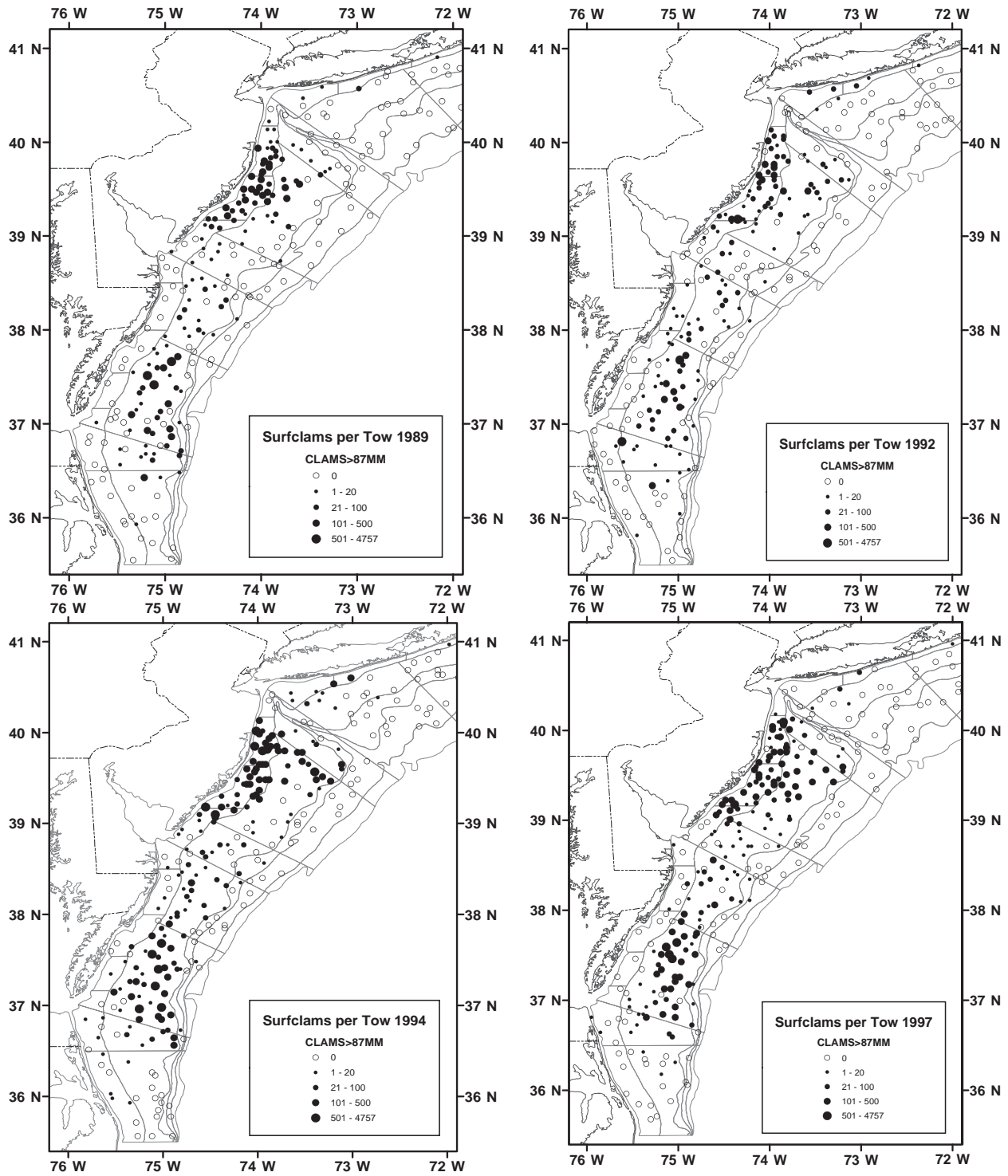


Figure C43.  
 Number of surfclams (88mm+), by station, in NMFS clam surveys, 1989-1997. Catch was not adjusted for distance. Only includes random stations without gear problems.



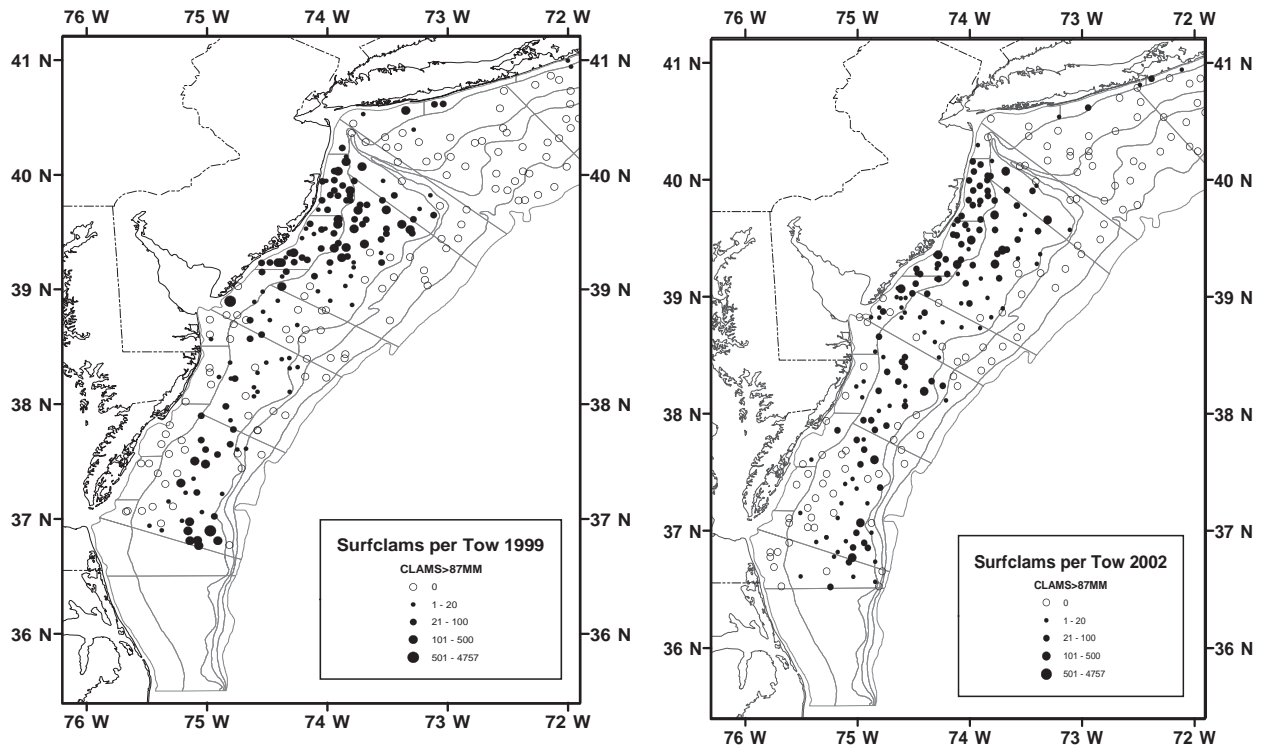


Figure C44.  
 Number of surfclams (88mm+), by station, in NMFS clam surveys, 1999-2002. Catch was not adjusted for distance. Only includes random stations without gear problems.

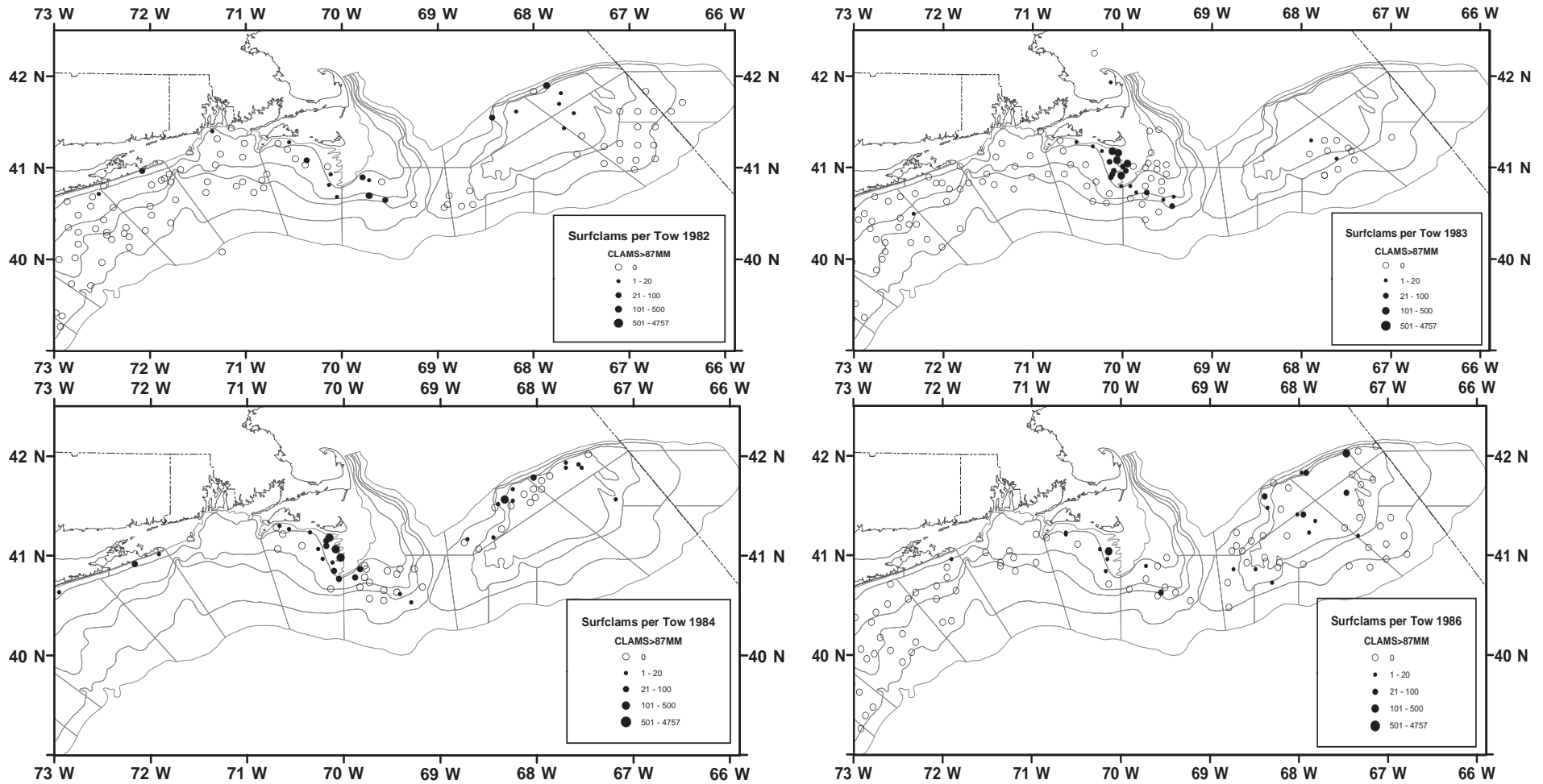


Figure C45.  
 Number of surfclams (88mm+), by station, in NMFS clam surveys, 1982-1986. Catch was not adjusted for distance. Only includes random stations without gear problems.

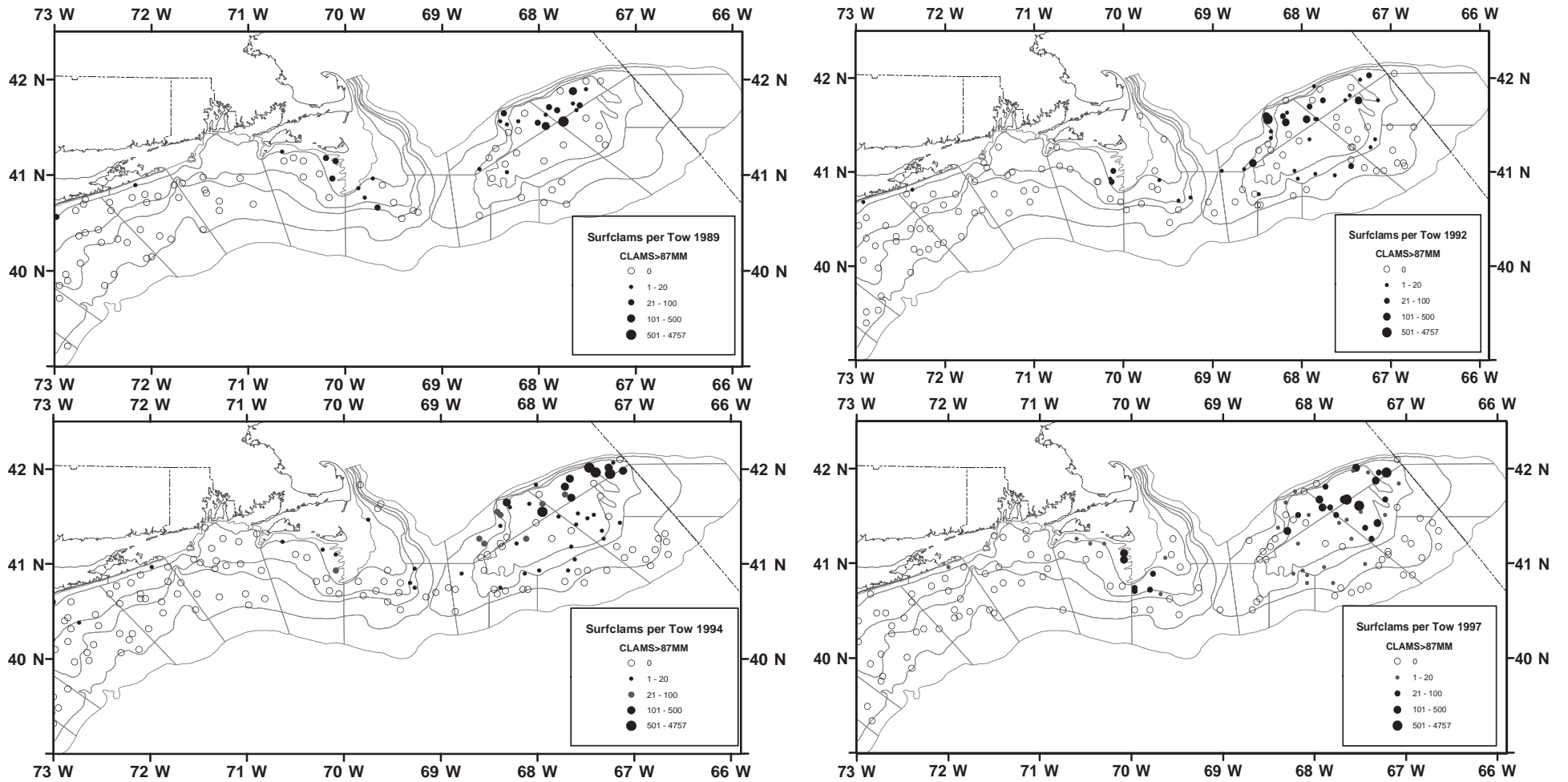


Figure C46.  
 Number of surfclams (88mm+), by station, in NMFS clam surveys, 1989-1997. Catch was not adjusted for distance. Only includes random stations without gear problems.

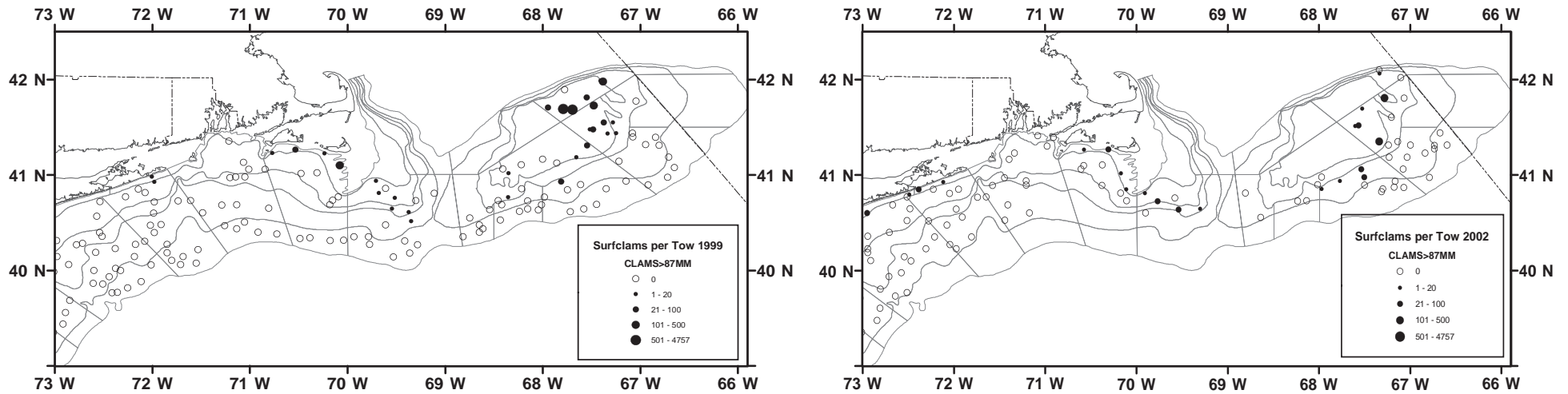


Figure C47.

Number of surfclams (88mm+), by station, in NMFS clam surveys, 1999-2002. Catch was not adjusted for distance. Only includes random stations without gear problems.

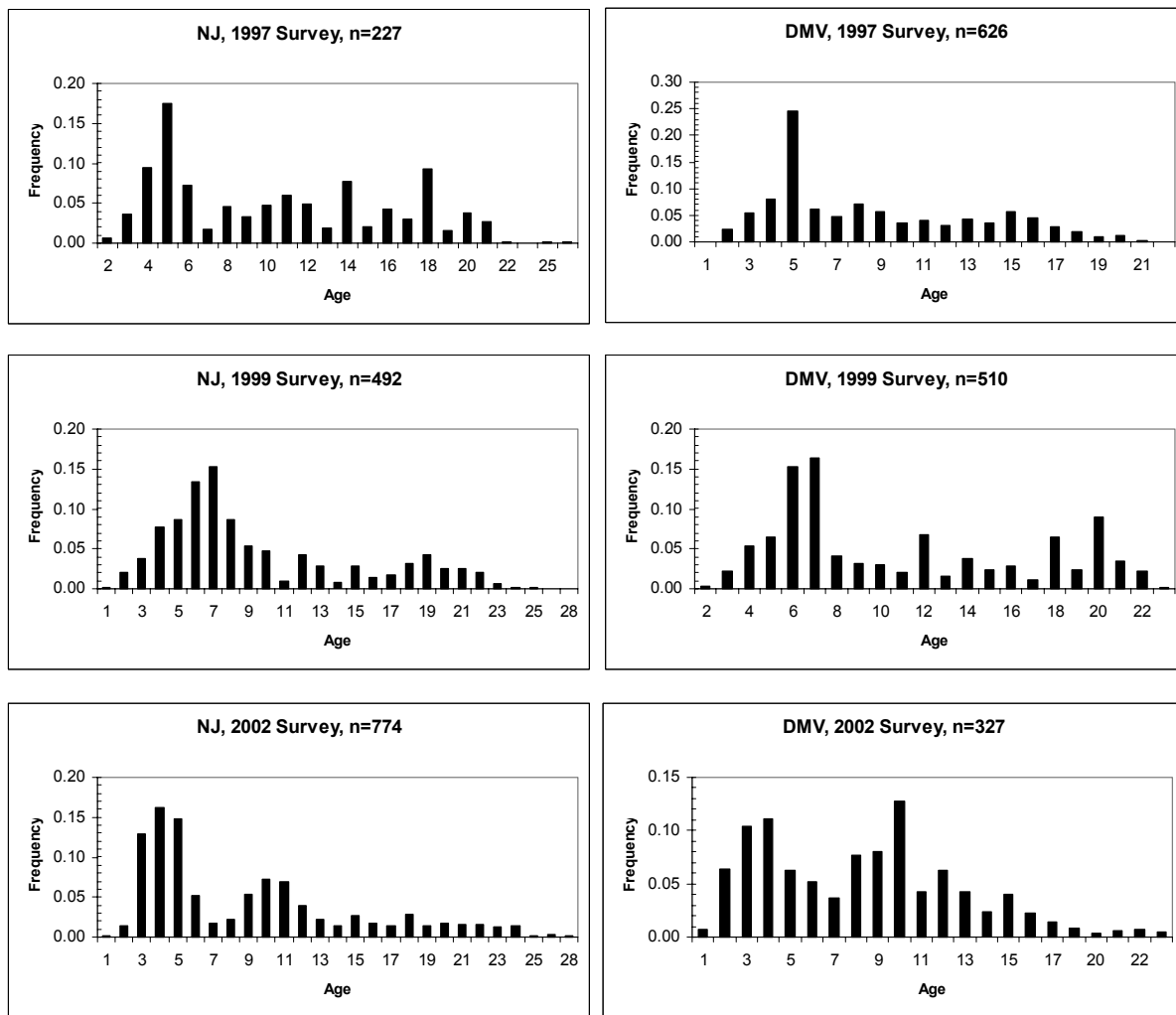


Figure C48.

Age-structure of surfclams in the New Jersey (NJ) and Delmarva (DMV) regions, by year. Results are based on NMFS survey data on surfclams shell length and age. “n”= number of surfclams that were aged and used to estimate an age-length key.

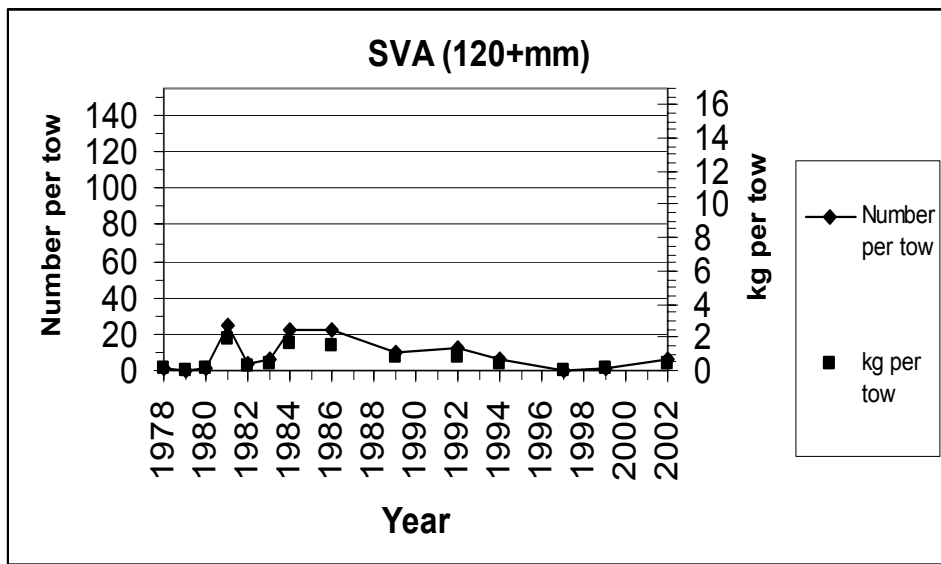
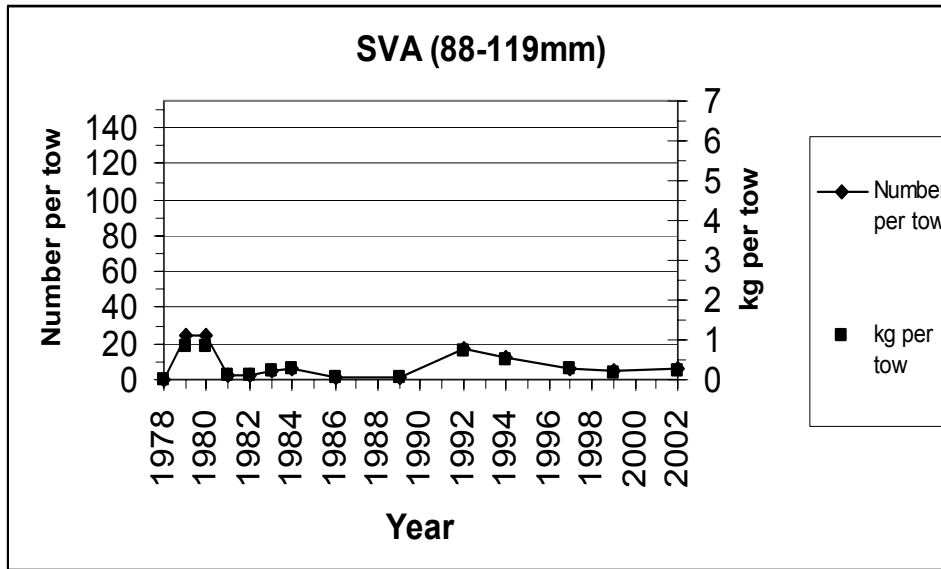


Figure C49.  
 Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a). Region: S. Virginia/N. Carolina (SVA).

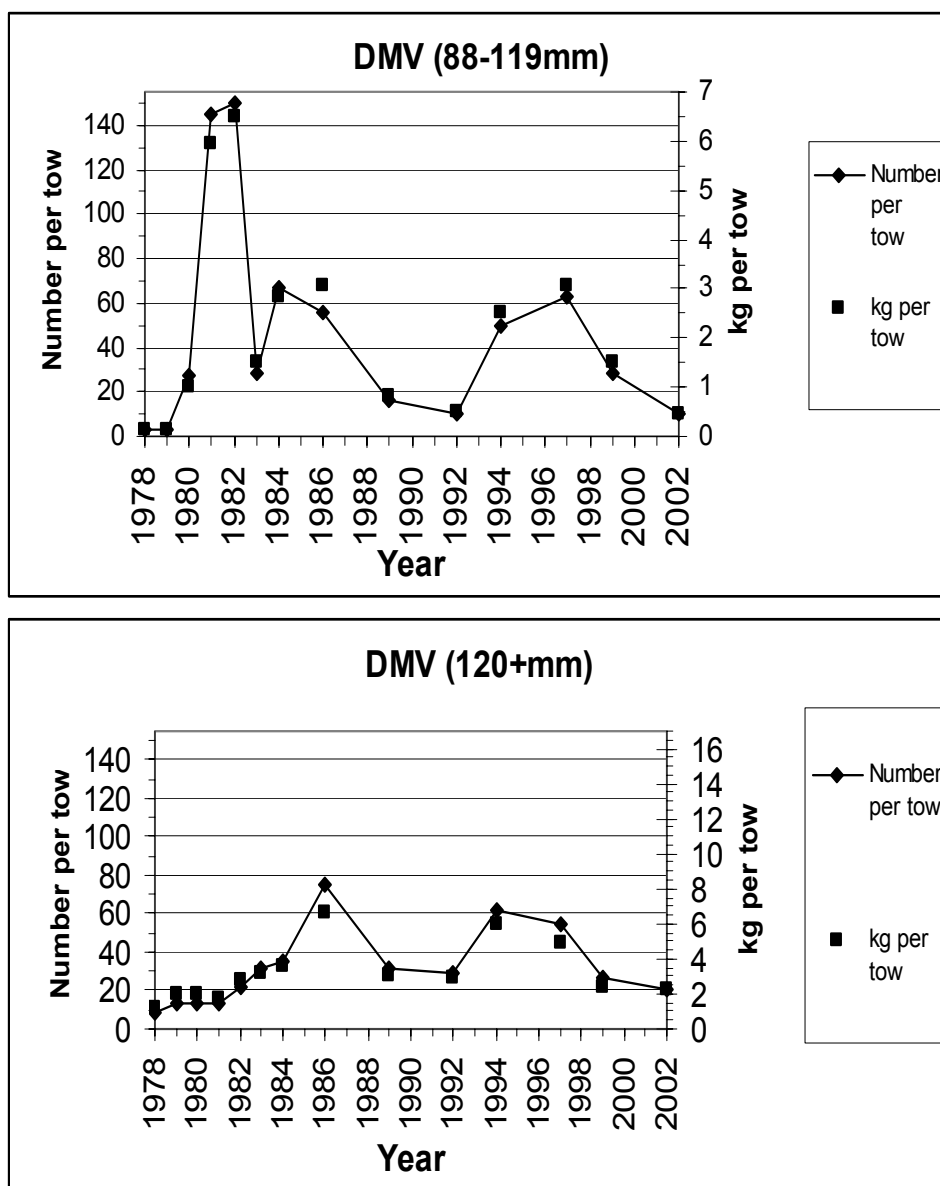


Figure C50. Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a). Region: Delmarva (DMV).

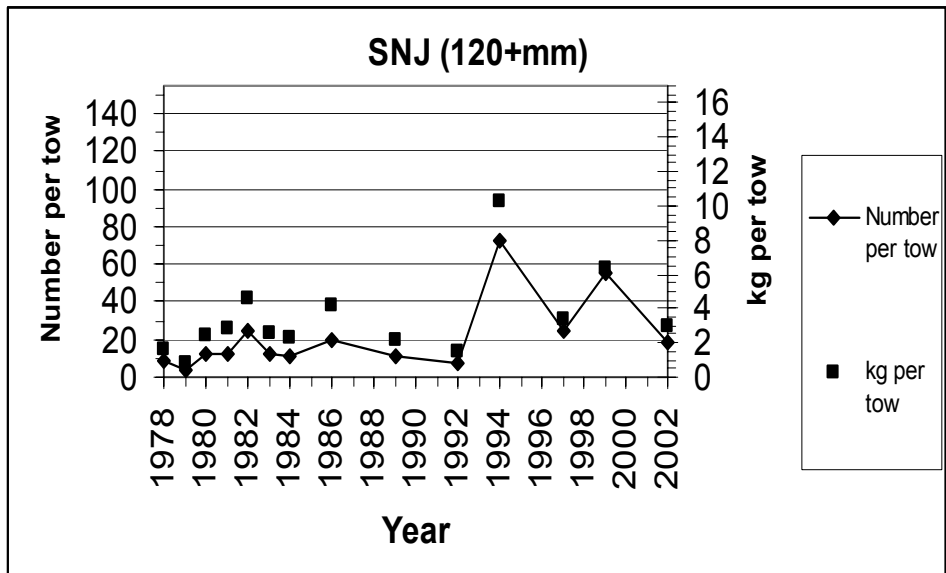
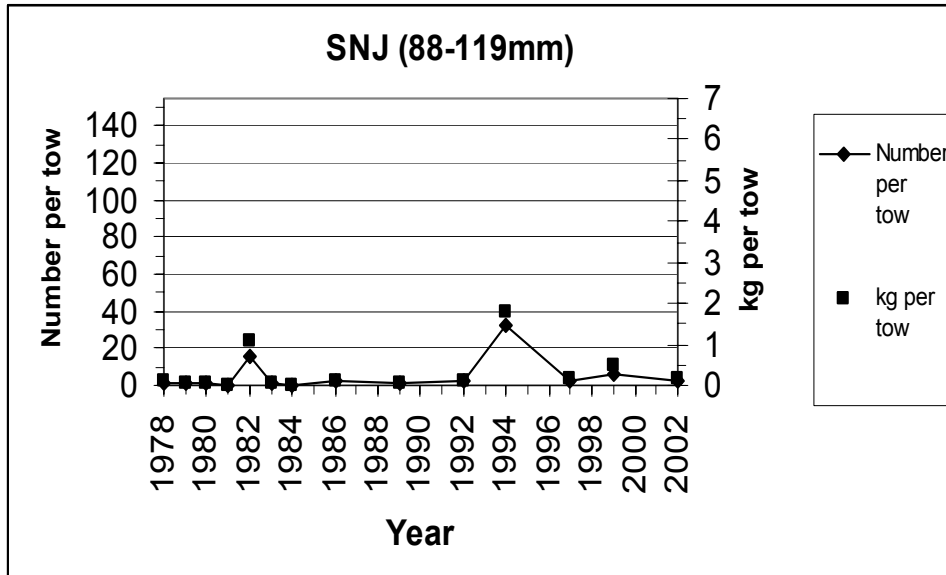


Figure C51.  
 Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a). Region: S. New Jersey (SNJ).



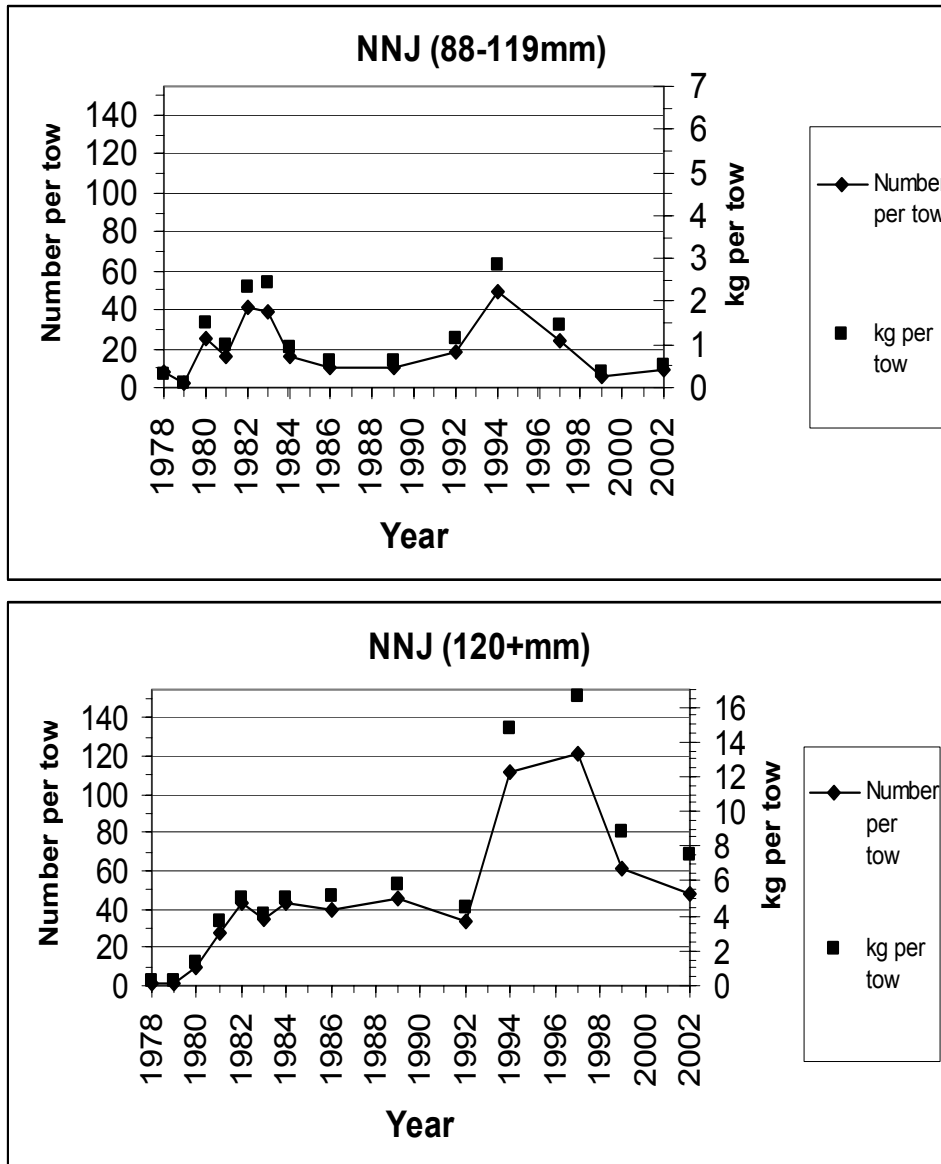


Figure C52.

Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a). Region: N. New Jersey (NNJ).

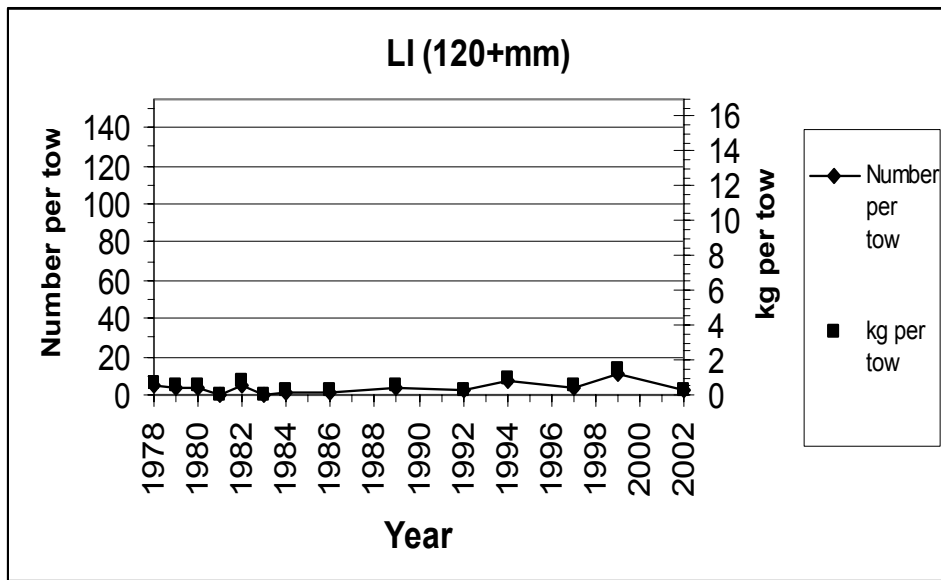
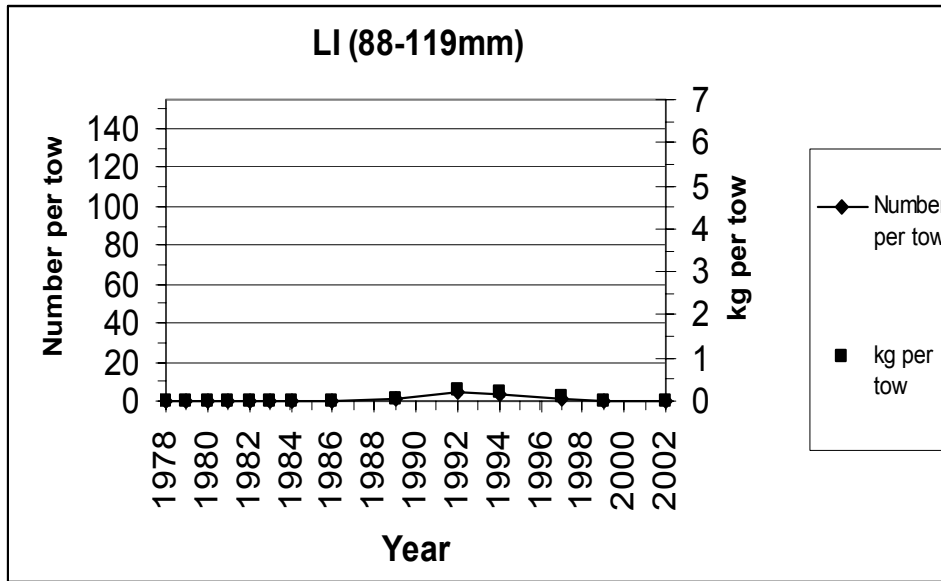


Figure C53.

Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a).

Region: Long Island (LI).

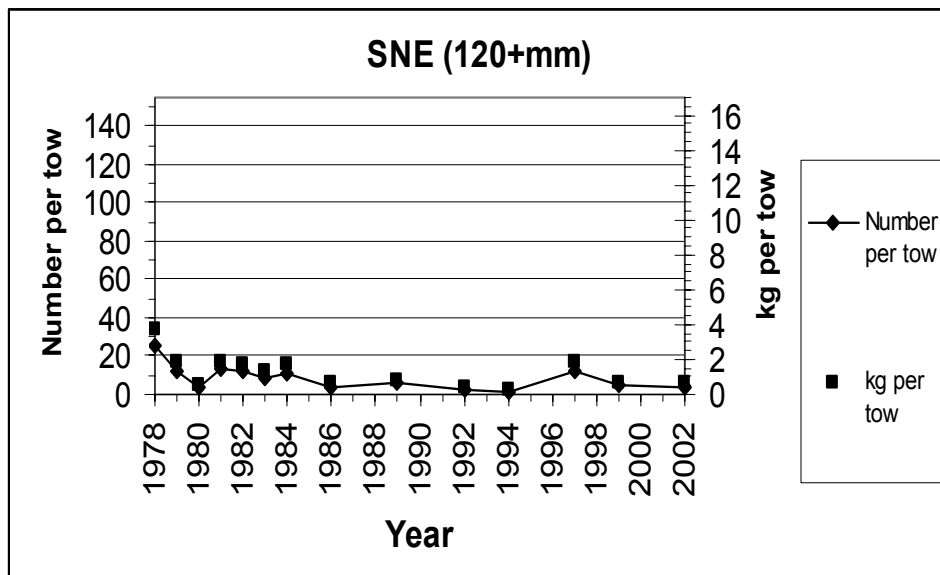
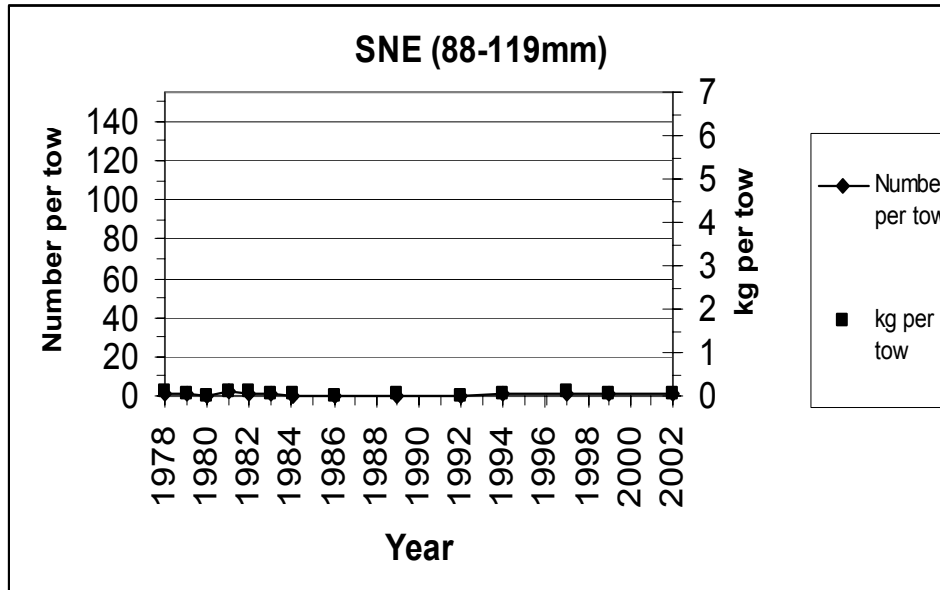


Figure C54.  
 Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a).  
 Region: S. New England (SNE).

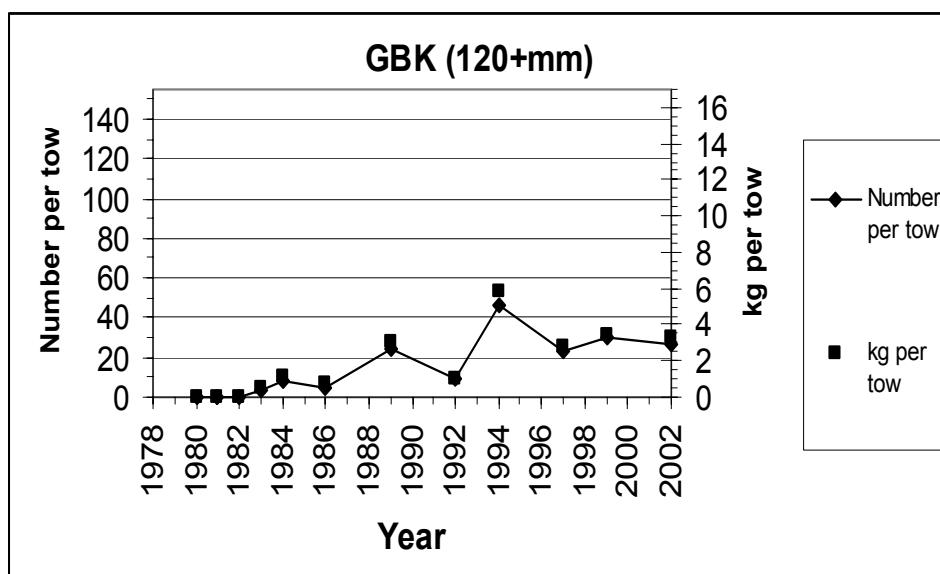
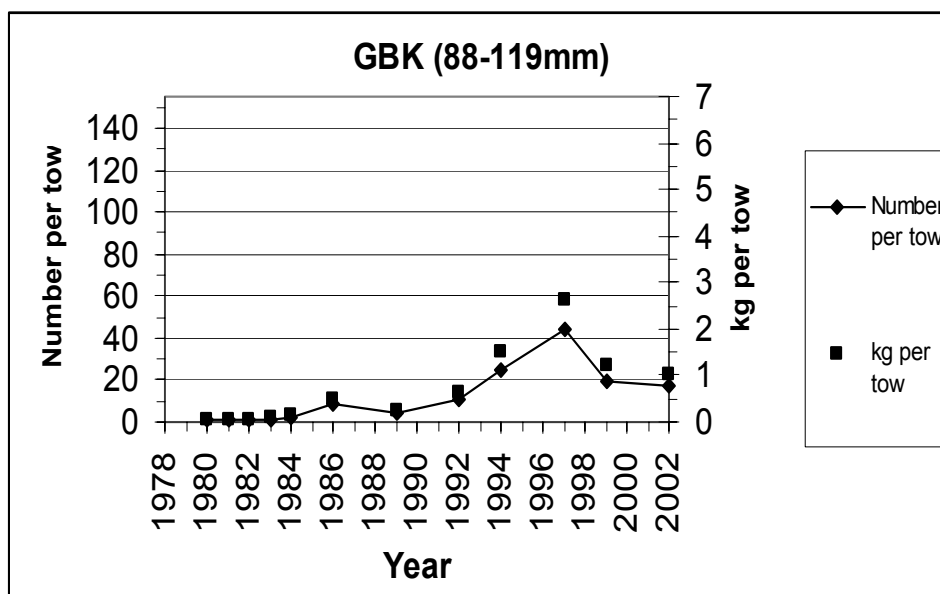


Figure C55.  
 Number and meat weight (kg) of surfclams per tow for NMFS surveys, 1978-2002. Data are presented for two size groups. Standardized to a tow distance of 0.15 n. mi. based on doppler distance, and assuming length/weights from Sarc-30 (NEFSC, 2000a).  
 Region: Georges Bank (GBK).

Figure C56. Parametric bootstrap distributions (8000 iterations) depicting uncertainty in efficiency corrected swept area biomass estimates for surfclam during 2002. Biomass (1000 mt) is for 120+ mm surfclam in NNJ and SNJ and for 100+ mm surfclam in other regions.

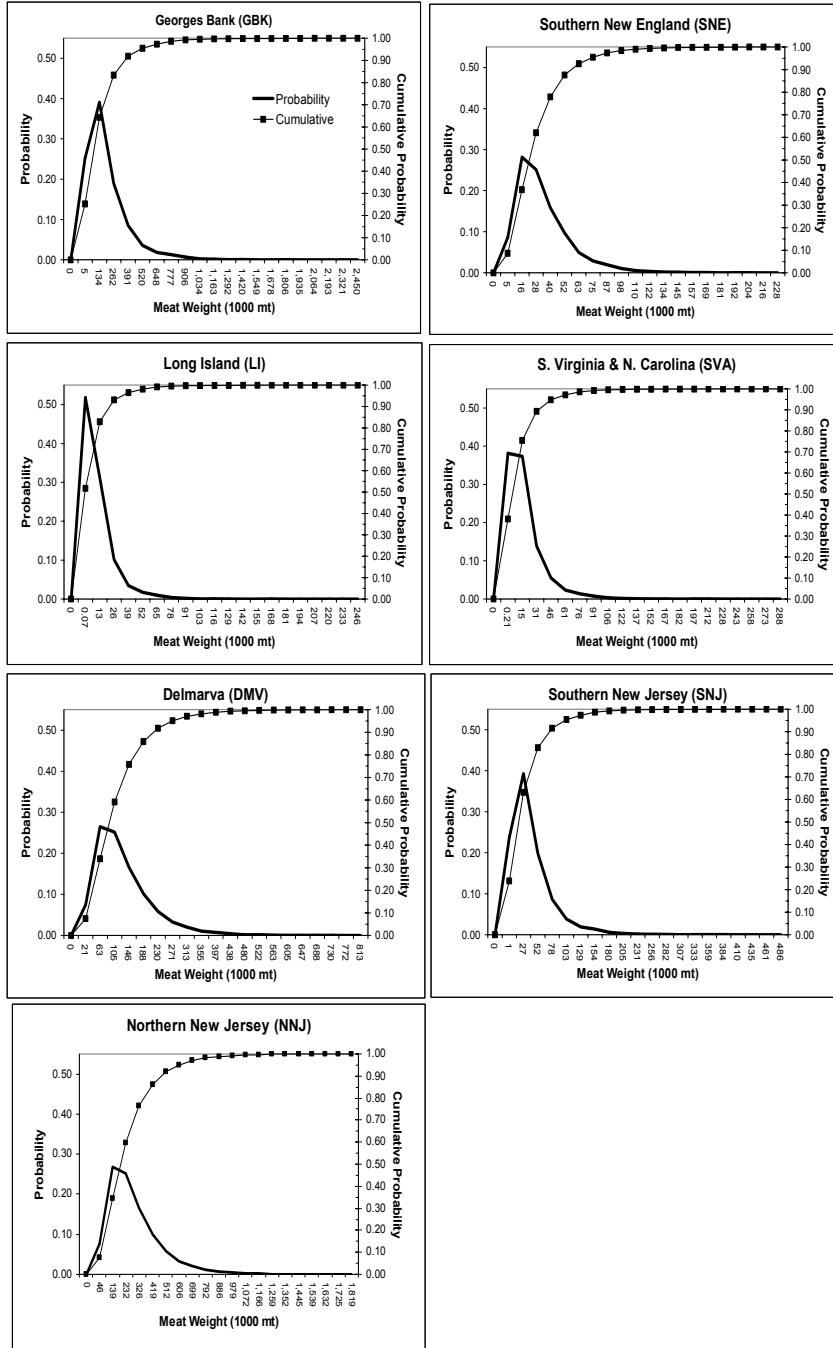


Figure C57. Summary of KLAMZ model results for DMV surfclam.

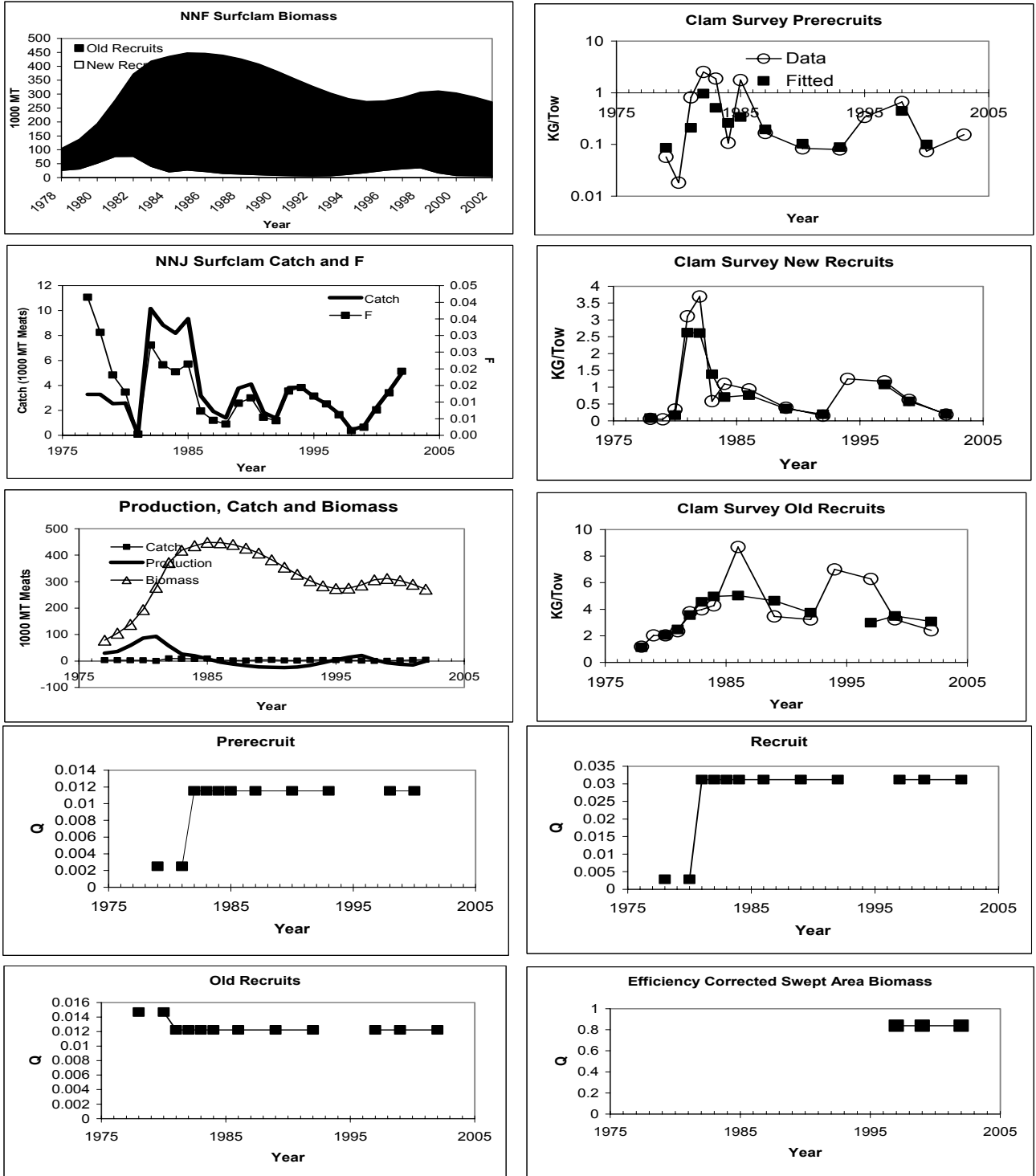


Figure C58. Biomass estimates and 80% bootstrap confidence intervals for DMV surfclam.

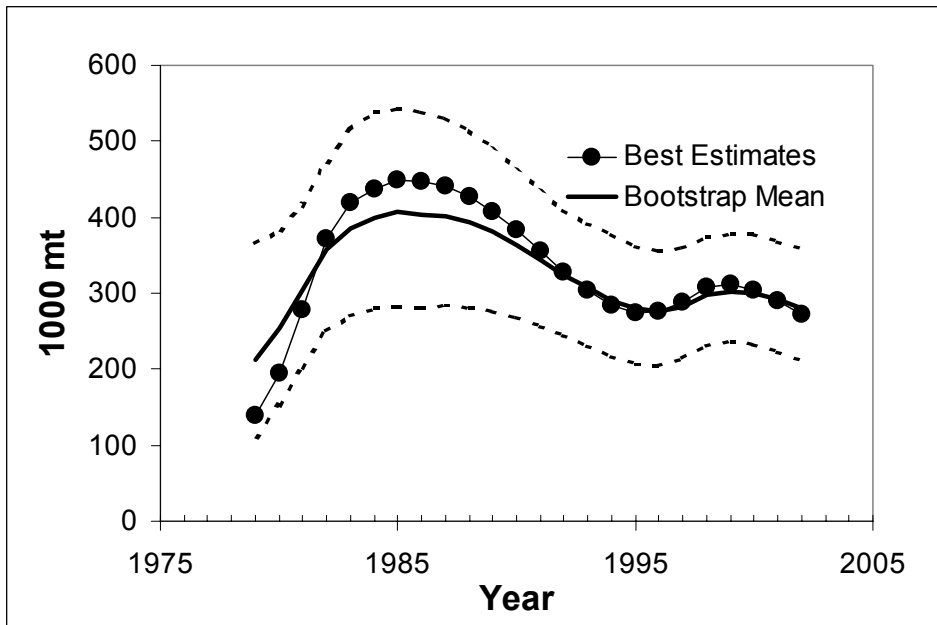


Figure C59. Retrospective analysis for DMV surfclam biomass estimates.

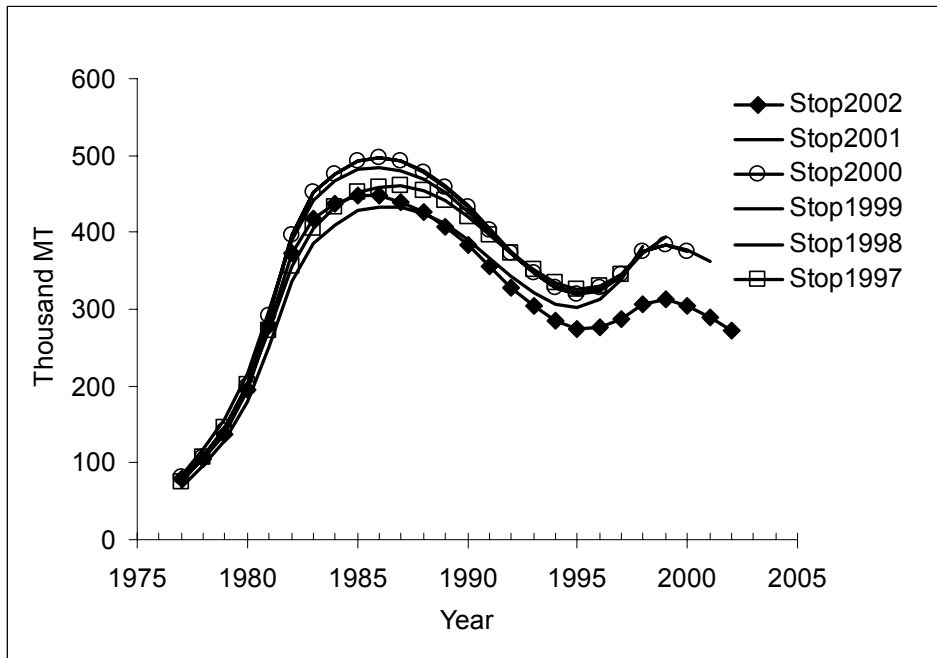


Figure C60. Sensitivity of DMV biomass estimates to recruitment assumptions.

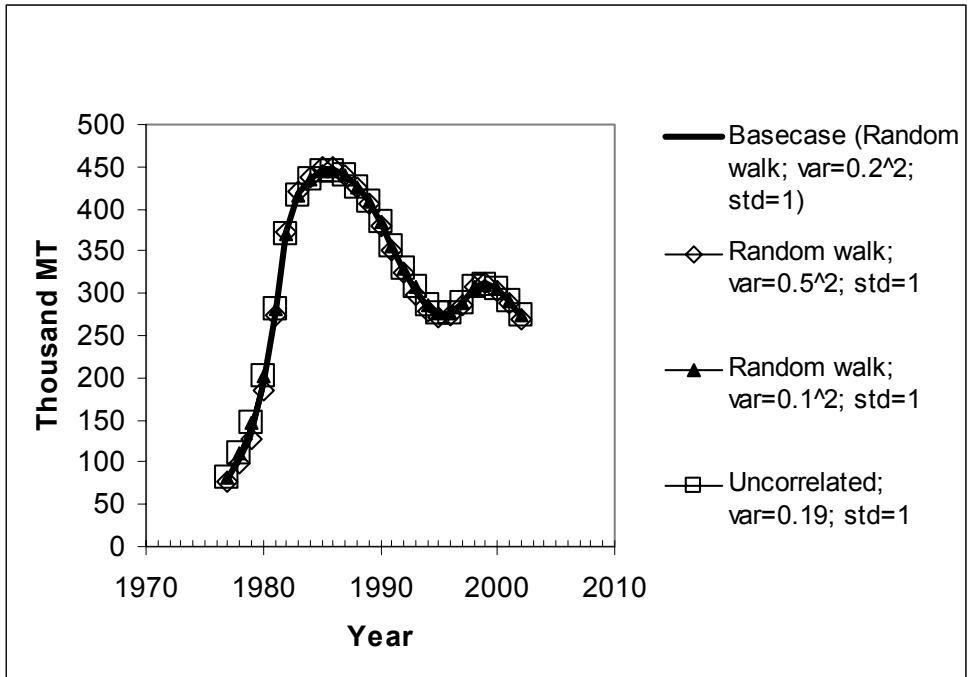


Figure C61. Sensitivity of DMV recruitment estimates to recruitment assumptions.

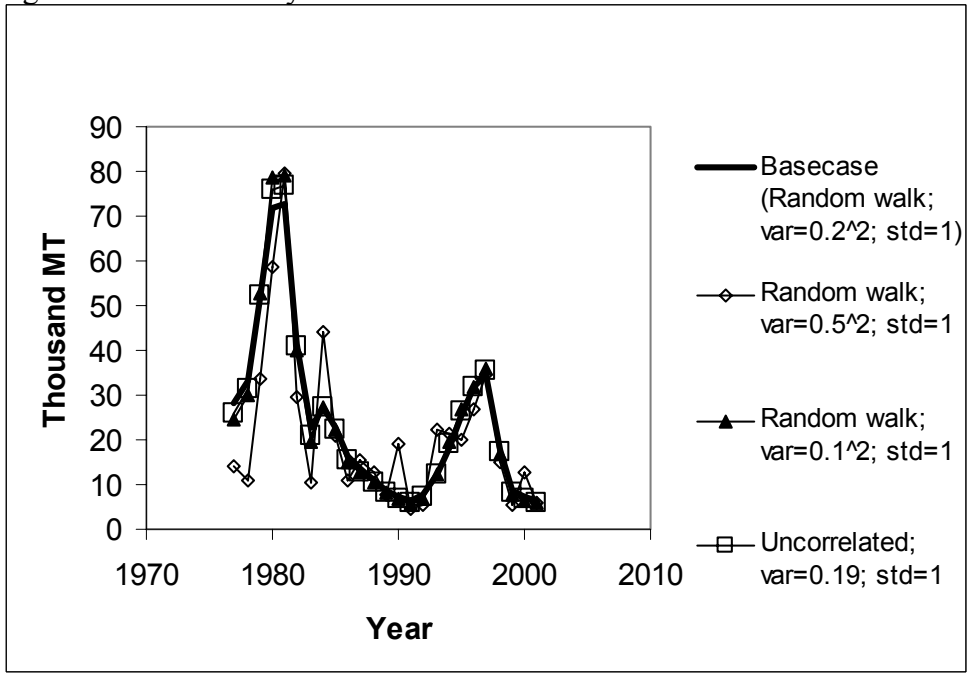




Figure C62. Survey data, efficiency corrected swept area biomass estimates used as data, biomass and recruitment estimates for Delmarva (DMV) surfclam from the KLAMZ model used in this assessment (and in the previous assessment (NEFSC 2000a). Y-axes are not labeled for pre-, new- and old recruit data because only the trends are important.

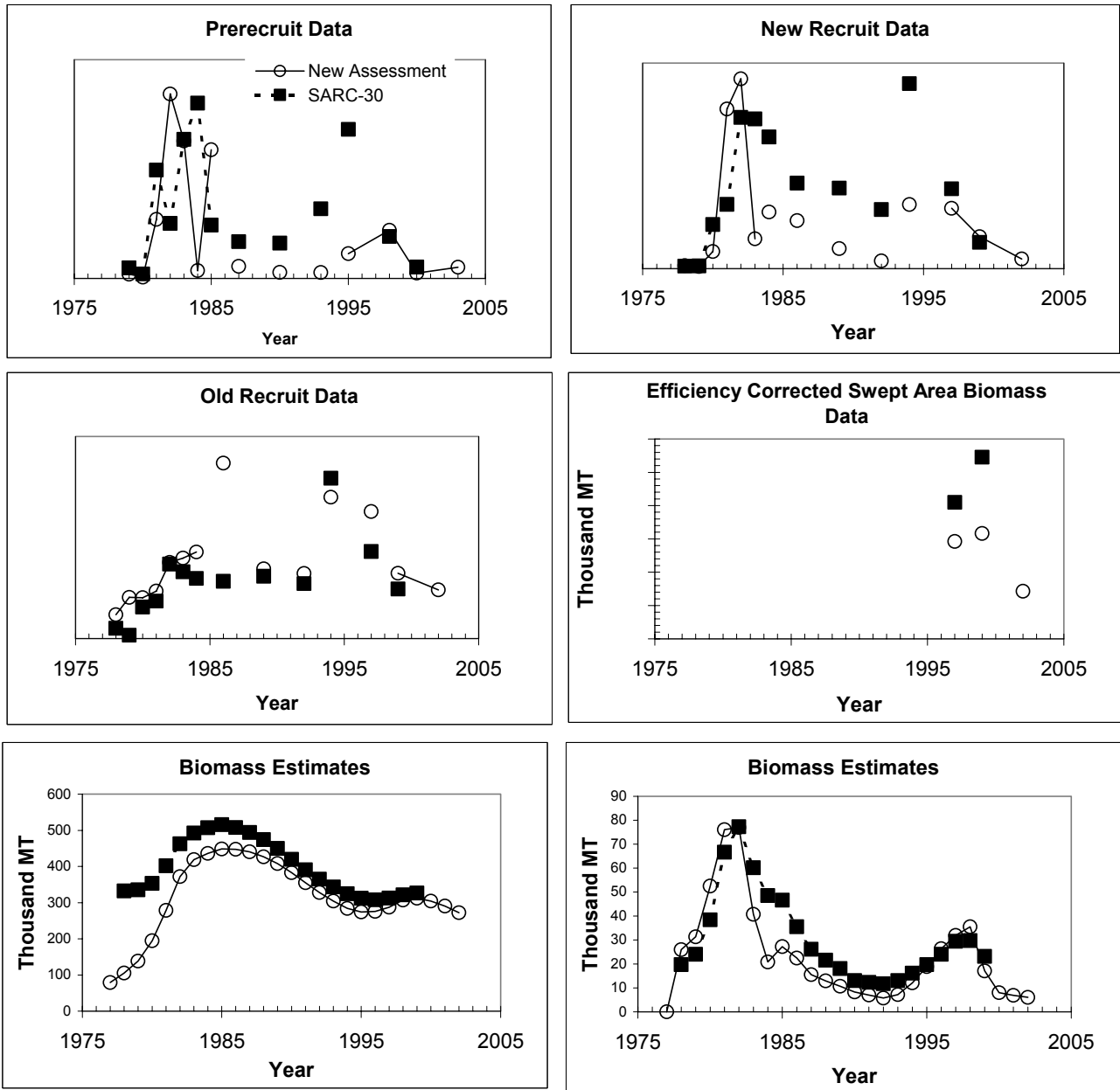


Figure C63. Residual plots for the final KLAMZ model for NNJ surfclam (not reliable enough for use by managers)

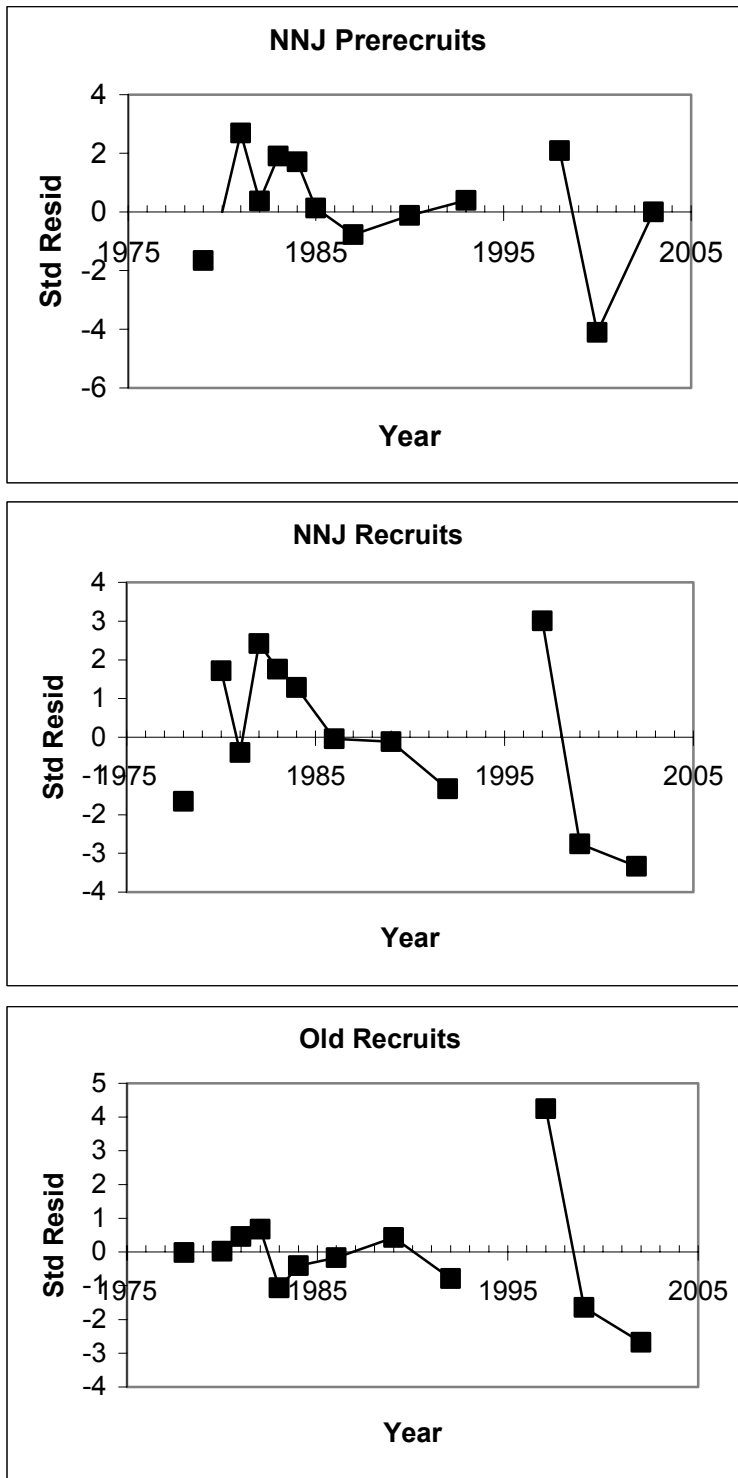


Figure C64. Summary of KLAMZ model results for NNJ surfclam (not reliable enough for use by managers).

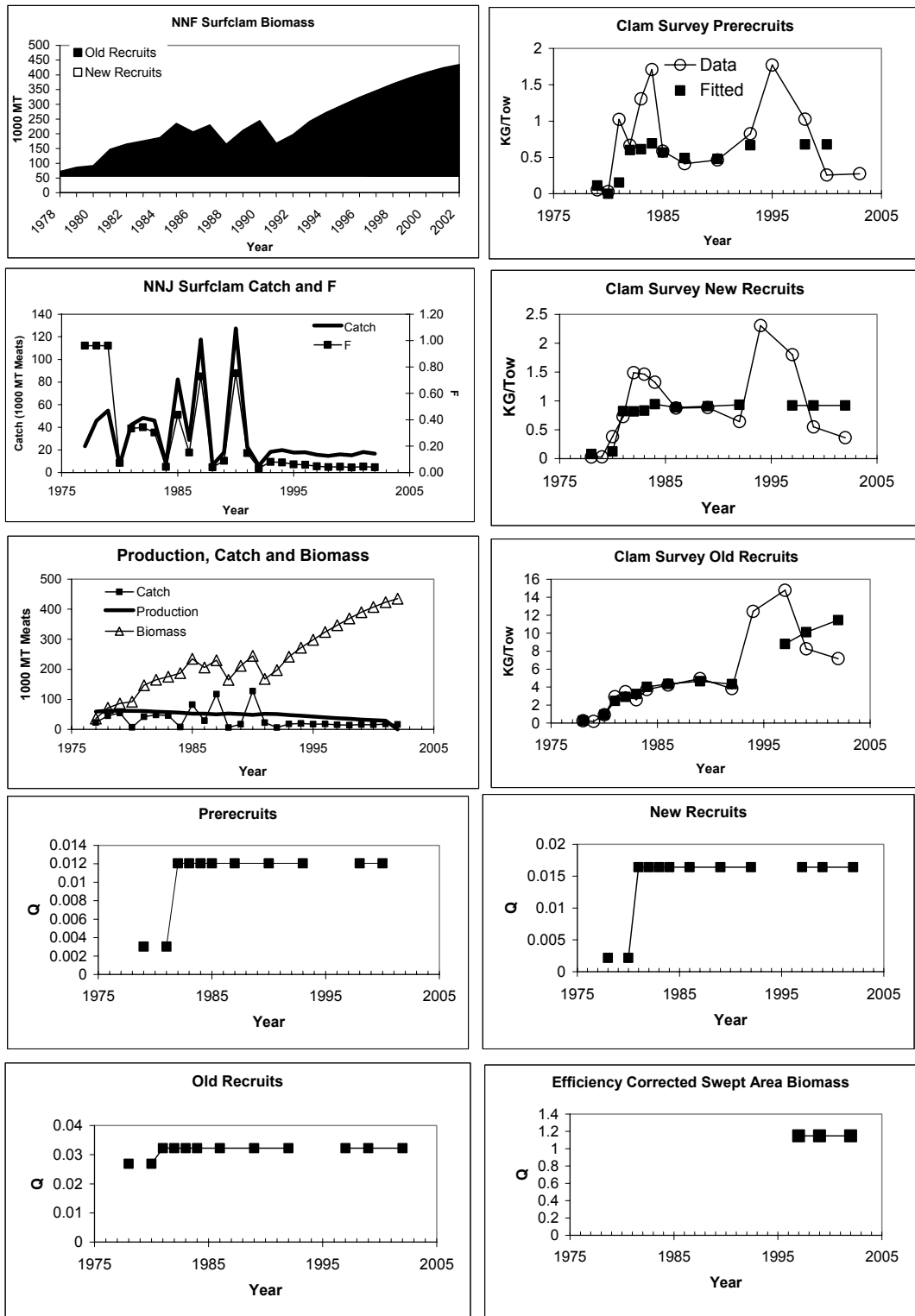
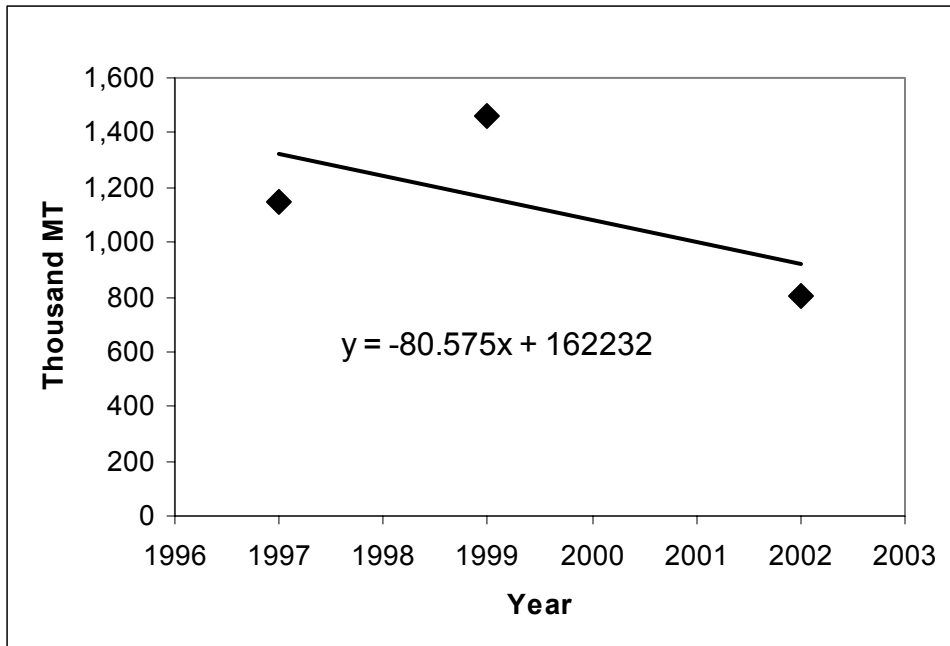


Figure C65. Efficiency corrected swept area biomass estimates for the EEZ surfclam stock.



**Appendix A.**  
**(of “C. Atlantic Surfclam” SARC-37 Report):**

**The KLAMZ Assessment Model**

The KLAMZ assessment model (NEFSC 2000; 2001) is based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is a relatively simple and implicitly age structured model that counts fish in either numerical or biomass units. It gives the same results as explicitly age-structured models (e.g. Leslie matrix model) if fishery selectivity is “knife-edged”, somatic growth follows the von Bertalanffy equation, and natural mortality is the same for all age groups in each year. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate.<sup>1</sup> Natural and fishing mortality rates, growth parameters and recruitment may change from year to year, but delay-difference calculations assume that all individuals share the same mortality and growth parameters within each year.

As in many other simple models, the delay difference equation explicitly distinguishes between two age groups. In KLAMZ, the two age groups are called “new” recruits and “old” recruits. New recruits are individuals that recruited at the beginning or during the current year. Old recruits are all older individuals in the model. As described above, KLAMZ assumes that new and old recruits are fully vulnerable to the fishery. The most important differences between the delay-difference and other simple models (e.g. Prager 1994; Conser 1995; Jacobson et al. 1994) are that von Bertalanffy growth is used to calculate biomass dynamics and that the delay-difference model captures transient age structure effects due to variation in recruitment, growth and mortality exactly. Transient effects on population dynamics are captured exactly because, as described above, the delay-difference equation is algebraically equivalent to an explicitly age-structured model with von Bertalanffy growth. As described above, delay-difference calculations can be carried out in units of biomass or numerical abundance. The KLAMZ model includes simple numerical models as special cases (e.g. Conser 1995) because growth can be turned off so that all calculations are in numerical units (see below).

The KLAMZ model incorporates a few extensions to Schnute’s (1985) revision of Deriso’s (1980) original delay difference model. Most of the extensions facilitate tuning to a wider variety of data that anticipated in Schnute (1985). The KLAMZ model was programmed in both Excel and in C++ using AD Model Builder libraries<sup>2</sup>. The AD

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<sup>1</sup> In applications, assumptions about knife-edge selectivity can be relaxed by assuming the model tracks “fishable”, rather than total, biomass (NEFSC 2000a; 2000b). An analogous approach assigns pseudo-ages based on recruitment to the fishery so that new recruits in the model are all pseudo-age  $k$ . The synthetic cohort of fish pseudo-age  $k$  may consist of more than one biological cohort. The first pseudo-age ( $k$ ) can be the predicted age at first, 50% or full recruitment based on a von Bertalanffy curve and size composition data (Butler et al. 2002). The “incomplete recruitment” approach (Deriso 1980) calculates recruitment to the model in each year  $R_t$  as the weighted sum of contributions from two or more cohorts due to spawning in

successive years (i.e.  $R_t = \sum_{a=1}^k r_a \Pi_{t-a}$  where  $k$  is the age at full recruitment to the fishery,  $r_a$  is the

contribution of fish age  $k-a$  to the fishable stock, and  $\Pi_{t-a}$  is the number or biomass of fish age  $k-a$  during year  $t$ ).

<sup>2</sup> Otter Research Ltd., Box 2040, Sydney, BC, V8L 3S3 (otter@otter-rsch.com).

Model Builder version is faster, more reliable and probably better for producing “official” stock assessment results. The Excel version is slower but useful in developing prototype assessment models, teaching and for checking calculations.

## Population dynamics

The assumed birth date and first day of the year are assumed the same in derivation of the delay-difference equation. It is therefore natural (but not strictly necessary) to tabulate catch and other data using annual accounting periods that start on the assumed biological birthday of cohorts.

Schnute’s (1985) delay-difference equation in the KLAMZ model is:

$$B_{t+1} = (1 + \rho) \tau_t B_t - \rho \tau_t \tau_{t-1} B_{t-1} + R_{t+1} - \rho \tau_t J_t R_t$$

where  $B_t$  is total biomass of individuals at the beginning of year  $t$ ;  $\rho$  is Ford’s growth coefficient (see below);  $\tau_t = \exp(-Z_t) = \exp[-(F_t + M)]$  is the fraction of the stock that survived in year  $t$ ,  $Z_t$ ,  $F_t$ , and  $M$  are instantaneous rates for total, fishing and natural mortality; and  $R_t$  is the biomass of new recruits (at age  $k$ ) at the beginning of the year. The natural mortality rate  $M_t$  may vary or be constant over time. Instantaneous mortality rates in KLAMZ model calculations are biomass-weighted averages if von Bertalanffy growth is turned on in the model. However, biomass-weighted mortality estimates in KLAMZ are the same as rates for numerical calculations because all individuals are fully recruited. The growth parameter  $J_t = w_{t-1,k-1} / w_{t,k}$  is the ratio of mean weight one year before recruitment (age  $k-1$  in year  $t-1$ ) and mean weight at recruitment (age  $k$  in year  $t$ ).

It is not necessary to specify body weights at and prior to recruitment in the KLAMZ model (parameters  $v_{t-1}$  and  $V_t$  in Schnute 1985) because the ratio  $J_t$  and recruitment biomass contain the same information. Schnute’s (1985) original delay difference equation is:

$$B_{t+1} = (1 + \rho) \tau_t B_t - \rho \tau_t \tau_{t-1} B_{t-1} + w_{t+1,k} N_{t+1} - \rho \tau_t w_{t-1,k-1} N_t$$

To derive the equation used in KLAMZ, substitute recruitment biomass  $R_{t+1}$  for the product  $w_{t+1,k} N_{t+1,k}$  and adjusted recruitment biomass  $J_t R_t = (w_{t-1,k-1} / w_{t,k}) w_{t,k} N_{t,k} = w_{t-1,k-1} N_t$  in the last term on the right hand side. The advantage in using the alternate parameterization for biomass dynamic calculations in KLAMZ is that recruitment is estimated directly in units of biomass and the number of growth parameters is reduced.

## Growth

As described in Schnute (1985), biomass calculations in the KLAMZ model are based on Schnute and Fournier’s (1980) re-parameterization of the von Bertalanffy growth model:

$$w_a = w_{k-1} + (w_k - w_{k-1}) (1 + \rho^{1+a-k}) / (1 - \rho)$$

where  $w_k = V$  and  $w_{k-1} = v$ . Schnute and Fournier’s (1980) growth model is the same as the traditional von Bertalanffy growth model  $\{W_a = W_{max} [1 - \exp(-K(a - t_{zero}))]$  where  $W_{max}$ ,  $K$  and  $t_{zero}$  are parameters}. The two growth models are the same because  $W_{max} = (w_k - \rho w_{k-1}) / (1 - \rho)$ ,  $K = -\ln(\rho)$  and  $t_{zero} = \ln[(w_k - w_{k-1}) / (w_k - \rho w_{k-1})] / \ln(\rho)$ .

In the KLAMZ model, the growth parameters  $J_t$  can vary with time but  $\rho$  is constant. Use of time-variable  $J_t$  values with  $\rho$  is constant is the same as assuming that the von Bertalanffy parameters  $W_{max}$  and  $t_{zero}$  change over time. It is possible to accommodate a wide range growth patterns by changing only  $W_{max}$  and  $t_{zero}$ . Growth parameters are usually estimated externally, rather than directly in the KLAMZ model. The KLAMZ model uses catch-at-age information indirectly, if catch-at-age is used to estimate growth parameters.

#### *Numerical population dynamics (growth turned off)*

Growth can be turned on off so that abundance, rather than biomass, is tracked in the KLAMZ model. Set  $J_t=1$  and  $\rho=0$  in the delay difference equation, and use  $N_t$  (for numbers) in place of  $B_t$  to get:

$$N_{t+1} = \tau_t N_t + R_{t+1}$$

All of the calculations in KLAMZ for biomass dynamics are also valid for numerical dynamics.

#### *Instantaneous growth rates*

Instantaneous growth rate (IGR) calculations in the KLAMZ model are an extension to the original Deriso-Schnute delay difference model. IGRs are used extensively in KLAMZ for calculating catch biomass and projecting stock biomass forward to the time at which surveys occur. The IGR for new recruits depends only on growth parameters:

$$G_t^{New} = \ln\left(\frac{w_{k+1,t+1}}{w_{k,t}}\right) = \ln(1 + \rho - \rho J_t)$$

IGR for old recruits is a biomass-weighted average that depends on the current age structure and growth parameters. It can be calculated easily by projecting biomass of old recruits  $S_t=B_t-R_t$  (escapement) forward one year with no mortality:

$$S_t^* = (1 + \rho)S_t - \rho\tau_{t-1}B_{t-1}$$

where the asterisk (\*) means just prior to the start of the subsequent year  $t+1$ . By definition, the IGR for old recruits in year  $t$  is  $G_t^{Old} = \ln(S_t^*/S_t)$ . Dividing by  $S_t$  gives:

$$G_t^{Old} = \ln\left[(1 + \rho) - \rho\tau_{t-1}\frac{B_{t-1}}{S_t}\right]$$

IGR for the entire stock is the biomass weighted average of the IGR values for new and old recruits:

$$G_t = \frac{R_t G_t^{New} + S_t G_t^{Old}}{B_t}$$

All IGR values are zero if growth is turned off.

#### Recruitment

In the Excel version of the KLAMZ model, annual recruitments are calculated  $R_t = e^{\Omega_t}$  where  $\Omega_t$  is a log transformed annual recruitment parameter usually estimated in the model. In the C++ version, recruitments are calculated based on log geometric mean

recruitment ( $\mu$ ) and a set of annual log scale deviation parameters ( $\omega_t$ ):

$$\Omega_t = \mu + \omega_t$$

The deviations  $\omega_t$  are constrained to average zero.<sup>3</sup> With the constraint, estimation of  $\mu$  and the set of  $\omega_t$  values (1+  $n$  years parameters) is equivalent to estimation of the smaller set ( $n$  years) of  $\Omega_t$  values.

### Natural mortality

Natural mortality rates ( $M$ ) are assumed constant in the Excel version of the KLAMZ model but can change from year to year in the C++ version based on covariates (e.g. predator density) or natural mortality rate process errors. Natural mortality rate process errors represent variation in predation, disease, parasitism and other factors that affect natural mortality rates in fish populations. Annual process error parameters are estimated to improve model fit to survey and other data. Calculations are basically the same as for survey covariates and survey process errors described below.

### Fishing mortality and catch

Fishing mortality rates ( $F_t$ ) are calculated so that predicted and observed catch data (landings plus estimated discards in units of weight) “agree”. It is not necessary, however, to assume that catches are measured accurately (see “Observed and predicted catch”).

Fishing mortality rate calculations in Schnute (1985) are applicable when catches are in units of numbers but catch data are usually in units of weight. Calculation of predicted catches in units of weight is more complicated because somatic growth occurs throughout the year as fishing occurs.

The KLAMZ model uses a generalized catch equation that incorporates continuous growth through the fishing season. By the definition of instantaneous rates, the catch equation expresses catch as the product:

$$\hat{C}_t = F_t \bar{B}_t$$

where  $\hat{C}_t$  was predicted catch weight (landings plus discard) and  $\bar{B}_t$  is average biomass.

Following Ricker (1970) and Zhang and Sullivan (1988), let  $X_t = G_t - F_t - M_t$  be the net instantaneous rate of change for biomass.<sup>4</sup> If the rates for growth and mortality are equal, then  $X_t = 0$ ,  $\bar{B}_t = B_t$  and  $C_t = F_t B_t$ . If the growth rate  $G_t$  exceeds the combined rates of natural and fishing mortality ( $F_t + M_t$ ), then  $X_t > 0$ . If mortality exceeds growth, then  $X_t < 0$ . In either case, with  $X_t \neq 0$ , average biomass is computed:

$$\bar{B}_t \approx -\frac{(1 - e^{X_t})B_t}{X_t}$$

When  $X_t = 0$ , the expression for  $\bar{B}_t$  is an approximation because  $G_t$  approximates the rate of change in mean body weight due to von Bertalanffy growth. However, the approximation is reasonably accurate and preferable to calculating catch biomass with the

<sup>3</sup> The constraint is implemented by adding  $L = \lambda \bar{\omega}^2$  to the objective function, generally with  $\lambda = 1000$ .

<sup>4</sup> By convention, the instantaneous rates  $G_t$ ,  $F_t$  and  $M_t$  are always expressed as numbers  $\neq 0$ .



traditional catch equation that ignores growth during the fishing season.<sup>5</sup> Average biomass can be calculated for new recruits, old recruits or for the whole stock by using either  $G_t^{New}$ ,  $G_t^{Old}$  or  $G_t$ .

In the Excel version of KLAMZ, the modified catch equation is solved analytically for  $F_t$  given  $C_t$ ,  $B_t$ ,  $G_t$  and  $M$ . In the C++ version, fishing mortality rates are calculated using a log geometric mean parameter ( $\Phi$ ) and a set of annual log scale deviation parameters ( $\psi_t$ ):

$$F_t = e^{\Phi + \psi_t}$$

where the deviations  $\psi_t$  are constrained to average zero.

### Surplus production

Annual surplus production was calculated exactly by projecting biomass at the beginning of each year forward with no fishing mortality:

$$B_t^* = (1 + \rho) e^{-M} B_t - \rho e^{-M} L_{t-1} B_{t-1} - \rho e^{-M} J_t R_t$$

By definition, surplus production  $P_t = B_t^* - B_t$ .

### Per recruit modeling

Per recruit model calculations in the Excel version of the KLAMZ simulate the life of a hypothetical cohort of arbitrary size (e.g.  $R=1000$ ) with constant  $M$ ,  $F$  (survival) and growth ( $\tau$  and  $J$ ) in a population initially at zero biomass. In the first year:

$$B_1 = R$$

In the second year:

$$B_2 = (1 + \rho) \tau B_1 - \rho \tau J R_1$$

In the third and subsequent years:

$$B_{t+1} = (1 + \rho) \tau B_t - \rho \tau^2 B_{t-1}$$

This iterative calculation is carried out until the sum of lifetime cohort biomass from one iteration to the next changes by less than a small amount (0.0001). Total lifetime biomass, spawning biomass and yield in weight are calculated by summing biomass, spawning biomass and yield over the lifetime of the cohort (in each iteration). Lifetime biomass, spawning biomass and yield per recruit are calculated by dividing totals by initial recruitment ( $R$ ).

### Status determination variables

The user may specify a range of years (e.g. the last three years) to use in calculating recent average fishing mortality  $\bar{F}_{Recent}$  and biomass  $\bar{B}_{Recent}$  levels. These status determination variables are often useful in calculation of status ratios such as  $\bar{F}_{Recent} / F_{MSY}$  and  $\bar{B}_{Recent} / B_{MSY}$ .

<sup>5</sup> The traditional catch equation  $C_t = F_t(1 - e^{-Z_t})B_t / Z_t$  where  $Z_t = F_t + M_t$  underestimates catch biomass for a given level of fishing mortality  $F_t$  and overestimates  $F_t$  for a given level of catch biomass. The errors can be substantial for fast growing fish, particularly if recent recruitments were strong.

## Goodness of Fit and Parameter Estimation

Parameters estimated in the KLAMZ model are chosen to minimize an objective function based on a sum of weighted negative log likelihood (NLL) components:

$$\Xi = \sum_{v=1}^{N_{\Xi}} \lambda_v L_v$$

where  $N_{\Xi}$  is the number of NLL components ( $L_v$ ) and the  $\lambda_v$  are emphasis factors used as weights. The objective function  $\Xi$  may be viewed as a NLL or a negative log posterior (NLP) distribution, depending on the nature of the individual  $L_v$  components and modeling approach. Except during sensitivity analyses, weighting factors for objective function components ( $\lambda_v$ ) are usually set to one. An arbitrarily large weighting factor (e.g.  $\lambda_v=1000$ ) is used for “hard” constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g.  $\lambda_v=0.0001$ ) can be used for “soft” model-based constraints. For example, an internally estimated spawner-recruit curve or surplus production curve might be estimated with a small weighting factor to summarize stock-recruit or surplus production results with minimal influence on biomass, fishing mortality and other estimates from the model. Use of a small weighting factor for an internally estimated surplus production or stock-recruit curve is equivalent to fitting a curve to model estimates of biomass and recruitment or surplus production in the output file, after the model is fit (Jacobson et al. 2002).

### NLL kernels

NLL components in KLAMZ are generally programmed as “concentrated likelihoods” to avoid calculation of values that do not affect derivatives of the objective function. For  $x \sim N(\mu, \sigma^2)$ , the complete NLL for one observation is:

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

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

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

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

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

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

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

where  $N$  is the number of observations. The second approach is equivalent but used when the weights for each observation ( $\lambda_i$ ) may differ:

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

In the latter case, the maximum likelihood estimator:

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

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

In practice, it is often useful to use a different emphasis factor ( $\lambda_{v,i}$ ) for each observation so that the emphasis for specific observations or specific instances of a constraint can be increased or decreased. KLAMZ allows the user to specify observation- an instance-specific weights for most types of data and constraints.

### Observed and predicted catch

In the AD Model Builder version, fishing mortality rates (based on the parameters  $\Phi$  and  $\psi_f$ ) are estimated to satisfy a NLL for observed and predicted catches:

$$L = \sum_{t=0}^N w_t \left( \frac{\hat{C}_t - C_t}{\kappa_t} \right)^2$$

where the standard error  $\kappa_t = CV_{catch} \hat{C}_t$  with  $CV_{catch}$  and weights are  $w_t$  supplied by the user. The weights can be used, for example, if catch data in some years are less precise than in others. The AD Model Builder version of KLAMZ can potentially estimate any or every catch in the time series.

### *Solving the generalized catch equation*

A few years of catches can be estimated in the Excel version of KLAMZ (see below) but catches are generally assumed measured without error. The Excel version does not compute a NLL for catch. Instead,  $F_t$  values are calculated iteratively using the Newton-Raphson method (Kennedy and Gentle 1980).

Subtracting predicted catch (from the generalized catch equation, see above) from the observed catch data gives:

$$g(F_t) = C_t + \frac{F_t(1 - e^{-X_t})}{X_t} B_t = 0$$

where  $X_t = G_t - M_t - F_t$ . If  $X_t = 0$ , then  $\bar{B}_t = B_t$  and  $F_t = C_t/B_t$ .

If  $X_t \neq 0$ , then the Newton-Raphson algorithm is used to solve for  $F_t$ . At each iteration of the algorithm, the current estimate  $F_t^i$  is updated using:

$$F_t^{i+1} = F_t^i - \frac{g(F_t^i)}{g'(F_t^i)}$$

where  $g'(F_t^i)$  is the derivative  $F_t^i$ . Omitting subscripts, the derivative is:

$$g'(F) = -\frac{Be^{-F}[(e^F - e^\gamma)\gamma + e^\gamma F\gamma - e^\gamma F^2]}{X^2}$$

where  $\gamma = G - M$ . Iterations continue until  $g(F_t^i)$  and  $abs[g(F_t^{i+1}) - g(F_t^i)]$  are both  $\leq 0.00001$ .

Initial values are important in algorithms that solve the catch equation numerically (Sims 1982). If  $M_t + F_t > G_t$  so that  $X_t < 0$ , then the initial value  $F_t^0$  is calculated according to Sims (1982). If  $M_t + F_t < G_t$  so that  $X_t > 0$ , then initial values are calculated based on a generalized version of Pope's cohort analysis (Zhang and Sullivan 1988):

$$F_t^0 = \gamma_t - \ln \left[ \frac{(B_t e^{0.5\gamma_t} - C_t) e^{0.5\gamma_t}}{B_t} \right]$$

### Initial population age structure

In the KLAMZ model, old and new recruit biomass during the first year ( $R_1$  and  $S_1 = B_1 - R_1$ ) and biomass prior to the first year ( $B_0$ ) are estimated as log scale parameters. Survival in the year prior to the first year ("year 0") is  $\tau_0 = e^{-F_0 - M_1}$  with  $F_0$  chosen to obtain catch  $C_0$  (specified as data) from the estimated biomass  $B_0$ . IGRs during year 0 and year 1 are assumed equal ( $G_0 = G_1$ ) in catch calculations.

Biomass in the second year of a series of delay-difference calculations depends on biomass ( $B_0$ ) and survival ( $\tau_0$ ) in year 0:

$$B_2 = (1 + \rho) \tau_1 B_1 - \rho \tau_1 \tau_0 B_0 + R_2 - \rho \tau_1 J_1 R_1$$

There is, however, there is no direct linkage between  $B_0$  and escapement biomass ( $S_1 = B_1 - R_1$ ) at the beginning of the first year.

The missing link between  $B_0$ ,  $S_1$  and  $B_1$  means that the parameter for  $B_0$  tends to be relatively free and unconstrained by the underlying population dynamics model. In some cases,  $B_0$  can be estimated to give good fit to survey and other data, while implying unreasonable initial age composition and surplus production levels. In other cases,  $B_0$  estimates can be unrealistically high or low implying, for example, unreasonably high or low recruitment in the first year of the model ( $R_1$ ). Problems arise because many different combinations of values for  $R_1$ ,  $S_1$  and  $B_0$  give similar results in terms of goodness of fit. This issue is common in stock assessment models that use forward simulation calculations because initial age composition is difficult to estimate. It may be exacerbated in delay-difference models because age composition data are not used.

The KLAMZ model uses two constraints to help estimate initial population biomass and initial age structure.<sup>6</sup> The first constraint links IGRs for escapement ( $G^{Old}$ ) in the first years to an adjacent value. The purpose of the constraint is to ensure consistency in average growth rates (and implicit age structure) during the first few years. For example, if IGRs for the first  $n_G$  years are constrained<sup>7</sup>, then the NLL for the penalty is:

$$L_G = 0.5 \sum_{t=1}^{n_G} \left[ \frac{\ln(G_t^{Old} / G_{n_G+1}^{Old})}{\sigma_G} \right]^2$$

where the standard deviation  $\sigma_G$  is supplied by the user. It is usually possible to use the standard deviation of  $Q_t^{Old}$  for later years from a preliminary run to estimate  $\sigma_G$  for the first few years. The constraint on initial IGRs should probably be “soft” and non-binding ( $\lambda \approx 1$ ) because there is substantial natural variation in somatic growth rates due to variation in age composition.

The second constraint links  $B_0$  to  $S_1$  and ensures conservation of mass in population dynamics between years 0 and 1. In other words, the parameter for escapement biomass in year 1 is constrained to match an approximate projection of the biomass in year 0, accounting for growth, and natural and fishing mortality. The constraint is intended to be binding and satisfied exactly (e.g.  $\lambda = 1000$ ) because incompatible values of  $S_1$  and  $B_0$  are biologically impossible. In calculations:

$$S_1^p = B_0 e^{G_1 - F_0 - M_1}$$

where  $S_1^p$  is the projected escapement in year 1 and  $B_0$  is the model’s estimate of total biomass in year 0. The instantaneous rates for growth and natural mortality from year 1 ( $G_1$  and  $M_1$ ) are used in place of  $G_0$  and  $M_0$  because the latter are unavailable. The NLL for the constraint:

$$L = \left[ \ln \left( \frac{S_1^p}{S_1} \right) \right]^2 + (S_1^p - S_1)^2$$

uses a log scale sum of squares and an arithmetic sum of squares. The former is effective when  $S_1$  is small while the latter is effective when  $S_1$  is large.

### Goodness of fit for survey trends

The NLL used to measure goodness-of-fit for observed and predicted abundance index data with lognormal errors is:

$$L = 0.5 \sum_{j=1}^{N_v} \left[ \frac{\ln \left( I_{v,j} / \hat{I}_{v,j} \right)}{\sigma_{v,j}} \right]^2$$

<sup>6</sup> Quinn and Deriso (1999) describe another approach attributed to a manuscript by C. Walters.

<sup>7</sup> Normally,  $n_G = 2$ .

where  $I_{v,t}$  is an abundance index datum from survey  $v$ , hats “ $\hat{\phantom{x}}$ ” denote model estimates,  $\sigma_{v,j}$  was a log scale standard error (see below), and  $N_v$  was the number of observations. There are two approaches to calculating standard errors for log normal abundance index data in KLAMZ and it is possible to use different approaches for different types of abundance index data in the same model (see below).

Abundance indices with statistical distributions other than log normal may be used as well, but are not currently programmed in the KLAMZ model. For example, Butler et al. (in press) used abundance indices with binomial distributions in a delay-difference model for cowcod rockfish.

#### *Standard errors for goodness of fit*

In the first approach, all observations for one type of abundance index share the same standard error, which is calculated based on overall goodness of fit. The first approach implicitly estimates the standard error based on goodness of fit, along with the rest of the parameters in the model (see “NLL kernels” above).

In the second approach, each observation has a potentially unique standard error that is calculated based on its CV. The second approach calculates log scale standard errors from arithmetic CVs supplied as data by the user (Jacobson et al. 1994):

$$\sigma_{v,t} = \sqrt{\ln(1 + CV_{v,t}^2)}$$

Arithmetic CV’s are usually available for abundance data. It is sometimes convenient to use  $CV_{v,t}=1.31$  to get  $\sigma_{v,t}=1$ .

There are advantages and disadvantages to both approaches. CV’s carry information about the relative precision of abundance index observations. However, CV’s usually overstate the precision of data as a measure of fish abundance.<sup>8</sup> Implicitly estimated standard errors are often larger and more realistic, but imply that all observations in the same survey are equally reliable.

#### *Predicted values for abundance indices*

Predicted values for abundance indices are calculated:

$$\hat{I}_{v,t} = Q_v A_{v,t}$$

where  $Q_v$  is a survey scaling parameter (constant here but see below) that converts units of biomass to units of the abundance index.  $A_{v,t}$  is available biomass at the time of the survey.

In the simplest case, available biomass is:

$$A_{v,t} = s_{v,New} R_t e^{-X_t^{New} \Delta_{v,t}} + s_{v,Old} S_t e^{-X_t^{Old} \Delta_{v,t}}$$

where  $s_{v,New}$  and  $s_{v,Old}$  are survey selectivity parameters for new recruits ( $R_t$ ) and old recruits ( $S_t$ );  $X_t^{New} = G_t^{New} - F_t - M_t$  and  $X_t^{Old} = G_t^{Old} - F_t - M_t$ ;  $j_{v,t}$  was the Julian date at the time of the survey, and  $\Delta_{v,t}=j_{v,t}/365$  was the fraction of the year elapsed at the time of the survey.

Survey selectivity parameter values ( $s_{v,New}$  and  $s_{v,Old}$ ) are specified by the user and must be set between zero and one. For example, a survey for new recruits would have

<sup>8</sup> The relationship between data and fish populations is affected by a host of factors (process errors) that are not accounted for in CV calculations.

$s_{v,New}=1$  and  $s_{v,Old}=0$ . A survey that measured abundance of the entire stock would have  $s_{v,New}=1$  and  $s_{v,Old}=1$ .

Terms involving  $\Delta_{v,t}$  are used to project beginning of year biomass forward to the time of the survey, making adjustments for mortality and somatic growth.<sup>9</sup> As described below, available biomass  $A_{v,t}$  is adjusted further for nonlinear surveys, surveys with covariates and surveys with time variable  $Q_{v,t}$ .

#### Scaling parameters ( $Q$ ) for log normal abundance data

Scaling parameters for surveys with lognormal statistical errors were computed using the maximum likelihood estimator:

$$Q_v = e^{\frac{\sum_{i=1}^{N_v} \left[ \ln \left( \frac{I_{v,i}}{A_{v,i}} \right) \right]^2 / \sigma_{v,i}^2}{\sum_{j=1}^{N_v} \left( 1 / \sigma_{v,j}^2 \right)}}$$

where  $N_v$  was the number of observations with individual weights greater than zero. The closed form maximum likelihood estimator gives the same answer as if scaling parameters are estimated as free parameters in the assessment model assuming lognormal survey measurement errors.

#### Survey covariates

Survey scaling parameters may vary over time based on covariates in the KLAMZ model. The survey scaling parameter that measures the relationship between available biomass and survey data becomes time dependent:

$$\hat{I}_{v,t} = Q_{v,t} A_{v,t}$$

and

$$Q_{v,t} = Q_v e^{\sum_{r=1}^{n_v} d_{r,t} \theta_r}$$

with  $n_v$  covariates for the survey and parameters  $\theta_r$  estimated in the model.

Covariates might include, for example, a dummy variable that represents changes in survey bottom trawl doors or a continuous variable like average temperature data if environmental factors affect distribution and catchability of fish schools. Dummy variables are either 0 or 1, depending on whether the effect was present in a particular year. With dummy variables,  $Q_v$  is the value of the survey scaling parameter with no intervention ( $d_{r,t}=0$ ). For ease in modeling, it is useful to center continuous covariates around their mean:

$$d'_{r,t} = d_{r,t} - \bar{d}_r$$

where  $d'_{r,t}$  is the original covariate. With covariates that are continuous and mean-centered,  $Q_v$  is the value of the survey scaling parameter under average conditions ( $d_{r,t}=0$ )

<sup>9</sup> It may be important to project biomass forward if an absolute estimate of biomass is available (e.g. from a hydroacoustic or daily egg production survey), if fishing mortality rates are high or if the timing of the survey varies considerably from year to year.

and units for the covariate parameter are easy to interpret (for example, units for the parameter are  $1/^\circ\text{C}$  if the covariate is mean centered temperature in  $^\circ\text{C}$ ).

Covariate effects and available biomass are multiplied to compute an adjusted available biomass:

$$A'_{v,t} = A_{v,t} e^{\sum_{r=1}^{n_v} d_{r,t} \theta_r}$$

The adjusted available biomass  $A'_{v,t}$  is used instead of the original value  $A_{v,t}$  in the closed form maximum likelihood estimator described above.

It is possible to use a survey covariate to adjust for differences in relative stock size from year to year due to changes in the timing of a survey. However, this adjustment may be made more precisely by letting the model calculate  $A_{v,t}$  as described above, based on the actual timing data for the survey during each year.

### *Nonlinear abundance indices*

With nonlinear abundance indices, and following Methot (1990), the survey scaling parameter is a function of available biomass:

$$Q_{v,t} = Q_v A_{v,t}^\Gamma$$

so that:

$$\hat{I}_{v,t} = (Q_v A_{v,t}^\Gamma) A_{v,t}$$

Substituting  $e^\gamma = \Gamma + 1$  gives the equivalent expression:

$$\hat{I}_{v,t} = Q_v A_{v,t}^{e^\gamma}$$

where  $\gamma$  is a parameter estimated by the model and the survey scaling parameter is no longer time dependent. In calculations with nonlinear abundance indices, the adjusted available biomass:

$$A'_{v,t} = A_{v,t}^{e^\gamma}$$

is computed first and used in the closed form maximum likelihood estimator described above to calculate the survey scaling parameter. In cases where survey covariates are also applied to a nonlinear index, the adjustment for nonlinearity is carried out first.

### *Survey Q process errors*

The AD Model Builder version of the KLAMZ model incorporates a very useful ability to let survey scaling parameters change, in a tightly controlled fashion, from year to year (NEFSC 2002):

$$Q_{v,t} = Q_v e^{\varepsilon_{v,t}}$$

where the deviations  $\varepsilon_{v,t}$  are constrained to average zero. Variation in survey Q process errors is controlled by the NLL penalty:

$$L = 0.5 \sum_{j=1}^N \left[ \frac{\varepsilon_{v,j}}{\sigma_v} \right]^2$$

where the log scale standard deviation  $\sigma_v$  is supplied by the user (e.g. see NEFSC 2002).



## Recruitment models

Recruitment parameters in KLAMZ may be freely estimated or estimated around an internal recruitment model, possibly based on spawning biomass. An internally estimated recruitment model may be used to reduce variability in recruitment estimates (often necessary if data are limited), to summarize stock-recruit relationships, or to make use of information about recruitment in similar stocks. There are four types of internally estimated recruitment models in KLAMZ: 1) random variation around a constant mean; 2) random walk around a constant mean (autocorrelated variation); 3) random variation around a Beverton-Holt recruitment model; and 4) random variation around a Ricker recruitment model.

The first step in recruit modeling is to calculate the expected log recruitment level  $E[\ln(R_t)]$  given the recruitment model. For random variation around a constant mean, the expected log recruitment level is the log geometric mean recruitment:

$$E[\ln(R_t)] = \sum_{j=1}^N \ln(R_j) / N$$

For a random walk around a constant mean recruitment, the expected log recruitment level is the logarithm of recruitment during the previous year:

$$E[\ln(R_t)] = \ln(R_{t-1})$$

with no constraint on recruitment during the first year  $R_1$ .

For the Beverton-Holt recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln[e^a T_{t-\ell} / (e^b + T_{t-\ell})]$$

where  $a=e^\alpha$  and  $b=e^\beta$ , the parameters  $a$  and  $b$  are estimated in the model,  $T_t$  is spawning biomass, and  $\ell$  is the lag between spawning and recruitment. Spawner-recruit parameters are estimated as log transformed values ( $e^\alpha$  and  $e^\beta$ ) to enhance model stability and ensure the correct sign of values used in calculations. Spawning biomass is:

$$T_t = m_{new} R_t + m_{old} S_t$$

where  $m_{new}$  and  $m_{old}$  are maturity parameters for new and old recruits specified by the user. For the Ricker recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln(S_{t-\ell} e^{a-bS_{t-\ell}})$$

where  $a=e^\alpha$  and  $b=e^\beta$ , and the parameters  $a$  and  $b$  are estimated in the model.

Given the expected log recruitment level, log scale residuals for the recruitment model are calculated:

$$r_t = \ln(R_t) - E[\ln(R_t)]$$

Assuming that residuals are log normal, the NLL for recruitment residuals is:

$$L = \sum_{t=\ell}^N \lambda_t \left[ \ln(\sigma_r) + 0.5 \left( \frac{r_t}{\sigma_r} \right)^2 \right]$$

where  $\lambda_t$  is an instance-specific weight usually set equal one. The additional term in the NLL  $[\ln(\sigma_r)]$  is necessary because the variance  $\sigma_r^2$  is estimated internally, rather than specified by the user.

The log scale variance for residuals is calculated using the maximum likelihood estimator:

$$\sigma_r^2 = \frac{\sum_{j=t_{first}}^N r_j}{N}$$

where  $N$  is the number of residuals. For the recruitment model with constant variation around a mean value,  $t_{first}=1$ . For the random walk recruitment model,  $t_{first}=2$ . For the Beverton-Holt and Ricker models,  $t_{first}= +1$  and the recruit model imposes no constraint on variability of recruitment during years 1 to (see below). The biased maximum likelihood estimate for  $\sigma^2$  (with  $N$  in the divisor instead of the degrees of freedom) is used because actual degrees of freedom are unknown. The variance term is calculated explicitly because it is used in other calculations.

#### *Constraining the first few recruitments*

It may be useful to constrain the first years of recruitments when using either the Beverton-Holt or Ricker models if the unconstrained estimates for early years are erratic. In the KLAMZ model, this constraint is calculated:

$$NLL = \sum_{t=1}^{t_{first}-1} \lambda_t \left\{ \ln \left( \sigma_r + 0.5 \left[ \frac{\ln(R_t / E(R_{t_{first}}))}{\sigma_r} \right]^2 \right) \right\}$$

where  $t_{first}$  is the first year for which expected recruitment  $E(R_t)$  can be calculated with the spawner-recruit model. In effect, recruitments that not included in spawner-recruit calculations are constrained towards the first spawner-recruit prediction. The standard deviation and weights used are the same as used in calculating the NLL for the recruitment model.

#### Prior information about abundance index scaling parameters ( $Q$ )

A constraint on one or more survey scaling parameters ( $Q_v$ ) may be useful if prior information about potential values is available (e.g. NEFSC 2000; NEFSC 2001; NEFSC 2002). In the Excel version, it is easy to program these (and other) constraints in an *ad-hoc* fashion as they are needed. In the AD Model Builder version, log normal and beta distributions may be used as prior information in estimating  $Q_v$  for any abundance index

The user must specify which surveys have prior distributions, minimum and maximum legal bounds ( $q_{min}$  and  $q_{max}$ ), the arithmetic mean ( $\bar{q}$ ) and the arithmetic CV for the prior the distribution. Goodness of fit for  $Q_v$  values outside the bounds ( $q_{min}$ ,  $q_{max}$ ) are calculated:

$$L = \begin{cases} 10000 (Q_v - q_{max})^2 & \text{if } Q_v \geq q_{max} \\ 10000 (q_{min} - Q_v)^2 & \text{if } Q_v \leq q_{min} \end{cases}$$

Goodness of fit for  $Q_v$  values inside the legal bounds depend on whether the distribution of potential values is log normal or follows a beta distribution.

#### *Lognormal case*

Goodness of fit for lognormal  $Q_v$  values within legal bounds is:

$$L = \left[ \frac{\ln(Q_v) - \tau}{\varphi} \right]^2$$

where the log scale standard deviation  $\varphi = \sqrt{\ln(1 + CV)}$  and  $\tau = \ln(\bar{q}) - \frac{\varphi^2}{2}$  is the mean of the corresponding log normal distribution.

#### *Beta distribution case*

The first step in calculation goodness of fit for  $Q_v$  values with beta distributions was to calculate the mean and variance of the corresponding “standardized” beta distribution:

$$\bar{q}' = \frac{\bar{q} - q_{\min}}{D}$$

and

$$Var(q') = \left( \frac{\bar{q} CV}{D} \right)^2$$

where the range of the standardized beta distribution is  $D = q_{\max} - q_{\min}$ . Equating the mean and variance to the estimators for the mean and variance for the standardized beta distribution (the “method of moments”) gives the simultaneous equations:

$$\bar{q}' = \frac{a}{a + b}$$

and

$$Var(q') = \frac{ab}{(a + b)^2 (a + b + 1)}$$

where  $a$  and  $b$  are parameters of the standardized beta distribution.<sup>10</sup> Solving the simultaneous equations gives:

$$b = \frac{(\bar{q}' - 1)[Var(q') + (\bar{q}' - 1)\bar{q}']}{Var(q')}$$

and:

$$a = \frac{b\bar{q}'}{1 - \bar{q}'}$$

Goodness of fit for beta  $Q_v$  values within legal bounds was calculated with the NLL:

$$L = (a - 1)\ln(Q'_v) + (b - 1)\ln(1 - Q'_v)$$

where  $Q'_v = Q_v / (Q_v - q_{\min})$  is the standardized value of the survey scaling parameter  $Q_v$ .

#### Surplus production modeling

Surplus production models can be fit internally to biomass and surplus production estimates in the model (Jacobson et al. 2002). Models fit internally can be used to

<sup>10</sup> If  $x$  has a standardized beta distribution with parameters  $a$  and  $b$ , then the probability of  $x$  is

$$P(x) = \frac{x^{a-1}(1-x)^{b-1}}{\Gamma(a,b)}.$$

constrain estimates of biomass and recruitment, to summarize model estimates in terms of surplus production parameters, or as a source of information in tuning the model. The NLL for goodness of fit assumes normally distributed process errors in the surplus production process:

$$L = 0.5 \sum_{j=1}^{N_P} \left( \frac{\tilde{P}_j - P_j}{\sigma} \right)^2$$

where  $N_p$  was the number of surplus production estimates (number of years less one),  $\tilde{P}_t$  was a predicted value from the surplus production curve,  $P_t$  was the assessment model estimate, and the standard deviation  $\sigma$  was supplied by the user based, for example, on preliminary variances for surplus production estimates.<sup>11</sup> Either the symmetrical Schaefer (1957) or asymmetric Fox (1970) surplus production curve may be used to calculate  $\tilde{P}_t$  (Quinn and Deriso 1999).

It may be important to use a surplus production curve that is compatible with assumptions about the underlying spawner-recruit relationship. More research is required, but the asymmetric shape of the Fox surplus production curve appears reasonably compatible with the assumption that recruitment follows a Beverton-Holt spawner-recruit curve (Mohn and Black 1998). In contrast, the symmetric Schaefer surplus production model appears reasonably compatible with the assumption that recruitment follows a Ricker spawner-recruit curve.

The Schaefer model has two log transformed parameters that are estimated in KLAMZ:

$$\tilde{P}_t = e^\alpha B_t - e^\beta B_t^2$$

The Fox model also has two log transformed parameters:

$$\tilde{P}_t = -e \left( e^{e^\alpha} \right) \frac{B_t}{e^\beta} \log \left( \frac{B_t}{e^\beta} \right)$$

See Quinn and Deriso (1999) for formulas used to calculate reference points ( $F_{MSY}$ ,  $B_{MSY}$ ,  $MSY$ , and  $K$ ) for both surplus production models.

### Catch/biomass

Forward simulation models like KLAMZ may estimate absurdly high fishing mortality rates. The likelihood constrain used to prevent this potential problem was calculated:

$$L = 0.5 \sum_{t=0}^N d_t^2$$

where:

<sup>11</sup> Variances in NLL for surplus production-biomass models are a subject of ongoing research. The advantage in assuming normal errors is that negative production values (which occur in many stocks, e.g. Jacobson et al. 2001) are accommodated. In addition, production models can be fit easily by linear regression of  $P_t$  on  $B_t$  and  $B_t^2$  with no intercept term. However, variance of production estimate residuals increases with predicted surplus production. Therefore, the current approach to fitting production curves in KLAMZ is not completely satisfactory.

$$d_t = \begin{cases} (C_t/B - \kappa) & \text{if } C_t/B > \kappa \\ 0 & \text{otherwise} \end{cases}$$

with the threshold value  $\kappa$  normally set by the user to about 0.95. Values for  $\kappa$  can be linked to maximum F values using the modified catch equation described above. For example, to use a maximum fishing mortality rate of about  $F = 4$  with  $M=0.2$  and  $G=0.1$  (maximum  $X=4+0.2-0.1=4.1$ ), set  $\kappa = F/X(1-e^{-X})=4 / 4.1 (1-e^{-4})=0.96$ .

## Uncertainty

The AD Model Builder version of the KLAMZ model automatically calculates variances for parameters and quantities of interest (e.g.  $R_t$ ,  $F_t$ ,  $B_t$ ,  $F_{MSY}$ ,  $B_{MSY}$ ,  $\bar{F}_{Recent}$ ,  $\bar{B}_{Recent}$ ,  $\bar{F}_{Recent} / F_{MSY}$ ,  $\bar{B}_{Recent} / B_{MSY}$ , etc.) by the delta method using exact derivatives. If the objective function is the log of a proper posterior distribution, then Markov Chain Monte Carlo (MCMC) techniques implemented in AD Model Builder libraries can be used estimate posterior distributions representing uncertainty in the same parameters and quantities.

### Bootstrapping

A FORTRAN program called BootADM can be used to bootstrap survey data in the KLAMZ model. BootADM extracts the standardized residuals:

$$r_{v,j} = \frac{\ln \left( I_{v,j} / \hat{I}_{v,j} \right)}{\sigma_{v,j}}$$

log scale standard deviations ( $\sigma_{v,j}$ , originally from survey CV's or estimated from goodness of fit), and predicted values ( $\hat{I}_{v,j}$ ) for all active survey observations in a "base case" KLAMZ model run. The standardized residuals are resampled from a single pool with replacement to form new sets of bootstrapped survey "data":

$${}^x I_{v,j} = \hat{I}_{v,j} e^{r \sigma_{v,j}}$$

where  $r$  is a resampled residual. BootADM builds new KLAMZ data files and runs the KLAMZ model repetitively, collecting the bootstrapped parameter and other estimates at each iteration and writing them to a comma separated text file that can be processed in Excel to calculate bootstrap variances, confidence intervals, bias estimates, etc. for all parameters and quantities of interest (Efron 1982).

### Projections

Stochastic projections can be carried out using another FORTRAN program called SPROJDDF based on bootstrap output from BootADM. Basically, bootstrap estimates of biomass, recruitment, spawning biomass, natural and fishing mortality during the terminal years are used with recruit model parameters from each bootstrap run

to start and carry out projections.<sup>12</sup> Given a user-specified level of catch or fishing mortality, the delay-difference equation is used to project stock status for a user-specified number of years. Recruitment during each projected year is based on simulated spawning biomass, log normal random numbers, and spawner-recruit parameters (including the residual variance) estimated in the bootstrap run. This approach is similar to carrying out projections based on parameters and state variables sampled from a posterior distribution for the basecase model fit. It differs from most current approaches because the spawner-recruit parameters vary from projection to projection.

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<sup>12</sup> At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

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## **Appendix B.** **(of “C. Atlantic Surfclam” SARC-37 Report):**

### **A Review of Invertebrate Subcommittee meeting, 14-16 April 2003 – *Spisula solidissima* By Dr. Mike Bell, Lowestoft, UK**

The purpose of the meeting was to review the information and methods available for the SARC 37 surfclam stock assessment. This document describes my views, as an outside observer, of the effectiveness of the stock assessment process, in terms of both procedure (representation, meeting process) and scientific quality (biological and fisheries data, analytical approach).

The procedural aspects of the meeting could not be faulted. The agenda was clear and comprehensive, and sufficient relevant information was presented on each agenda item to allow in depth discussion of the scientific and technical issues. The presence of surfclam fishing industry representatives was a huge benefit for the meeting, particularly when it came to discussing technical issues of dredge and vessel performance. Wide industry participation at such meetings should certainly be encouraged in the future.

The science presented at the meeting was also of a very high standard. There were two principal themes for the discussions. Firstly, the meeting focused on the annual research surveys of surfclams, particularly the technical aspects of converting survey catch rates to biomass density estimates in the light of information on dredge performance and efficiency. Secondly, the meeting considered how this survey information can be used together with data on fishery removals to estimate historical trends and current status of both stock and fishery.

Discussions on the research surveys concentrated firstly on how best to use dredge sensor data (principally inclinometer and pump flow measurements) to judge when the survey dredge was fishing effectively. This is important for determining the effective area from which a survey catch is taken. Rigorous, in depth discussions resulted in a agreed criteria for determining the start and finish positions of a survey tow, with dredge performance between these positions considered to be a component of dredge efficiency. Information on survey and commercial dredge efficiency was drawn from a number of experiments and analyses. These included use of the new patch depletion model – an innovative and sophisticated approach for making best use of the available information. Some uncertainty about survey dredge efficiency remains, since estimates differ somewhat between the sources. However, discussions at the meeting led to the placing of effective bounds on the range of possible variation through comparison of the performance of research and commercial vessels. An important outcome of this meeting will be that the swept area biomass estimates for surfclams are as scientifically rigorous and defensible as is possible given the current survey data.

The research survey data are used to ‘tune’ the analytical assessment model. This is the ‘KLAMZ’ delay-difference model, a sophisticated forward simulation approach using fishery and survey data together with information on growth. The (provisional) outcome of the model shows a similar current surfclam stock status to the previous assessment (SARC 30), but a very different view of historical stock trends. This outcome is encouraging in the sense that recent biomass estimates appear to be robust to model assumptions. The updated view of historical trends is certainly plausible given the survey data, and probably the is best that is possible given the current state of understanding. However, some problems with the model were identified, such as the difficulty in modelling the fishing down of the older age groups and the sensitivity to assumptions about recruitment. Taken together, these difficulties indicate that there is still much uncertainty about historical stock trends. Critically, the



assessment also needs to reconcile the marked difference between modelled and observed trends in recent LPUE.

The suggested way forward for analytical assessment is to use explicitly age-based models. Besides moving away from some of the difficulties in defining growth within the 'KLAMZ' model, an age-based approach would be more transparent to all stakeholders in the assessments. Age in surfclams is readily determined and the introduction of routine age determination for fishery catch samples (as opposed to inferring age from size) would further facilitate the use of explicit age-based assessments in future. It will also be important to consider spatial patterns in both population processes and exploitation. Spatial patterns are important because fishery trends may be influenced by the targeting of high catch rate areas within a sedentary stock, and because locally acting and density-dependent factors may be very significant for bivalve population dynamics. Consideration of spatial factors (and gear width) in analyses of commercial CPUE will be helpful in this context. Interpretation of survey and fishery data also needs to take place in relation to what is considered 'normal' population behaviour. For example, are zero catches in recent research surveys in the inshore and southern stock areas a cause for concern? Or, are they merely a consequence of the temporal and spatial dynamics of recruitment in surfclams? The time series of age-composition and abundance data from the research surveys represents a substantial resource for investigating the temporal and spatial scales at which year class strength varies. It may be crucial to determine the influence of environmental factors on this variation – are recent temperature trends likely to change the long-term geographic range of successful reproduction in surfclams?

In summary, the assessment process witnessed at this meeting was of very high quality. The meeting was conducted in a spirit of rigorous science with free and frank discussion of its limitations. The assessment results represent the best current scientific understanding of the status of surfclam stocks. Some areas for future progress were nevertheless identified, indicating a continuing positive trend in the state of surfclam assessment science.

Mike Bell

14 May 2003

## D. Northern Shortfin Squid (*Illex illecebrosus*)

### TERMS OF REFERENCE

The following Terms of Reference were addressed:

1. Characterize fishery performance since the last assessment based on landings, discards, fishing effort and other relevant data.
2. Estimate fishing mortality and stock biomass in absolute or relative terms, as appropriate, and characterize uncertainty of estimates.
3. Evaluate stock status relative to current reference points. Using new biological information, update or re-estimate biological reference points as appropriate.
4. Evaluate new assessment approaches potentially useful for short-lived *Illex* squid. In particular, characterize performance of the new stock assessment model developed for SARC-29; propose improvements as appropriate. Evaluate recent experimental tow-by-tow fisheries data collection programs for use in real-time management. If possible, evaluate environmental indices that might be used to predict availability or productivity.

### INTRODUCTION

The *Illex illecebrosus* stock was last assessed in 1999 at the 29<sup>th</sup> Stock Assessment Workshop (SAW) (NEFSC 1999a). The assessment included updates of fisheries and research survey data for 1994 through 1998. A DeLury depletion-type model that assumed no recruitment, incorporated weekly landings and effort data from the Vessel Trip Report (VTR) database, mean body weights in the landings and a constant, weekly natural mortality rate of 0.06, were used to estimate initial stock size and fishing mortality in the U.S. fishing area during 1994-1998 (NEFSC 1999b). The fishing mortality estimate was interpreted as an upper bound for the U.S. stock component. An imprecise, lower bound on fishing mortality was computed by reducing the upper bound to account for unfished habitat in U.S. waters. The latter, lower bound estimate was considered the most appropriate metric for determining stock status because Northeast Fisheries Science Center (NEFSC) spring and autumn survey distribution maps indicated that *Illex* migrates through the fishing grounds in a “wave” pattern rather than a “gauntlet” pattern. However, the collection of tow-based fisheries data was recommended to better understand in-season LPUE trends and to assess the appropriateness of utilizing a DeLury depletion model for in-season stock assessment.

The SARC 29 assessment also included a weekly yield-per-recruit (YPR) and spawning stock biomass-per-recruit (SSB/R) analysis that incorporated a 1994-1998 composite exploitation pattern, a constant natural mortality rate of 0.06 per week, and input data from SARC 21 (NEFSC 1996) that was converted to weekly values. Growth and maturity of *Illex* were among the major model uncertainties because growth and maturity data were from *Illex* in the 1990 Newfoundland jig fishery where biological characteristics are substantially different. SARC-29

recommended a target fishing mortality rate of  $F_{50\%}$  as an  $F_{MSY}$  proxy in order to minimize the potential for recruitment overfishing. In addition, a constant escapement harvest policy and in-season stock assessment approaches were recommended to minimize recruitment overfishing and maximize yield. In addition, a constant escapement harvest policy and in-season stock assessment approaches were recommended to minimize recruitment overfishing and maximize yield.

With respect to stock status, SARC 29 concluded that overfishing was not likely to have occurred during 1994-1998 because the upper and lower bounds on fishing mortality estimates were below potential  $F_{MSY}$  proxies. However, an evaluation of whether the stock was overfished was not possible because no representative measure of stock biomass and corresponding reference point were available.

The current assessment pertains to the U.S. EEZ portion of the stock and updates fisheries data and indices of relative abundance and biomass during 1999-2002. A new maturation model that incorporates the semelparous life history of *Illex*, allows for estimation of spawning mortality rates and new information regarding the age composition, growth and maturity of *Illex* inhabiting U.S. waters is presented. Output from the maturation model, including the probability of spawning at age and spawning mortality rate estimates, are incorporated into yield-per-recruit and egg-per-recruit analyses along with revised selectivity estimates and mean weights in the catch, during 1999-2002, to derive new biological reference points that may serve as  $F_{MSY}$  proxies. Tow-based fisheries data from a real-time data collection program were utilized in a preliminary model which may be useful in future assessments for in-season estimation of stock size and fishing mortality rates.

## BACKGROUND

A review of the biology, population dynamics and exploitation of the *Illex illecebrosus* stock in the northwest Atlantic Ocean, in relation to stock assessment and management, 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; Hendrickson *In Review*). 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 et al. 1998). Recruitment dynamics are complex and have not been fully elucidated for the U.S. EEZ component of the stock, so that reliable predictions of annual recruitment levels are not currently possible. Stock structure is complex and, in Newfoundland waters, is complicated by overlapping seasonal cohorts that migrate through the fishing grounds (Dawe and Beck 1997). Mean size at sexual maturity varies between northern and southern geographic regions in some years (Coelho and O'Dor 1993). However, it is not known whether these differences were due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal spawning patterns could have played a role in the collapse of the Canadian fishery during the early 1980's.

The *Illex* stock is transboundary in nature 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 or biomass. The NEFSC bottom trawl surveys do not cover the entire habitat range of this species and it is unknown whether the survey indices measure relative abundance or availability to the survey gear. In addition, U.S. fisheries data is of coarse temporal and spatial resolution and age and growth information is lacking for the U.S. stock component. As a result, research recommendations in previous assessments have emphasized the need for improved stock assessment data, particularly since *Illex* lives for less than one year and the U.S. fishing season is of short duration (4-5 months on average). As a result, the NEFSC has conducted several cooperative research projects with the *Illex* fishing industry that have resulted in: (1) improved spatial and temporal resolution of fisheries catch, effort and biological data; (2) characterization of the age composition, growth, and maturity of *Illex* inhabiting U.S. waters prior to the start of the fishery; and (3) the collection of fisheries data, in real-time, via electronic logbook reporting. The products of these research projects are used extensively in the current assessment.

During 1999, a large portion of the *Illex* fleet participated in a real-time data collection study that involved recording tow-based catch, effort and fishing location data, in hardcopy form, with weekly submittals of these data to the NEFSC. In addition, squid processors provided mantle length and body weight data from squid collected daily during each trip. Study participants attended a workshop at which the results were presented and improvements for future data collection activities were recommended. The study results were also posted on an NEFSC website.

Data collection from the *Illex* fishery continued during 2000-2001 in hard copy format. In 2002, tow-based, data were collected electronically in real-time, via e-mail, and automatically loaded into Oracle tables (Hendrickson et al. 2003). Vessel operators were able to log on to secure, personal web sites to edit and confirm their fisheries data collected at sea, and to incorporate additional vessel data required for logbooks. The web site also allowed fishermen to view their personal catch and oceanographic data through the use of an interactive mapping tool and print hardcopy logbooks for their records. The study demonstrated that electronic logbook reporting offers an efficient, cost-effective means of collecting accurate, high resolution fisheries and oceanographic data that can rapidly be made available to fishermen and stock assessments scientists.

During May 2000, a pre-fishery bottom trawl survey was conducted with two squid vessels, chartered by the NEFSC, to assess initial stock size and distribution and to collect biological data for age, growth and maturity analyses (Hendrickson *In Review*).

## MANAGEMENT

Commercial fisheries for *I. illecebrosus* occur from Newfoundland to Cape Hatteras, North Carolina. The fishery operating within the U.S. EEZ (Northwest Atlantic Fisheries Organization Subareas 5 and 6) is managed by the Mid-Atlantic Fishery Management Council (MAFMC) and fisheries operating within Northwest Atlantic Fisheries Organization (NAFO) Subareas 2, 3 and

4 are managed by NAFO (Figure D1). During 1980-1998, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 was 150,000 mt (NAFO 1995). The NAFO TAC was reduced to 75,000 mt in 1999 (NAFO 1998) and has been 34,000 mt since 2000 (Hendrickson *et al.* 2003). 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 in 1996 (MAFMC 1995a) and 19,000 mt during the 1997-1999 fishing seasons (MAFMC 1996a; 1997a; 1998a). The DAH has been 24,000 mt since 2000 (MAFMC 2000; 2001; 2002).

Amendment 5 of the SMB FMP was enacted (MAFMC 1995b; 1996b) in recognition that the domestic resource was approaching full utilization and that expansion of the U.S. fleet might lead to overcapitalization. Amendment 5 established a permit moratorium to limit entry into the directed fishery, required mandatory logbook and dealer reporting as of January 1, 1997, and established a 5,000-pound trip limit for incidental catches of *Illex* by non-moratorium vessels. Amendment 6 (MAFMC 1996c) allowed for the potential to establish seasonal closures of the *Illex* fishery and set the current overfishing definition of  $F_{20\%}$  and established procedures for the specification of annual quotas based on  $F_{50\%}$ . Amendment 7 (MAFMC 1998b) was enacted to achieve consistency between FMP's with regards to Limited Access Federal permits. Based on the requirements of the Sustainable Fisheries Act (SFA), Amendment 8 (MAFMC 1998c) established a new overfishing definition and  $F$  target defined as the catch associated with  $F_{MSY}$  and 75% of  $F_{MSY}$ , respectively. In addition, a biomass target and minimum biomass threshold were specified as  $B_{MSY}$  and 50% of  $B_{MSY}$ , respectively. Amendment 8 also defined the essential habitat of *Illex* in the U.S. EEZ and established a framework adjustment process for specific management measures. Amendment 9 is currently in draft form, and with respect to *Illex*, could: 1) extend the moratorium on entry to the commercial *Illex* fishery, 2) allow for specification of management measures covering multiple years, 3) allow for the transit of vessels through the U.S. EEZ which possess greater than 5,000 pounds of *Illex* caught outside the U.S. EEZ when a trip limit is in effect, 4) implement management alternatives for Atlantic mackerel, squid, and butterfish to prevent, mitigate or minimize adverse effects from fishing which would bring the FMP into compliance with Section 303(a)(7) of the SFA, and 5) implement measures to reduce discards in the *Illex* fishery.

## THE FISHERIES

### Landings

*Illex* landings (mt) during 1963-2002 are presented by NAFO Subarea (Figure D1). Subareas 5+6 (U.S. EEZ) landings are partitioned into foreign and domestic components (Table D1). Total allowable catches (TACs) established for NAFO Subareas 3+4 and Subareas 5+6 during 1974-2002 are also presented in Table D1. Prior to 1976, U.S. EEZ landings of squid by distant water fleets were not consistently reported by species. As a result, *Loligo pealeii* landings are included with *Illex* landings prior to 1976. In addition, squid landings were not recorded by species in the NEFSC commercial fisheries "Weighout" database until 1979. As a result, U.S. EEZ landings during 1963-1978 were derived from 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). U.S. EEZ landings during 1979-2002 are from the Weighout database and include landings from joint ventures that occurred during 1982-1990 between U.S. and foreign fishing vessels. Landings from NAFO Subareas 3+4, during 1963-2002, were taken from Hendrickson et al. (2002) and 2003 landings were reported by E. Dawe, Canada Department of Fisheries and Oceans (pers. comm. 2003).

Historically, total *Illex* landings have varied considerably and consisted of three distinct levels of magnitude (Figure D2A). A period of high landings occurred during 1976-1981, when distant water fleets were active in all NAFO fishing areas, which was preceded and followed by periods of substantially lower landings. During 1963-1967, total landings were low, averaging 7,354 mt, and were primarily from the Subarea 3 inshore hand jig fishery. During 1968-1974, total landings averaged 13,470 mt and were predominately from distant water fleets fishing in Subareas 5+6. However, this trend was reversed during 1976-1981, when landings were predominately from Subareas 3+4. During this time, total landings averaged 100,300 mt, and in 1979, reached the highest level on record (179,333 mt). During 1979-1983, landings from Subareas 3+4 declined rapidly from 162,092 mt to 426 mt. However, landings from Subareas 5+6 remained stable, in part, due to effort limitations placed on the distant water fleets fishing in U.S. waters. Total landings have been dominated by the U.S. domestic bottom trawl fishery since its inception in 1982. The exception occurred in 1997, when landings from Subareas 3+4 (15,485 mt) exceeded U.S. EEZ landings (13,629 mt) and were at their highest levels since 1982. Landings from Subareas 3+4 declined to 1,902 mt in 1998 and have been less than 400 mt since then. The decline in landings was primarily due to the lack of a bycatch fishery for *Illex* in Subarea 4 since 2000 (Hendrickson et al. 2002).

U.S. EEZ landings were characterized by two distinct periods (Figure D2B). During 1968-1982, U.S. EEZ landings were predominately taken by distant water fleets, and in 1976, reached a peak of 24,936 mt. U.S. EEZ landings subsequently declined to 1,958 mt in 1988 (Figure D2B). There has been no foreign participation permitted in the U.S. *Illex* fishery since 1987 in order to foster development of a domestic fishery. During 1998-1994, landings from the domestic fishery increased from 1,958 mt to 18,350 mt, then reached a peak of 23,597 mt in 1998. This 1998 peak led to an early closure of the fishery because the landings quota was exceeded. Since 1998, U.S. EEZ landings have been below the 1982-2002 average, and in 2002, reached their lowest level since 1988 (2,723 mt).

The Weighout database indicates that a majority ( $\geq 98\%$ ) of the annual U.S. landings are taken with bottom trawls. 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 the bottom trawl fishery. The Vessel Trip Report (VTR) database and NEFSC Sea Sampling database indicate that the U.S. EEZ *Illex* fishery occurs primarily at depths between 128 and 366 m. Gear limitations prevent fishing, by the larger freezer trawlers, in waters deeper than 457 m (Glenn Goodwin, pers. Comm. 1999).

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 of the continental shelf, although worldwide squid market conditions also influence the timing of the fishing season

in the U.S. EEZ. Inshore migration in Subarea 3 generally occurs during July, 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 presumably a result of the position 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 during July, in Subareas 4, 5, and 6, during September in Subarea 3 (NEFSC 1999b).

In-season trends in *Illex* landings and the duration of the fishing season vary by year (NEFSC 1999b). Since 1987, the U.S. fishery has occurred between May and November, but most of the landings (90%) are taken between June and September (NEFSC 1999b). Weekly trends in *Illex* landings from the VTR database are similar to those from the Weighout database, with the exception of weeks 30 through 33 in 2000. A comparison of landings by vessel and trip in both databases confirmed missing VTR data for one vessel during those weeks. During 1999-2002, the fishery began during weeks 22 or 23 and lasted for a period of 17 to 21 weeks (Figure D3). Weekly landings were highly variable, which made it difficult to detect the inflection point after which landings declined, particularly in 2001 and 2002. This variability is partly attributable to the coarser temporal resolution of the VTR database, which necessitates assigning week of the year by the date landed instead of the tow date, as is possible with use of the real-time reporting data (Figure D4). In-season landings variability is also attributable to a reduction in the number of tows across weeks due to reduced participation in the fishery during 1999-2002 (see section Landings per Unit Effort below).

#### Discard Estimation

In addition to the *Illex* fishery, which is characterized by a codend mesh size of approximately 38.1 mm, other fisheries likely to incur *Illex* bycatch are those that utilize bottom trawls of similarly small mesh and that occur during May-November, when *Illex* is present on the U.S. continental shelf. The offshore *Loligo* fishery meets both criteria and catch data from observed trips from the NEFSC Observer Program database indicate that a majority of the *Illex* bycatch, during 1995-2002, occurred in the offshore *Loligo* fishery.

*Illex* discards (mt) in the *Illex* and *Loligo* fisheries were estimated, by month and year, from catch data collected during trips sampled by observers from the NEFSC Sea Sampling Program during 1995-2002. The *Illex* fishery was defined as bottom trawl trips that occurred during May-October in which *Illex* landings comprised  $\geq 25\%$  of the total trip weight. The *Loligo* fishery was defined as bottom trawl trips that occurred during November-April in which *Loligo* landings comprised  $\geq 25\%$  of the total trip weight. Annual estimates of *Illex* discards were computed by multiplying the discard ratio (*Illex* discarded/*Illex* or *Loligo* kept, mt) by either the *Illex* or *Loligo* landings.

The annual sampling intensity of trips observed in the *Illex* fishery was low, ranging between 2 and 15 trips (Table D2), and represented 0.01-4.54% of the annual *Illex* landings (Table D3). There were no *Illex* trips sampled during 2001 or 2002. Temporal discarding patterns could not be discerned because the number of trips sampled by month was not representative of the seasonal landings pattern. The amount of *Illex* discarded in the *Illex* fishery, during 1995-2000, ranged between 29 mt and 150 mt per year.

The annual sampling intensity of trips observed in the *Loligo* fishery was also low, ranging between 3 and 18 trips (Table D4), and represented 0.07-2.25% of the annual *Loligo* landings (Table D3). Sampling coverage was inconsistent during the fishing season, so monthly trends in discarding could not be discerned. Inconsistent sampling may also be reflected in the spatial patterns of discarding which varied greatly during 1999-2001 (Figures D5A and B). During 2001, Gear Restriction Areas (GRA's) were established to reduce scup bycatch. The Southern GRA is closed to small-mesh (< 4.5 inch codend mesh) fisheries during January through March 15 (Figure D6). NEFSC spring survey data indicate that *Illex* migration onto the U.S. continental shelf generally begins in March, during the latter part of the closure period. However, observer data were inadequate to evaluate whether this closure area will also aid in the reduction of *Illex* discarding in the *Loligo* fishery. The amount of *Illex* discarded in the *Loligo* fishery, during 1995-2002, ranged between 1 mt and 303 mt per year.

In summary, *Illex* discard estimates are imprecise but the overall level of discard in recent years was likely small. During 1995-2002, *Illex* discarded in the two squid fisheries ranged between 53 mt and 453 mt and comprised 0.5-4.4% of the total *Illex* landings during this time period (Table D3). *Illex* discarding in both squid fisheries was highest during 1998, when *Illex* abundance was highest. However, a quantitative comparison of discarding between years and months was difficult due to low sampling intensity, by month and year, in both fisheries.

#### Mean Size of *Illex* in the Fishery

Average body size and within season trends in average size are potentially important for *Illex* because changes in size reflect the combined effects of growth, mortality, emigration and immigration from fishing grounds. Consequently, mean size data likely contain information useful in stock assessment modeling (NEFSC 1999b). *Illex* landings were sampled by squid processors, for mantle length (cm) and body weight (g), during 1999-2002 (Table D5) and during 1994-1998 (NEFSC 1999b). *Illex* landed during 1999-2002 were smaller and weighed less than in most years since 1994. Median mantle lengths were highest during 1994 and lowest in 1996 and 2001 (Figure D7A). Likewise, median body weight was highest during 1994 and lowest in 2001 (Figure D7B). Median mantle length and body weight, during 2001, was significantly lower than during 1994-1998, with the exception of 1996. Interannual trends in squid size are likely attributable to environmental conditions, particularly if they persist across multiple years, but size trends may also reflect fishing in different geographic areas. A review of bottom water temperature anomalies in the Mid-Atlantic Bight indicated that bottom temperatures near the shelf edge were warmer than average during large portions of the year in 1999-2002 (Jossi and Benway 2003) when *Illex* mean body size was small and fishing success was low.

The Lowess-smoothed trend line of average weight in the landings during 1994-1998 show a steady increase in average size from 50-175 g between week 20 and 34 (Figure D8A). A 1999-



2002 composite of average body weights indicated a different pattern of seasonal change in average body size. During weeks 22 through 30, the increase in average body weight was more gradual and average body size was smaller, an increase from 70 to 110 g (Figure D8B). Thereafter, average size was generally stable. The attainment of an asymptotic average size may be partially driven by the recruitment of smaller squid, but most likely reflects the emigration of larger squid. In autumn, the density of large squid increases with depth and is highest in the deepest strata (186-366 m) during this offshore migration period (Brodziak and Hendrickson 1999). Maximum average size in the fishery during 1999-2002 occurred one month earlier, at week 30, than during 1994-1998 and was only 60% (110 g) of the 1994-1998 value.

## ABUNDANCE AND BIOMASS INDICES

### Research Vessel Survey Indices

Although there are no stock-wide indices of abundance or biomass for the *Illex* stock, a number of surveys may provide some information about local abundance or trends. The NEFSC spring bottom trawl survey occurs at a time when *Illex* are migrating onto the U.S. continental shelf and the autumn survey occurs during an offshore migration period (Hendrickson et al. 1996). A portion of the stock may reside outside the range of the surveys and the fishery, and therefore, LPUE and survey indices may represent the on-shelf availability of *Illex* rather than abundance or biomass indices. The outer shelf and continental slope are important *Illex* habitats (Lange 1981) that are not intensively sampled during NEFSC bottom trawl surveys (Figure D9). In addition, the survey bottom trawl gear is not likely to sample pelagic species efficiently.

The NEFSC autumn bottom trawl survey occurs near the end of the fishing season and approximates a post-fishery index for the area surveyed. Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean weight per tow, in kg) from NEFSC autumn bottom trawl surveys, conducted during 1967-2002, are the best abundance information available for *Illex* in U.S. waters. 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 D10) were used to compute abundance and biomass indices, which were adjusted for differences in research vessel effects. 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 *Delaware II* catches to the *Albatross IV* catches (Hendrickson et al. 1996). Indices from NEFSC spring surveys, conducted during March, were also computed. Abundance and biomass indices from the Canadian bottom trawl survey, conducted on the Scotian Shelf (NAFO Division 4VWX) during July, are presented for comparative purposes. The Canadian survey occurs just after the start of the fishery and may approximate a pre-fishery index for the area surveyed.

As might be expected for an annual species with environmental effects on availability and recruitment, all of the survey indices show a large degree of interannual variability. Autumn survey indices indicate that *Illex* abundance on the U.S. shelf was high during 1976-1981 and during 1987-1990 (Figure D11A). However, autumn survey abundance indices have been below the 1982-2002 average since 1998, and in 1999, were the lowest on record (Table D6). NEFSC spring survey indices are more variable than those from the autumn survey due to variability in

the timing of on-shelf migrations. However, a notable trend is the peak in abundance and biomass indices that occurred during 1997 and 1998, which coincides with the 1998 peak in domestic landings (Figure D11B). Canadian survey indices also show a peak in abundance and biomass during 1976, but not for an extended period of time. During 1992-1994, *Illex* were fairly abundant, but abundance has declined since 1997 and was at the lowest level on record during 2000 and 2001, with only a slight increase during 2002 (Figure D11A). Based on an extended period of low *Illex* biomass in the July 4VWX surveys (Figure D11C) and smaller than average body size, since 1982, the SA 3+4 component of the stock has been characterized as being in a low productivity regime (Hendrickson et al 2002). The average body size of *Illex* caught in the NEFSC autumn surveys has also been much lower since 1982 and below average during most years since (Figure D12A). Average body size in the NEFSC spring survey has been below average since 1995 (Figure D12B). This observed difference in mean weights may be due to differing contributions of seasonal breeding components or differing growth conditions during these periods.

The percentage of tows in which *Illex* were caught in all offshore strata, was computed from the NEFSC spring and autumn survey data to assess *Illex* availability on the U.S. continental shelf. *Illex* are generally caught at less than 10% of the offshore stations sampled during spring surveys, but both spring and autumn surveys suggest that the distribution of *Illex* is more dispersed during periods of high survey abundance (Figure D13).

The migration of *Illex* squid into northern fishing areas off Newfoundland is affected by oceanographic conditions (Rowell et al. 1985; Dawe and Warren 1992; Dawe et. al. 1998). The autumn distribution of adult *Illex* on the U.S. continental shelf is affected by water temperature conditions and bottom temperatures ranging from 9-13°C are preferred (Brodziak and Hendrickson 1999). An increasing trend in areal average surface and bottom temperature anomalies (warmer than average temperatures) has been occurring in the Mid-Atlantic Bight during the spring since 1996 (Figure D14) (Holzwarth and Taylor 1992, 1993 and 1994; Taylor and Almgren 1996a and 1996b; Taylor and Kalidas 1997; Taylor and Bascunan 1998, 1999, 2000 and 2001; Taylor et. al. 2002). Anomalies were computed in relation to a 1977-1987 reference period using the method of Holzwarth and Mountain (1990). Autumn surface and bottom temperature anomalies increased after 1998. A correlation analysis was used to investigate the relationships between environmental trends and trends in *Illex* abundance, biomass, and average body size in U.S. waters. The results indicated that abundance and biomass indices from the autumn surveys and spring average body weights were significantly negatively correlated with bottom water temperature anomalies from the autumn surveys (Table D7). Interpretation is complicated because spring and autumn bottom water temperature anomalies are correlated. However, relationships between environmental conditions and the availability of *Illex* to U.S. fisheries is an important topic for future research.

#### Landings per Unit Effort

During previous assessments, standardized LPUE indices for 1982-1993 were computed for the domestic *Illex* fleet (NEFSC 1996). However, this LPUE time series could not be updated because of methodological changes in data collection since 1993. The 1982-1993 time series consisted of fishing effort and location data collected by port agents during interviews with fishing vessel captains. This data collection method was changed in May of 1994, when fishing

effort and location data were reported by vessel operators on Vessel Trip Reports (VTR). However, submittal of VTR data did not become mandatory for *Illex* squid moratorium permit holders until January 1, 1997. Consequently, fishing effort and location data for the *Illex* fishery are incomplete for the 1994-1996 fishing seasons (NEFSC 1999b).

Within season LPUE data are potentially important for *Illex* assessments because, as noted by Caddy (1991), the seasonal pattern of LPUE 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. Implementation of in-season management would require an ability to detect such point changes in the LPUE slope. However, a declining trend in weekly LPUE data from the U.S. *Illex* fishery was not detectable in some years (NEFSC 1999b). In order to better understand the LPUE trends, spatial changes in fishing patterns were evaluated and the effects of various factors on the standardization of fishing effort were assessed.

### Fishing Effort

A geographic information system (GIS) was used to examine the spatial distribution of effort in the *Illex* fishery, by quarter-degree square, during 1999-2002. A substantial decrease in the area fished by the *Illex* fleet occurred between 1999 and 2002 (Figure D15). During 2000-2002, fishing effort (days fished) became concentrated along the shelf edge in more southerly, localized areas (south of 38° N latitude). This spatial pattern is due to a feedback effect such that high catch rates lead to more tows in the same vicinity. Fishing locations varied between the two fleet sectors; freezer trawlers and recirculating seawater system (RSW) trawlers. An areal decrease in the area fished between 1999 and 2002 occurred in the RSW fleet (Figure D16), but the freezer trawlers consistently fished a core area during this time period (Figure D17). This difference in fishing patterns is attributable to the ability of freezer trawlers, with greater hold capacities, to make trips of longer duration. Freezer trawlers did not fish on the northernmost fishing grounds, near the shelf edge in southern New England, during 2001 or 2002.

Spatial patterns in fishing effort are partly due to a reduction in the number of vessels participating in the fishery during 1999-2002. A decline in the number of RSW vessels occurred between 1999 and 2000 then stabilized at a low level (Figure D18A). However, the number of RSW trips consistently declined during 1999-2002 (Figure D18B). Freezer trawler participation declined more rapidly, particularly between 1999 and 2001 (Figure D18A), yet the landings during 1999-2002 were predominately (82-96%) from the freezer trawler fleet (Figure D18C). This is explained by the fact that the average trip duration and the average effort (days fished) of freezer trawlers during this period was approximately three times that of RSW trawlers (Figure D19, Table D8).

As discussed in the Landings section, trends in weekly landings from the Weighout database closely match those from the VTR database. As a result, the VTR data were used in the current assessment to assess annual and in-season trends in LPUE, by assigning each subtrip to a week of the year based on the date landed. Subtrips in the *Illex* fishery are defined as fishing within different Statistical Areas (Figure D20). Nominal LPUE was estimated using a ratio estimator of total VTR landings divided by total VTR effort during each week in 1999-2002. Average LPUE for RSW vessels declined drastically during 1999-2002, from 23.9 mt to 7.3 mt, but freezer

trawler LPUE was stable during this time period. Overall, total landings and effort declined during 1999-2002 and this resulted in a nominal LPUE trend that was low and stable (Table D9, Figure D21).

Similar to weekly landings trends, in-season trends in nominal LPUE were highly variable and this variability increased between 1999 and 2002. Standardization of catch rates was evaluated in order to determine whether this would improve the ability to detect a declining trend in weekly catch rates. A three-factor, main effects General Linear Model (GLM) was applied to log-transformed LPUE data (mt per day fished) for each year (1999-2002). As in previous assessments, directed trips used in the GLM were defined as otter trawl trips that occurred during May through November and that landed at least 25%, by weight, of *Illex*. Factors included in the initial model runs included: week of the year and either quarter-degree square or latitude and depth, and either vessel type (RSW or freezer trawler) or crew size. Final model runs included the factors: vessel type, quarter-degree square and week of the year, because initial model runs indicated that these factors were significant at the 5% level during most years. However, the significance of these effects varied between years (Table D10). Significant model results were obtained for 1999-2001 and indicated that week of the year and vessel type are important factors in explaining changes in LPUE. Vessel type was not significant during 1999 and week of year was not significant during 2002. The influence of spatial effects (quarter-degree square) on LPUE were less important and were only significant during 2000. GLM model results for 1999 are presented in Table D11 and indicated good fit ( $r^2 = 0.70$ ). Standardized fishing effort and LPUE during 1999 are presented, by week, in Table D12. Standardized LPUE was not as variable as nominal LPUE, and in 1999, showed a general increase between weeks 25 and 32, followed by a decline (Figure D22B). The use of LPUE indices in future stock assessment models should include standardization.

## LIFE HISTORY PARAMETERS

Previous *Illex* stock assessments (NEFSC 1996; NEFSC 1999b) incorporated growth and maturity data from a statolith-based aging study conducted on *Illex* sampled in the Newfoundland jig fishery during 1990 (Dawe and Beck 1992; Dawe and Beck 1997). The current assessment incorporates new information about the growth, maturity and age composition of *Illex* sampled from U.S. waters prior to the start of the fishery. The new data are the result of a statolith-based age analysis of squid caught during an *Illex* bottom trawl survey conducted by the NEFSC during May 19-29, 2000 (Hendrickson *In Review*). The age analysis was conducted using the method of Dawe and Beck (1997) and included a double-blind age analysis of 20 individuals in order to estimate aging error. Unlike the Newfoundland growth rate study (Dawe and Beck 1997), growth rates estimated from the May 2000 survey data included the full range of the maturity spectrum, including the largest number of mature females captured to date.

A major discovery during the May 2000 survey was in the initial documentation of a spawning site for the *Illex* stock, on the continental shelf in the Mid-Atlantic Bight, which was based on the distribution of mature and mated females (Figure D23).

### Growth Rates

Weight-at-age relationships, for females and combined sexes, used in the assessment were for squid collected during the May 2000 *Illex* survey (Hendrickson *In Review*) and are shown in Figure D24.

### Natural Mortality

Stock assessment models should account for the fact that *Illex illecebrosus* is a semelparous species with high post-spawning natural mortality rates. The maximum longevity of *Illex* inhabiting U.S. waters is about 215 days (Hendrickson *In Review*). Although the exact time span between spawning and death is unknown, it is probably several days. Female *Illex* held in captivity spawned multiple egg balloons then died shortly after spawning (O’Dor et al. 1980). A weekly time step was used for modeling in this assessment, with all individuals within a weekly time bin being assumed to be in the middle of their age bin. All mortality and maturity parameter estimates are in units of weeks.

### Maturation-Natural Mortality Model

A maturation-mortality model was developed to estimate female maturation rates and natural mortality of females attributable to spawning. Because females die soon after spawning, natural mortality was partitioned into spawning ( $M_{SP}$ ) and non-spawning ( $M_{NS}$ , due e.g., from predation) components, based on age and maturity data collected during a May 2000, pre-fishery survey of *Illex* inhabiting U.S. waters (Hendrickson *In Review*). The model tracks maturity and mortality in an unfished cohort of females as they begin to mature, spawn and die at a higher rate than non-mature females. The model incorporated female age composition data for spawners and non-spawners, with spawners defined as mature (Stage 5) females. The model also incorporated maturity at age data that was used to estimate the weekly probability of spawning at age to estimate a weekly probability of spawning throughout the lifespan of an individual. Because of substantial imprecision in ageing *Illex*, ageing error is incorporated explicitly in the model calculations. Corrections for ageing error are based on data from a double-blind aging precision study of 20 squid captured during the May 2000 *Illex* survey (Hendrickson *In Review*). In addition, model calculations deal explicitly with under-representation of spawning females in field samples due to their higher natural mortality rate. Sensitivity analysis was used to evaluate a range of model and parameter assumptions. The model was implemented in AD Model-Builder, allowing for parameters estimates and their standard deviations

The model starts with a cohort of females at age twelve weeks (one week younger than the youngest observed mature female). Let  $N_t$  and  $S_t$  be the number of immature and mature females in the cohort of age  $t$  during week  $t$  (where age and time are both given in weeks). Assuming no fishing (the data were collected prior to the start of the fishery), the number of immature females in the next age group at the beginning of the following week will be:

$$N_{t+1} = N_t[1 - \exp(-M_{NS}) - p_t],$$

where  $M_{NS}$  is the non-spawning natural mortality (assumed constant with age), and  $p_t$  is the probability that an immature female of age  $t$  will become mature at age  $t$ . The number of mature females at age  $t+1$  will be:

$$S_{t+1} = \exp(-M_{SP})S_t + N_t p_t \exp(-M_{NS}).$$

It will be assumed that the probability of maturing is a logistic function of age:

$$p_t = p_\infty / [1 + \exp(-a(t-h))],$$

where  $p_\infty$  is taken to be 1,  $a$  is the shape parameter, and  $h$  is the half-saturation age at which the probability of becoming mature is 50%. Note that the probability  $p_t$  of a female maturing in a given week is not equal to the probability that a female of age  $t$  in field samples will be mature because the latter depends on the mortality rates of mature females.

The model is fit to two types of data. The first is the proportion of animals of age  $t$  weeks that are mature. Given that there are  $N_t$  individuals in the sample of age  $t$  weeks, and the probability of that age being mature is  $\varphi_t$ , the likelihood that  $k_t$  of them are mature is:

$$L_t = \binom{N_t}{k_t} \varphi_t^{k_t} (1 - \varphi_t)^{N_t - k_t}$$

Using logarithmic transformation and summing over all age groups gives the log-likelihood function:

$$L_b = \sum_t \ln L_t$$

The second type of data is the proportion  $\rho_t$  of all individuals that are of a given age  $t$ . Because of trawl selectivity issues, this calculation is restricted to squid of estimated age 20 weeks or greater. If there are  $m$  mature individuals of these ages, and the probability of any of them being of age  $t$  is  $q_t$ , the likelihood that they will be  $k_1, \dots, k_n$  mature individuals in age classes  $1, \dots, n$  is:

$$L_\omega = \binom{m}{k_1 \dots k_n} \prod_{t=1}^n q_t^{k_t}$$

so that the log-likelihood function for these data is:

$$L_m = \ln \binom{m}{k_1 \dots k_n} + \sum_{t=1}^n k_t \ln q_t$$

These two functions are combined to form a total log-likelihood function that is maximized by the software program:

$$L = \lambda_b L_b + \lambda_m L_m$$

For these runs, the weighting parameters  $\lambda_b$  and  $\lambda_m$  were both taken to be 0.5, so that the two types of data were given equal weight. Because of ageing error, an observation error term (normal with mean zero, standard deviation 13.14 days) was added to “true” ages in the model before predicted values of numbers at age and predicted proportions mature at age were compared in log likelihood calculations to the actual data (which contains measurement errors). This was accomplished by convolving the ageing error vector

$$\mathbf{e} = (0.007, 0.024, 0.062, 0.122, 0.183, 0.122, 0.062, 0.024, 0.007),$$

representing the probability of an ageing error of -4,-3,-2,-1,0,1,2,3, and 4 weeks, respectively, with the predicted age distribution without ageing error.

### Results

As expected, the model results suggested that natural mortality rates of spawning females are substantially higher than for non-spawning females. Model fits were best at a relatively high level of spawning natural mortality (0.80 per week) and at relatively low values of non-spawning natural mortality (Table D13). However,  $M_{NS}$  was difficult to estimate in the model, probably because it is only a small portion of total mortality. In lieu of direct estimates, the model was run with  $M_{NS}$  values of 0.01, 0.03 and 0.06 per week (Figure D25). For each of these values of  $M_{NS}$ , maximal likelihood estimates of  $M_{SP}$  and the logistic parameters  $a$  and  $h$  were found. Model estimates for the “half” and “shape” parameters (Table D13) were relatively insensitive to assumptions about  $M_{NS}$ . In addition, the model was run with and without the inclusion of ageing error for each combination of  $M_{NS}$  and  $M_{SP}$  (Figure D25). Standard deviations for parameter estimates were about 0.1 for  $a$ , 2.9 for  $h$  and 0.3 for  $M_{SP}$  in most runs.

The inclusion of ageing error in model calculations improved the goodness of fit for all model scenarios (Figure D25). The model fit the age composition data well for non-spawning natural mortality rates  $M_{NS}=0.01$  and  $0.03$  per week, but not for the highest level  $M_{NS}=0.06$  (Figure D25). Fit to proportion mature-at-age data was mediocre (Figure D25). A second sensitivity analysis (not shown) indicated that model fit to maturity data was strongly influenced by the observation of a single, young (13 weeks old) mature female squid (Figure D25). The age and maturity stage of the observation was confirmed. It is not uncommon to sample precocious individuals of either sex (Hendrickson personal observation). Further aging studies will be needed to better estimate the maturity of young female squid.

Maturity and natural mortality estimates from the maturation-mortality model were used provisionally in per-recruit modeling described below, despite problems with goodness of fit to maturity data. This decision was made because the new per-recruit model for *Illex* represents a substantial improvement over traditional approaches, but requires estimates of natural mortality for both mature and immature females. Parameter estimates from the maturation-mortality model seemed reasonable on biological grounds and were estimated in a biologically plausible model. Moreover, they were based on all available data and constitute the best available information. Use of reasonable estimates from the model was preferable to using arbitrary values in per-recruit modeling (e.g., a total  $M$  value of 0.06 was used in previous assessments). However, it is important to acknowledge the uncertainty in the maturity and mortality parameters and to carry out sensitivity analyses in per-recruit and other modeling where the uncertainty is important with respect to providing management advice.

## **BIOLOGICAL REFERENCE POINTS**

### Yield-per-recruit and egg-per-recruit models

A semelparous life history model was derived to estimate yield-per-recruit (YPR) and the number of eggs-per-recruit (EPR) for a cohort of female squid as a function of fishing mortality.

Consistent with the maturation-mortality model, the YPR and EPR models track females in two bins: the number of immature females,  $N_t$ , and the number of mature females,  $S_t$ . At each weekly time step, immature individuals have four possible fates: (1) death due to either non-spawning natural mortality,  $M_{NS}$ , (e.g., from predation, which is assumed to occur at a constant rate) or (2) death due to fishing mortality (calculated as  $F_t = F\theta_t$ , where  $\theta_t$  is the fishery selectivity of the individuals of age  $t$  weeks); (3) survival to the next week either as an immature individual; or (4) survive and mature at rate  $P_t$ . The instantaneous rate  $P_t$  is related to the probability of maturing within a week  $p_t$  by  $P_t = -\ln(1 - p_t)$ . The population dynamics equation for immature squid is:

$$N_{t+1} = N_t \exp(-M_{NS} - F_t - P_t).$$

Mature individuals can: (1) die due to non-spawning natural mortality or (2) die due to fishing mortality, both of which are assumed to occur at the same rates,  $M_{NS}$  and  $F_t$ , as for immature squid; (3) spawn (at rate  $R_t = M_{SP} - M_{NS}$ ) and die; or (4) survive to the next week as mature individuals without spawning. The population equation for mature squid is:

$$S_{t+1} = S_t \exp(-M_{SP} - F_t) + N_t \exp(-M_{NS} - F_t)[1 - \exp(-P_t)].$$

The number of eggs,  $E_t$ , produced during the  $t^{\text{th}}$  week per female recruit is:

$$E_t = V_t S_t R_t [1 - \exp(-M_{NS} - F_t - R_t)] / (M_{NS} + F_t + R_t),$$

where  $V_t$  is the mean number of eggs produced by a female of age  $t$  weeks.

The yield,  $Y_t$ , produced in week  $t$  is:

$$Y_t = W_t F_t \{ N_t [1 - \exp(-M_{NS} - F_t - P_t)] / (M_{NS} + F_t + P_t) + S_t [1 - \exp(-M_{NS} - F_t - R_t)] / (M_{NS} + F_t + R_t) \},$$

where  $W_t$  is the mean weight of an individual at week  $t$ .

The total number of eggs-per-recruit and the yield-per-recruit, respectively, were computed as:

$$E = \sum_t E_t / N_0$$

and

$$Y = \sum_t Y_t / N_0$$

where  $N_0$  is the initial cohort size. The calculations were started at week 12, (just prior to the youngest age at maturation and spawning) and ended at week 31, which was assumed to be a plus group. Model input data are presented in Table D14. The maturation rates,  $P_t$ , and spawning rates,  $R_t$ , were obtained from the maturation-mortality model described above. The mean weights at age in the catch ( $W_t$ ) were based on a weight-at-age relationship, for combined sexes, from the May 2000 *Illex* survey (Figure D23) (Hendrickson *In Review*). Fishery selectivity at age ( $\theta_t$ ) was assumed to be piecewise-linear, between ages 17 and 23 weeks, based on a 1999-2002 composite age distribution of landings in the directed fishery (Figure D26). The composite age distribution was derived by converting body weights to ages using the May 2000 *Illex* survey weight-at-age relationship for combined sexes (Figure D23) (Hendrickson *In Review*).



The fecundity of *Illex* sp. increases with size (Laptikhovskiy and Nigmatullin 1993). Therefore, the fecundity-at-age parameters ( $V_i$ ) were assumed to be proportional to the predicted average body weights-at-age of females from the May 2000 *Illex* survey and multiplied by an estimate of fecundity per unit body weight. (Hendrickson *In Review*). The fecundity of a 31-week old female was fixed at 60,255 eggs. This value was determined based on fecundity values from the literature and the average weight (89 g) of mature females from the May 2000 *Illex* survey (Hendrickson *In Review*). The ovary weight of a mature *I. illecebrosus* female is 25% of the body weight and the average weight of a mature egg is 240  $\mu\text{g}$  (Durward et al. 1978). Thus, based on an average body weight of 89g, for mature females, the predicted number of mature ova produced by each female would be 92,700 eggs. However, the actual fecundity for a congener, *I. argentinus*, represents only 65% of the potential fecundity (Laptikhovskiy and Nigmatullin 1993). Therefore, on average, the actual fecundity of an 89 g female would be approximately 60,255 eggs.

## Results

The results of per-recruit model sensitivity runs for the three pairs of  $M_{SP}$  and  $M_{NS}$  values are shown in Table D15 and Figure D27. Depending on assumptions about natural mortality rates for spawning and non-spawning females, the ranges of instantaneous, fully-recruited values for  $F_{0.1}$ ,  $F_{50\%}$  and  $F_{40\%}$  were: 0.21-0.24, and 0.27-0.33 per week, respectively (Table D16 and Figure D27).

Reference points that minimize the risk of recruitment overfishing, by ensuring that escapement exceeds a threshold minimum spawning stock biomass or number of eggs per recruit, have been considered to be the most appropriate for annual squid stocks that exhibit highly variable trends in interannual recruitment (Beddington et al. 1990). The current MSY-based biological reference points were based on a biomass dynamics model for which bootstrap analyses indicated poor precision of  $r$ ,  $q$  and  $K$  estimates (NEFSC 1996). Given these considerations, %MSP-based proxies for MSY-based reference points are recommended. Further, the source of the reference point proxies should be derived from a model that accounts for the semelparous life history of *Illex*.

Potential reference point proxies estimated using the new EPR model ( $F_{40\%}=0.27$  and  $F_{50\%}=0.21$  per week) were considered preliminary by the SARC 37 panel. A sensitivity analysis (Table D16 and Figure D27) showed that the reference point calculations were sensitive to changes in assumed natural mortality rates. In particular, a model run using the new input data and  $M_{TOT}=0.06$  per week (the total natural mortality rate assumed for all individuals in the SARC 29 model) gave substantially lower F values for all per-recruit reference points (Table D16).

Per-recruit reference points from SARC 29 (NEFSC 1999b) are lower than reference points estimated with the new data and the new model (Table D16). However, the comparison is misleading due to differences in input data (Figure D28) and methods of calculation. The new model counts time as the age of a hypothetical cohort whereas the SARC 29 analysis counted time as week of the fishery without reference to age. The two conventions are related but it is difficult to compare one to the other. In the new model, stock weights represent female weight-at-age data based on statolith-derived ages and body weights from *Illex* sampled during the May

2000 *Illex* survey (Hendrickson *In Review*), while the SARC 29 model used the 1990 growth curve from squid collected in the Newfoundland jig fishery (Figure D28). The catch mean weights in the new model are based on statolith-derived ages and body weights for *Illex* of both sexes sampled during the May 2000 *Illex* survey (Hendrickson *In Review*). Catch mean weights in the SARC 29 model were weekly mean weights in the landings during 1994-1998. The latter are asymptotic, whereas weights-at-age from the May 2000 *Illex* survey increase exponentially with age (Figure D28). In the current assessment, fishery selectivity was an increasing asymptotic function of age, unlike SARC 29, where selectivity was approximated by using a variable, dome-shaped trend in weekly fishing effort (Figure D28). Selectivity and growth patterns assumed in SARC 29 were protracted relative to patterns estimated based on data for this assessment (Figure D28). Mean weights in the catch also varied between the two models. The F values for reference points in SARC 29 were expressed as seasonal totals computed as the sum of weekly fishing mortality rates during each week of a 31-week fishery. In contrast, F values for reference points in this assessment are maximum values for fully-recruited age groups.

### Uncertainties

A significant seasonal increase in the growth rates, in terms of mantle length and body weight, of *I. illecebrosus* from Newfoundland waters occurs in both sexes (Dawe and Beck 1997). Similar growth trends are likely for *Illex* inhabiting U.S. waters, but this has not been verified. The YPR and EPR models incorporate spring growth rates and assume that growth rates are constant throughout the lifespan of an individual. As a result, estimates of yield-per-recruit and the number of eggs-per-recruit may be underestimated. However, if seasonal growth increases proportionately across all age groups, reference points such as  $F_{0.1}$  and  $F_{50\%}$  would remain unaffected.

The maturation-mortality model is based solely on females, but yield is obtained from both sexes. This could create error in the YPR (though not the EPR) estimates if growth, maturation or mortality of males differs substantially from that of females.

As described above, the maturity and natural mortality estimates of  $M_{NS}$  which were used in per-recruit modeling were imprecise. Fortunately, immature natural mortality is a relatively small portion of total natural mortality. Sensitivity analysis indicates that changes in  $M_{NS}$  had modest effects on reference point calculations.

## **STOCK SIZE AND FISHING MORTALITY RATES**

### Relative Exploitation Indices

Relative exploitation indices, computed as a ratio of U.S. landings to the NEFSC autumn survey biomass index, generally increased during 1988-1999 (Figure D29). After reaching the highest level since the inception of the domestic fishery, in 1999, relative exploitation indices declined drastically.

### In-season assessment modeling approaches

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 annual-based approaches to stock assessment inappropriate (Caddy 1983). This has certainly been true for the *I. illecebrosus* stock, for which biomass dynamics models provide very 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 applied to the stock but resulted in poor model fit. Part of the problem with applying annual models to this stock lies in the fact there are no reliable indices of abundance or biomass for the stock as a whole. The very short life cycle (less than one year) is another significant problem with annual-based modeling approaches.

According to the ICES Working Group on Cephalopod Fisheries and Life History, within-season, “real-time” 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 body 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 and spatial resolution, tow-based, and available throughout the fishing season.

The in-season assessment model from SARC 29 (NEFSC 1999b) was run with 1999 data that included: weekly VTR effort and landings data; total landings from the Weighout database; weekly, loess-smoothed mean body weights of landed *Illex*; and natural mortality rate estimates from the maturation model. The SARC 29 model used mean weight to estimate emigration from the fishing grounds, assuming a constant total natural mortality rate of 0.06 per week, and did not include recruitment during the fishing season. However, biological data collected as part of the 1999 real-time reporting study indicate that recruits entered the fishery continuously during the first ten weeks of the season. In addition to not accounting for in-season recruitment, application of the 1999 VTR data to the SARC 29 model resulted in unrealistic solutions. Thus, the Invertebrate Subcommittee decided not to accept the model results for use in the current assessment.

In order to address the data requirements for in-season modeling and the possibility of real-time management, the NEFSC collaborated with the *Illex* fishing industry and conducted a real-time fisheries data collection study in 1999 (refer to Background Section). The 1999 real-time data were used in the current assessment to further test and refine in-season modeling approaches. These 1999 data were considered the most representative of the real-time data sets because the 1999 data set consisted of the highest percentage of total annual landings (Table D17).

The results from the new model (Appendix A) were informative, but are considered preliminary and not yet recommended for management use because the model was not fully evaluated or rigorously tested due to lack of time.

## CONCLUSIONS

### Abundance and biomass indices

Seasonal bottom trawl surveys do not cover the whole range of the stock. *Illex* inhabit areas outside the range of the surveys based on survey data and anecdotal reports. Since 1999, NEFSC autumn survey abundance indices have been below the 1982-2002 average. However, it is unknown whether this trend is due to low abundance, low availability or both. Spring survey abundance indices and the proportion of spring and autumn survey tows with *Illex* catch has also been low in recent years. The July Scotian Shelf survey indices have been low since 1998.

Surface and bottom water temperatures in the Mid-Atlantic Bight have been warmer than average during recent years. *Illex* abundance and biomass indices from the autumn surveys and spring average body weights were significantly negatively correlated with bottom water temperature anomalies from the autumn surveys. Average body weights of *Illex* in multiple surveys have been low for an extended period of time. This likely represents another indication of an environmental effect on productivity.

The annual LPUE time series for 1999-2002 is too short to interpret and confounded by changes in fleet composition. In-season LPUE trends were generally flat during 2000-2002.

### Fishery Characteristics

*Illex* landed during 1999-2002 were smaller and weighed less than in most years since 1994. This fact, coupled with a similar decrease observed in multiple surveys over an extended time period and increased bottom temperatures in recent years, is likely related to productivity. The number of vessels has declined since 1999, particularly the number of RSW vessels. The area fished also decreased in size, which may be due to the reduction in fishery participation. Landings have been below the 1982-2002 average since 1998 and this may be due to the reduced effort observed during this time period, low biomass or both factors.

### Stock status

It is unknown whether the stock is overfished because available survey indices do not include sampling of the entire habitat range. Consequently, an appropriate  $B_{MSY}$  proxy could be recommended and stock status relative to  $B_{MSY}$  could not be determined. However, the stock may be at a relatively low biomass level based on biomass indices from multiple surveys and poor fishery performance during 1999-2002. It is not clear whether recent low trends in LPUE and survey indices are due to reduced availability, reduced biomass or both.

An  $F_{MSY}$  estimate is not available. However,  $F_{40\%}$  or  $F_{50\%}$  have been recommended, based on previous SARC recommendations regarding the need to reduce the potential for recruitment overfishing. The best available estimates of  $F_{40\%}$  and  $F_{50\%}$  are from the new per-recruit model used in this assessment, although there is uncertainty regarding the underlying biological parameters which were estimated in the maturity-natural mortality model. The relationship of  $F_{40\%}$  or  $F_{50\%}$  reference points to  $F_{MSY}$  is unknown and an important topic for future research.

It was unlikely that overfishing occurred during 1999-2002 because:

1. The current small fleet size and effort levels make it is unlikely that the fishery could exert the very high fishing mortality rate required to exceed the new estimate of  $F_{50\%}$ .
2. The fishing season is short and recruitment appears to occur during most months, so fishing mortality estimates from any model for the fished portion of the stock represent a worst-case scenario or an upper bound on  $F$  for the stock in US waters over the entire year. The short fishing season makes high annual average  $F$  values unlikely.
3. The geographic range of the U.S. fishery is restricted by gear conflicts and depth limitations, although *Illex* inhabit waters to the north, south and offshore of the fishery. In addition, fishing mortality outside U.S. waters (e.g. in Canada) has been low in recent years. The restricted geographical distribution of the fishery makes high annual average  $F$  values for the entire stock unlikely.
4. Relative exploitation indices have declined considerably since 1999 and have been below the 1982-2002 median since then.
5. Preliminary model results (Appendix A) indicate that fishing mortality rates as high as  $F_{50\%}$  are unlikely to have occurred during 1999, when relative  $F$  was the highest in recent years.

## SARC COMMENTS

The WG and panel expressed the imperative need for a new management schema. Currently, management uses a fixed quota based on the catch associated with a  $F_{MSY}$  target (75% of  $F_{MSY}$ ). The relative exploitation index for *Illex* may not be useful because it is based on the fall survey after most of the fishery has occurred. Also, the spring survey index is considered to track availability of the stock rather than stock abundance. In addition, the WG considered that the survey indexes do not encompass the entire habitat range for the *Illex* stock.

Management based on fixed quotas may be risk prone for this type of fishery, where recruitment is highly variable year to year. The WG and panel agreed that management targets should primarily avoid recruitment overfishing, either by an escapement spawning biomass target or another proxy to protect a minimum spawning success of the stock taking into consideration possible environmental constraint on the stock. The panel suggested evaluating weekly SSB fraction analysis over the fishing season as a proxy for spawning biomass targets. This will reiterate the need to move towards a scheme of in season stock management approaches. Another approach would be to control fishing effort rather than fixed quotas, due to the present lack of ability to determine if the current quota is too high or too low for the *Illex* stock in a given year. The WG also suggested adopting management schemes for the stock under conditions of high or low productivity of the stock as in the NAFO management plans. Although it recognized that this schema will require several years of evaluations before it can be decided if the stock has switched between a low or a high productivity regime, and this situation can be detrimental especially due to the fact that the successful recruitment depends exclusively in a single-prior year's spawning biomass.

The panel discussed the possible reasons for the lower asymptotic average mean size and weight trends of *Illex* from survey samples in the latest years (1999-2002) compared to corresponding values in 1994-1998 (Fig D7-D8). Possible causes include both environmental and non environmental effects. It was suggested that these plots of mean size or weight do reflect the net product of several factors including growth, mortality and availability, and that is unlikely to be able to discriminate any single cause beyond of the absence of larger size individuals in the latest years. These changes in asymptotic size and weight of *Illex* were not obvious in the average trends from the commercial catches.

The group pointed out that in the latest years the total catch has been as low as 10% of the quota. It was suggested that the low availability had caused a switch of fishing effort from squid to scallops. While the price for scallops remains high there is unlikely to be increased *Illex* effort, but future effort trends are of course difficult to predict accurately. The Group mentioned that *Illex* is available in the shelf and deep ocean, although possibly in lower densities than those required to sustain current commercial fishery operations, or beyond of the gear operability.

The panel commended the development of models that incorporate more realistic characteristic of the biology of *Illex* stocks, particularly ageing of US *Illex* samples, the distinction between mortality of pre and post spawners, and maturity at age relationship. These models are on the right track and further refinement and evaluation is highly recommended.

The WG expressed the importance of translate F weekly rates to some Management reference proxy, the WG articulated the need for directions on how to express weekly F estimates as seasonal or yearly F value.

The panel reviewed the correlation of environmental variables and *Illex* abundance and biomass indices. The results indicated an inverse correlation between bottom sea temperature and *Illex* abundance, corroborating that recent low density of *Illex* might be related to the positive anomalies (e.g. average temperatures above the average base line) of sea temperature in recent years. However, it is not possible to distinguish between overall reduction of *Illex* stock biomass or simply changes in the spatio-temporal distribution of the stock in response to the temperature changes. The panel recommended pursuing the evaluation of oceanographic conditions and *Illex* stock dynamics.

The panel expressed concern about the *Illex* stock status, in lieu of the recent severe declines of catches, shrinkage of the fishing grounds, reductions of maximum average size and weight of mature animals, as well low catch rates from the fall and spring surveys. Standardized LPUE had also decline although overall total fishing effort has by significantly reduced. However, at this point it is not possible to assess if declines of exploitable biomass are due to fishing mortality or other factors such as the shift of stock productivity towards a low regime or environmental related changes. It was mentioned that similar trends have been observed in the *Illex* NAFO management unit. Thus a precautionary management approach ought to be follow.

## RESEARCH RECOMMENDATIONS

### Stock assessment and modeling

- Model development should continue, with the objective of producing sound statistical models for stock assessment purposes.
- Consideration should be given to the development of “operating models” which can subsequently be used to test the effectiveness and robustness of alternative management strategies (i.e., Management Strategy Evaluation).

### Biological Research

- Evaluate the relationship between growth rates and sea temperature to define possible changes in stock productivity associated with environmental conditions.
- Evaluate seasonal and latitudinal clines in growth rates.
- Define biological indicators of low or high productivity regimes.
- Explore food chain relationship for *Illex*, for what ?

### Fisheries Research

- Evaluate and design cooperative research programs with commercial vessels for sampling of size, weight and possible age of *Illex* during the fishing season
- Continue with cooperative ventures for pre-season survey to obtain possible indices of upcoming stock abundance and productivity.
- Evaluate catch rates by vessel by using VTR and Weight out database to improve procedures for standardization of nominal LPUE.

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Table D1. *Illex illecebrosus* landings (mt) in NAFO Subareas 5+6 (U.S. EEZ) and Subareas 3+4 during 1963-2002<sup>1,2,3,4,5</sup> and TACs.

Year	Cape Hatteras to the Gulf of Maine (Subareas 5+6)			Subareas (3+4)	All Subareas (3-6)	TAC (mt)	
	Domestic (mt)	Foreign (mt)	Total (mt)	Total (mt)	Total (mt)	3+4	5+6
1963	810		<b>810</b>	2,222	<b>3,032</b>		
1964	358	2	<b>360</b>	10,777	<b>11,137</b>		
1965	444	78	<b>522</b>	8,264	<b>8,786</b>		
1966	452	118	<b>570</b>	5,218	<b>5,788</b>		
1967	707	288	<b>995</b>	7,033	<b>8,028</b>		
1968	678	2,593	<b>3,271</b>	56	<b>3,327</b>		
1969	562	975	<b>1,537</b>	86	<b>1,623</b>		
1970	408	2,418	<b>2,826</b>	1,385	<b>4,211</b>		
1971	455	6,159	<b>6,614</b>	8,906	<b>15,520</b>		
1972	472	17,169	<b>17,641</b>	1,868	<b>19,509</b>		
1973	530	18,625	<b>19,155</b>	9,877	<b>29,032</b>		
1974	148	20,480	<b>20,628</b>	437	<b>21,065</b>		71,000
1975	107	17,819	<b>17,926</b>	17,696	<b>35,622</b>	25,000	71,000
1976	229	24,707	<b>24,936</b>	41,767	<b>66,703</b>	25,000	30,000
1977	1,024	23,771	<b>24,795</b>	83,480	<b>108,275</b>	25,000	35,000
1978	385	17,207	<b>17,592</b>	94,064	<b>111,656</b>	100,000	30,000
1979	1,493	15,748	<b>17,241</b>	162,092	<b>179,333</b>	120,000	30,000
1980	299	17,529	<b>17,828</b>	69,606	<b>87,434</b>	150,000	30,000
1981	615	14,956	<b>15,571</b>	32,862	<b>48,433</b>	150,000	30,000
1982	5,871	12,762	<b>18,633</b>	12,908	<b>31,541</b>	150,000	30,000
1983	9,775	1,809	<b>11,584</b>	426	<b>12,010</b>	150,000	30,000
1984	9,343	576	<b>9,919</b>	715	<b>10,634</b>	150,000	30,000
1985	5,033	1,082	<b>6,115</b>	673	<b>6,788</b>	150,000	30,000
1986	6,493	977	<b>7,470</b>	111	<b>7,581</b>	150,000	30,000
1987	10,102	0	<b>10,102</b>	562	<b>10,664</b>	150,000	30,000
1988	1,958	0	<b>1,958</b>	811	<b>2,769</b>	150,000	30,000
1989	6,801	0	<b>6,801</b>	5,971	<b>12,772</b>	150,000	30,000
1990	11,670	0	<b>11,670</b>	10,975	<b>22,645</b>	150,000	30,000
1991	11,908	0	<b>11,908</b>	2,913	<b>14,821</b>	150,000	30,000
1992	17,827	0	<b>17,827</b>	1,578	<b>19,405</b>	150,000	30,000
1993	18,012	0	<b>18,012</b>	2,686	<b>20,698</b>	150,000	30,000
1994	18,350	0	<b>18,350</b>	5,951	<b>24,301</b>	150,000	30,000
1995	14,058	0	<b>14,058</b>	1,055	<b>15,113</b>	150,000	30,000
1996	16,969	0	<b>16,969</b>	8,742	<b>25,711</b>	150,000	21,000
1997	13,629	0	<b>13,629</b>	15,614	<b>29,243</b>	150,000	19,000
1998	23,597	0	<b>23,597</b>	1,902	<b>25,499</b>	150,000	19,000
1999	7,388	0	<b>7,388</b>	305	<b>7,693</b>	75,000	19,000
2000	9,011	0	<b>9,011</b>	366	<b>9,377</b>	34,000	24,000
2001	4,009	0	<b>4,009</b>	57	<b>4,066</b>	34,000	24,000
2002	2,723	0	<b>2,723</b>	249	<b>2,972</b>	34,000	24,000
Avg. 1963-1967	554	122	651	6,703	7,354		
1968-1982	885	14,195	15,080	35,806	50,886		
1983-2002	10,933	222	11,155	3,083	14,238		
1999-2002	5,783	0	5,783	244	6,027		

<sup>1</sup> Landings during 1963-1978 were not reported by species, but are proration-based estimates by Lange and Sissenwine (1980)

<sup>2</sup> Landings during 1979-1997 are from the NEFSC Weighout Database and the Joint Venture Database

<sup>3</sup> Domestic landings during 1982-1991 include Joint-Venture landings

<sup>4</sup> Includes landings from Subarea 2

<sup>5</sup> Landings during 2002 are preliminary for all Subareas

Table D2. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Illex* fishery, by observers from the NEFSC Observer Program, during 1995-2002. *Illex* trips were defined as trips where *Illex* landings were  $\geq 25\%$ , by weight, of the total trip landings. Total discard estimates are the product of discard ratios and total *Illex* landings, for *Illex* trips in the Weighout database, for all months sampled.

	May	June	July	Aug	Sept	Oct	Total
<b>1995</b>							
Trips	0	0	0	0	1	1	2
Total Kept(mt)					0.902	0.113	1.015
Total Discard(mt)					0.007	0.023	0.030
Ratio discard/kept					0.008	0.204	0.030
Total Landings					1,263.819	905.822	2,169.641
Total Discards(mt)					9.808	184.371	64.127
<b>1996</b>							
Trips	0	4	3	6	1	1	15
Total Kept(mt)		112.696	236.297	182.447	136.617	166.106	834.163
Total Discard(mt)		0.769	3.499	0.045	0.163	0.000	4.476
Ratio discard/kept		0.007	0.015	0.000	0.001	0.000	0.005
Total Landings		3,817.659	2,736.593	3,787.278	2,455.642	2,436.032	15,233.204
Total Discards(mt)		26.050	40.522	0.936	2.930	0.000	81.741
<b>1997</b>							
Trips	0	0	7	3	0	0	10
Total Kept(mt)			773.388	343.904			1,117.292
Total Discard(mt)			1.941	5.286			7.227
Ratio discard/kept			0.003	0.015			0.006
Total Landings			5,077.722	3,600.592			8,678.314
Total Discards(mt)			12.744	55.343			56.134
<b>1998</b>							
Trips	0	0	2	2	0	0	4
Total Kept(mt)			106.141	48.761			154.902
Total Discard(mt)			1.656	0.000			1.656
Ratio discard/kept			0.016	0.000			0.011

Total Landings			7,526.991	6,501.153			14,028.144
Total Discards(mt)			117.435	0.000			149.970

**1999**

Trips	0	0	1	2	1	0	4
Total Kept(mt)			26.218	50.723	14.011		90.952
Total Discard(mt)			0.000	0.907	0.068		0.975
Ratio discard/kept			0.000	0.018	0.005		0.011
Total Landings			2,249.614	2,550.402	596.029		5,396.045
Total Discards(mt)			0.000	45.605	2.893		57.845

**2000**

Trips	0	2	4	7	0	0	13
Total Kept(mt)		85.820	135.459	182.796			404.075
Total Discard(mt)		0.000	0.680	1.198			1.878
Ratio discard/kept		0.000	0.005	0.007			0.005
Total Landings		1,409.981	2,753.821	2,122.142			6,285.944
Total Discards(mt)		0.000	13.824	13.908			29.215

**2001**

Trips	0	0	0	0	0	0	0
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**2002**

Trips	0	0	0	0	0	0	0
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Table D3. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Loligo* fishery, by observers from the NEFSC Observer Program, during 1995-2002. *Loligo* trips were defined as trips where *Loligo* landings were  $\geq 25\%$ , by weight, of the total trip landings. Estimates of total discards are based the product of discard ratios and reported *Loligo* landings, by month, for *Loligo* trips in the Weighout database.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
<b>1995</b>							
Trips	0	1	1	1	0	0	3
Total Kept(mt)		1.195	0.513	2.971			4.679
Total Discard(mt)		0.000	0.000	0.002			0.002
Ratio discard/kept		0.000	0.000	0.001			0.000
Total Landings		537.991	981.273	1,407.113			2,926.377
Total Discards(mt)		0.000	0.000	0.947			1.251
<b>1996</b>							
Trips	1	1	1	2	1	0	6
Total Kept(mt)	3.009	0.335	0.760	11.952	10.972		27.028
Total Discard(mt)	1.100	0.000	0.000	0.068	0.069		1.237
Ratio discard/kept	0.366	0.000	0.000	0.006	0.006		0.046
Total Landings	347.441	306.178	2,077.435	1,933.899	1,462.509		6,127.462
Total Discards(mt)	127.014	0.000	0.000	11.003	9.197		280.438
<b>1997</b>							
Trips	0	0	1	2	1	1	5
Total Kept(mt)			2.220	23.071	8.137	12.084	45.512
Total Discard(mt)			0.318	0.206	0.278	0.687	1.489
Ratio discard/kept			0.143	0.009	0.034	0.057	0.033
Total Landings			602.383	1,192.511	752.883	735.620	3,283.397
Total Discards(mt)			86.287	10.648	25.722	41.821	107.422
<b>1998</b>							
Trips	2	0	3	3	7	3	18
Total Kept(mt)	3.629		21.514	25.045	100.520	25.540	176.248
Total Discard(mt)	0.003		0.372	0.078	0.976	3.395	4.824
<b>Table D3. (continued)</b>							
Ratio discard/kept	0.001		0.017	0.003	0.010	0.133	0.027



Total Landings	1,442.321		1,202.271	3,697.553	3,720.621	1,009.754	11,072.520
Total Discards(mt)	1.192		20.789	11.516	36.125	134.225	303.061
<b>1999</b>							
Trips	2	3	0	0	4	5	14
Total Kept(mt)	40.183	14.411			31.508	37.670	123.772
Total Discard(mt)	0.032	0.155			2.015	2.376	4.578
Ratio discard/kept	0.001	0.011			0.064	0.063	0.037
Total Landings	1,783.164	1,286.115			1,197.348	1,343.383	5,610.010
Total Discards(mt)	1.420	13.833			76.573	84.733	207.499
<b>2000</b>							
Trips	1	0	4	5	5	0	15
Total Kept(mt)	0.429		14.527	63.171	53.083		131.210
Total Discard(mt)	0.000		0.005	0.492	0.530		1.027
Ratio discard/kept	0.000		0.000	0.008	0.010		0.008
Total Landings	292.562		1,232.910	2,182.140	1,769.293		5,476.905
Total Discards(mt)	0.000		0.424	16.995	17.665		42.869
<b>2001</b>							
Trips	2	1	1	4	5	1	14
Total Kept(mt)	21.32	11.05	2.864	29.828	61.793	23.918	150.773
Total Discard(mt)	0.227	0	0.906	1.789	0.402	0.228	3.552
Ratio discard/kept	0.011	0.000	0.316	0.060	0.007	0.010	0.024
Total Landings	1,908.420	1,691.437	519.057	850.685	1,557.575	979.096	7,506.270
Total Discards(mt)	20.319	0.000	164.199	51.022	10.133	9.333	176.837
<b>2002</b>							
Trips	0	0	1	3	0	3	7
Total Kept(mt)			20.117	24.937		15.183	60.237
Total Discard(mt)			0.15	1.026		0	1.176
Ratio discard/kept			0.007	0.041		0	0.020
Total Landings			1,272.791	1,338.373		111.488	2,722.652
Total Discards(mt)			9.490	55.066		0	53.154

Table D4. Summary of *Illex* discards (mt), by year and fishery, estimated from data collected by observers from the NEFSC Observer Program during 1995-2002.

Year	Percentage of landings sampled for <i>Illex</i> discards				<i>Illex</i> Discards (mt)			Total <i>Illex</i> Landings (mt)	<i>Illex</i> Discards (% of <i>Illex</i> landings)
	<i>Illex</i> Fishery		<i>Loligo</i> Fishery		<i>Illex</i> Fishery	<i>Loligo</i> Fishery	Total		
	<i>Illex</i> Landings (May-Oct, mt)	%	<i>Loligo</i> Landings (Jan-April and Nov-Dec, mt)	%					
1995	13,494	0.01%	6,702	0.07%	64.1	1.3	65	14,058	0.5%
1996	15,563	5.36%	7,070	0.38%	81.7	280.4	362	16,969	2.1%
1997	12,709	8.79%	6,484	0.69%	56.1	107.4	164	13,629	1.2%
1998	23,091	0.67%	12,755	1.38%	150.0	303.1	453	23,597	1.9%
1999	7,115	1.28%	7,811	1.59%	57.8	207.5	265	7,388	3.6%
2000	8,901	4.54%	5,810	2.25%	29.2	42.9	72	9,011	0.8%
2001	3,452	0.00%	7,506	2.01%	0.0	176.8	177	4,009	4.4%
2002	2,342	0.00%	6,107	0.98%	0.0	53.2	53	2,723	2.0%

Table D5. Numbers of *Illex* sampled weekly in the directed fishery (landings), for body weight (BW, g) and dorsal mantle length (DML, cm), during 1999-2002.

Week	1999		2000		2001		2002	
	DML	BW	DML	BW	DML	BW	DML	BW
22	520	520	0	0	0	0	0	0
23	1,299	1299	0	0	0	0	95	95
24	1,165	1165	0	0	502	403	511	511
25	1,112	1112	1,753	1753	592	374	496	496
26	1,275	1275	0	0	250	250	304	304
27	1,289	1289	1,384	1384	720	570	100	100
28	717	717	250	250	1,130	530	48	48
29	975	975	1,942	1942	1,482	480	200	200
30	1,329	1329	650	650	590	340	153	153
31	1,220	1220	1,076	1076	0	0	1,267	1267
32	929	929	250	250	0	0	45	45
33	960	960	0	0	0	0	418	418
34	800	800	719	719	450	450	683	683
35	0	0	717	717	1,052	1052	411	411
36	540	540	786	786	350	350	503	503
37	240	240	0	0	0	0	0	0
38	40	40	1,603	1603	0	0	738	738
39	40	40	100	100	0	0	0	0
40	0	0	988	988	0	0	0	0
41	0	0	275	275	0	0	923	923
42	0	0	0	0	0	0	295	295
43	0	0	0	0	0	0	874	874
Total	14,450	14,450	12,493	12,493	7,118	4,799	8,064	8,064

Table D6. Standardized, stratified mean catch per tow (delta-transformed) in numbers/tow, and kg/tow of *Illex illecebrosus*, pre-recruits ( $\leq 10$  cm) and recruits ( $\geq 11$  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 1967-2002.

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
1999	1.39	16	0.192	17	136	0.15	1.24
2000	7.41	28	0.706	22	94	0.95	6.46
2001	4.49	27	0.323	23	72	0.46	4.03
2002	6.36	20	0.444	19	70	1.01	5.35
Average							
1967-1981	9.05	22	2.510	21	209	0.89	8.16
1982-2002	8.68	23	1.02	23	113	0.61	8.07
1967-2002	8.83	23	1.639	22	153	0.73	8.11
1999-2002	4.91	23	0.416	20	93	0.64	4.27

Table D7. Pearson correlation coefficients and p-values for the null hypothesis of no correlation between surface and bottom temperature anomalies and *Illex illecebrosus* abundance and biomass indices for the NEFSC spring and autumn bottom trawl surveys during 1982-2002. Correlations that are significant at the 5% level are bold-faced.

	Spring SST Anomaly	Spring BT Anomaly	Autumn Survey SST Anomaly	Autumn BT Anomaly	Spring no./tow	Spring kg/tow	Spring Body Wt	Spring Propor. of <i>Illex</i> Tows	Autumn no./tow	Autumn kg/tow	Autumn Body Wt	Autumn Propor. of <i>Illex</i> Tows
Spring SST Anomaly	1.00000 0.0000	0.91038 <b>0.0001</b>	0.25890 0.2571	0.66079 <b>0.0011</b>	0.20286 0.3778	0.02682 0.9081	-0.35953 0.1094	0.04308 0.8529	-0.23921 0.2963	-0.23329 0.3088	-0.23704 0.3009	-0.07886 0.7340
Spring BT Anomaly		1.00000 0.0000	0.18391 0.4249	0.48899 <b>0.0245</b>	0.40871 0.0658	0.23933 0.2961	-0.30576 0.1777	0.13421 0.5619	-0.18468 0.4229	-0.19672 0.3927	-0.28563 0.2094	0.02864 0.9019
Autumn Survey SST Anomaly			1.00000 0.0000	0.19833 0.3888	0.00637 0.9781	0.01406 0.9518	0.13912 0.5476	0.02671 0.9085	-0.03353 0.8853	0.01356 0.9535	0.01271 0.9564	-0.21011 0.3606
Autumn BT Anomaly				1.00000 0.0000	0.20094 0.3824	0.01582 0.9457	-0.52887 <b>0.0137</b>	0.24008 0.2945	-0.54413 <b>0.0108</b>	-0.55161 <b>0.0095</b>	-0.16906 0.4638	-0.33556 0.1370
Spring no./tow					1.00000 0.0000	0.90963 <b>0.0001</b>	-0.22895 0.3181	0.39864 0.0735	-0.18019 0.4344	-0.22428 0.3284	-0.16334 0.4793	0.30221 0.1830
Spring kg/tow						1.00000 0.0000	0.13984 0.5455	0.55726 <b>0.0087</b>	-0.55000 0.8128	-0.02711 0.9072	0.07267 0.7542	0.36229 0.1065
Spring Body Wt							1.00000 0.0000	0.14016 0.5445	0.60788 <b>0.0035</b>	0.75478 <b>0.0001</b>	0.41047 0.0646	0.12941 0.5761
Spring Propor. of <i>Illex</i> Tows								1.00000 0.0000	-0.20954 0.3620	-0.14033 0.5440	0.30527 0.1784	-0.04143 0.8585
Autumn no./tow									1.00000 0.0000	0.95865 <b>0.0001</b>	-0.08363 0.7185	0.36906 0.0997
Autumn kg/tow										1.00000 0.0000	0.15168 0.5116	0.36850 0.1002
Autumn Body Wt											1.00000 0.0000	0.03543 0.8788
Autumn Propor. of <i>Illex</i> Tows												1.00000 0.0000

Table D8. Total fishing effort (days fished), landings (mt) and LPUE (mt/df) in the *Illex illecebrosus* fishery, during 1999-2002, based on Vessel Trip Reports.

Year	Effort (days fished)	Landings (mt)	LPUE (mt/df)
1999	220	6,211	28
2000	196	6,065	31
2001	76	2,866	38
2002	57	1,752	31

Table D9. Summary of average trip duration (days), nominal fishing effort (days fished), landings (mt), and LPUE (mt per day fished), for freezer trawlers versus trawlers with recirculating seawater systems (RSW), during the 1999-2002 *Illex* fishery.

Year	Freezer Trawlers				RSW Trawlers			
	Average				Average			
	Trip Duration (days)	Nominal Effort (days fished)	Landings (mt)	LPUE (mt/df)	Trip Duration (days)	Nominal Effort (days fished)	Landings (mt)	LPUE (mt/df)
1999	9.0	2.9	84.0	27.6	3.1	1.0	17.7	23.9
2000	9.1	2.1	71.4	38.8	2.2	0.8	17.8	12.3
2001	11.1	2.6	80.8	25.8	2.7	0.9	12.1	12.3
2002	10.4	3.0	98.3	36.8	3.5	1.2	5.8	7.3

Table D10. Probability values from General Linear Models used to standardize catch rates in the *Illex illecebrosus* fishery during 1999-2002. Vessel types were characterized as freezer trawler or recirculating seawater system (RSW) trawler.

<b>Effect</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
Week of the year	<b>0.0001</b>	<b>0.0165</b>	<b>0.0119</b>	0.1126
Vessel Type	0.9877	<b>0.0046</b>	<b>0.0413</b>	<b>0.0287</b>
Quarter-degree Square	0.1723	<b>0.0409</b>	0.4783	0.1041
Model	<b>0.0001</b>	<b>0.0019</b>	<b>0.0148</b>	0.0723
N	102	185	65	18



Table D11. Results of a General Linear Model that incorporated log-transformed landings per unit effort (LPUE) data from the 1999 U.S. *Illex illecebrosus* fishery as the dependent variable and week of year, vessel type (freezer trawler or recirculating seawater system trawler), and quarter-degree square as the effects.

Dependent Variable: LNLPUENT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	34	155.89767730	4.58522580	4.54	0.0001
Error	67	67.72960944	1.01088969		
Corrected Total	101	223.62728674			
	R-Square	C.V.	Root MSE	LNLPUENT Mean	
	0.697132	36.75573	1.00543010	2.73543737	
Source	DF	Type I SS	Mean Square	F Value	Pr > F
WKOFYR	23	140.59610413	6.11287409	6.05	0.0001
VESSCD	1	0.49370662	0.49370662	0.49	0.4871
QDSQ2	10	14.80786656	1.48078666	1.46	0.1723
Source	DF	Type III SS	Mean Square	F Value	Pr > F
WKOFYR	22	99.50833141	4.52310597	4.47	0.0001
VESSCD	1	0.00024126	0.00024126	0.00	0.9877
QDSQ2	10	14.80786656	1.48078666	1.46	0.1723

Parameter	Estimate	T for H0: Parameter=0	Pr >  T	Std Error of Estimate
INTERCEPT	3.544734824 B	6.24	0.0001	0.56820403
WKOFYR 18	-3.070705713 B	-2.66	0.0098	1.15496395
22	-1.304969553 B	-1.48	0.1425	0.87928524
23	-0.914839875 B	-1.33	0.1879	0.68759038
25	0.025191998 B	0.03	0.9751	0.80492072
26	-0.639377646 B	-0.79	0.4331	0.81070705
27	-0.221468011 B	-0.32	0.7484	0.68766738
28	-0.377876402 B	-0.47	0.6409	0.80638889
29	-0.140754720 B	-0.21	0.8314	0.65860392
30	-0.828994713 B	-1.35	0.1805	0.61257319
31	-0.189240548 B	-0.31	0.7609	0.61945774
32	-0.767451782 B	-1.10	0.2740	0.69581488
33	0.205063225 B	0.28	0.7786	0.72656386
34	-0.262353255 B	-0.42	0.6777	0.62841400
35	0.730323821 B	0.58	0.5648	1.26214307
36	1.216478837 B	1.02	0.3093	1.18733301
37	-0.224532115 B	-0.28	0.7802	0.80142980
38	-0.719627397 B	-0.94	0.3487	0.76249624
39	-1.283708701 B	-1.09	0.2790	1.17613667
41	-5.066227950 B	-5.65	0.0001	0.89717568
43	-3.555742230 B	-3.02	0.0035	1.17613667
44	-2.948739665 B	-3.20	0.0021	0.92023766

Dependent Variable: LNLPUENT					
Parameter	Estimate	T for H0: Parameter=0	Pr >  T	Std Error of Estimate	
WKOFYR 45	-5.628746536 B	-4.60	0.0001	1.22251188	
46	-6.014237820 B	-5.29	0.0001	1.13593343	
924	0.000000000 B	.	.	.	
VESSCD 1	-0.004257349 B	-0.02	0.9877	0.27558085	
90	0.000000000 B	.	.	.	
QDSQ2 36742	-0.317264089 B	-0.86	0.3903	0.36695291	
36744	-0.997386666 B	-1.76	0.0832	0.56721324	
37741	0.000000000 B	.	.	.	
37742	-0.823232945 B	-1.76	0.0832	0.46811852	
37743	-0.114377083 B	-0.19	0.8527	0.61345695	
37744	0.530468816 B	1.00	0.3218	0.53149016	
38731	-0.166007781 B	-0.45	0.6519	0.36636515	
38733	0.111292846 B	0.30	0.7649	0.37059476	
38741	1.309409732 B	1.08	0.2849	1.21471834	
39693	1.108356898 B	1.35	0.1810	0.81989344	
39694	1.131082892 B	1.36	0.1797	0.83422478	
938732	0.000000000 B	.	.	.	

Table D12. Standardized fishing effort and LPUE, by week, in the U.S. *Illex illecebrosus* fishery during 1999.

GLM Model Results (Sub-fleet)						
Week	Landings (mt)	Standardized Effort (Days fished)	LPUE (mt/df)	Total Landings (mt)	Ratio Total Landings/ Model Landings	Standardized Effort (days fished)
22	16.2	0.41	39.9	27.1	1.7	0.7
23	73.2	2.06	35.6	73.2	1.0	2.1
24	673.6	17.27	39.0	679.6	1.0	17.4
25	534.6	21.16	25.3	555.8	1.0	22.0
26	443.3	6.11	72.6	443.2	1.0	6.1
27	397.7	11.33	35.1	432.8	1.1	12.3
28	87.7	2.67	32.9	271.8	3.1	8.3
29	772.6	17.16	45.0	843.0	1.1	18.7
30	463.1	11.60	39.9	476.7	1.0	11.9
31	744.6	16.45	45.3	1,040.4	1.4	23.0
32	524.8	6.78	77.4	579.2	1.1	7.5
33	320.2	12.63	25.4	319.9	1.0	12.6
34	420.1	15.12	27.8	428.7	1.0	15.4
35	236.3	7.68	30.8	236.3	1.0	7.7
36	29.3	1.16	25.2	81.2	2.8	3.2
37	339.0	9.00	37.6	339.0	1.0	9.0
38	71.2	3.96	18.0	56.2	0.8	3.1
39	60.4	2.45	24.7	68.6	1.1	2.8
40	3.2	2.91	1.1	41.4	13.1	37.9

Table D13. Estimates of *Illex illecebrosus* spawning mortality ( $M_{sp}$ ) and the logistic function parameters "half" and "shape" from a maturation model for various values of non-spawning natural mortality ( $M_{NS}$ ) and various probabilities of mature female survival from week t to week t+1. The "half" parameter (h) represents the age, in weeks, at which the probability of becoming mature is 50% and the "shape" (a) parameter is a shape factor. Bold- faced values represent best fit parameter estimates.

Probability of survival of a mature female in week t to week t+1	$M_{NS}$	$M_{SP}$	Half	Shape
*Optimal (fit by model)	<b>0.01</b>	<b>0.80</b>	<b>19.40</b>	<b>0.33</b>
0.25	0.01	0.69	19.80	0.31
0.50	0.01	1.39	17.60	0.40
Optimal (fit by model)	<b>0.03</b>	<b>0.84</b>	<b>19.20</b>	<b>0.33</b>
0.25	0.03	0.69	19.90	0.31
0.50	0.03	1.39	17.60	0.40
Optimal (fit by model)	<b>0.06</b>	<b>0.91</b>	<b>18.90</b>	<b>0.34</b>
0.25	0.06	0.69	19.90	0.31
0.50	0.06	1.39	17.60	0.40

\* Overall best estimates used in per-recruit models

Table D14. Input data for *Illex illecebrosus* yield-per-recruit and egg-per-recruit analyses.

Age (weeks)	Selectivity	M non-spawning females			Catch mean weights (kg)	Proportion of predicted female body weight in relation to week 31 body weight (kg)
		0.01 Estimated M of spawning females	0.03	0.06		
		0.80	0.84	0.91		
		Probability of Maturation				
12	0.00	0.00	0.00	0.00	0.009	0.00
13	0.00	0.08	0.09	0.09	0.011	0.02
14	0.00	0.11	0.11	0.12	0.015	0.04
15	0.00	0.15	0.15	0.16	0.019	0.05
16	0.00	0.19	0.20	0.21	0.024	0.06
17	0.14	0.25	0.26	0.27	0.030	0.08
18	0.28	0.32	0.33	0.34	0.037	0.10
19	0.42	0.39	0.40	0.42	0.045	0.13
20	0.56	0.47	0.48	0.51	0.054	0.16
21	0.70	0.55	0.57	0.59	0.065	0.20
22	0.84	0.63	0.64	0.67	0.076	0.24
23	0.98	0.70	0.72	0.74	0.090	0.29
24	1.00	0.77	0.78	0.80	0.104	0.35
25	1.00	0.82	0.83	0.85	0.121	0.41
26	1.00	0.86	0.87	0.89	0.139	0.50
27	1.00	0.90	0.90	0.92	0.160	0.58
28	1.00	0.92	0.93	0.94	0.182	0.66
29	1.00	0.94	0.95	0.96	0.206	0.77
30	1.00	0.96	0.96	0.97	0.233	0.89
31	1.00	0.97	0.97	0.98	0.262	1.00

Table D15. Results of egg-per-recruit and yield-per-recruit models, for *Illex illecebrosus*, at three levels of non-spawning ( $M_{NS} = 0.01, 0.03$  and  $0.06$ ) and spawning mortality ( $M_{SP} = 0.80, 0.84$  and  $0.91$ ). Estimates for models with the best fit are bold-faced.

F	Eggs per recruit			Yield per recruit (g)		
	$M_{NS}$			$M_{NS}$		
	<b>0.01</b>	0.03	0.06	<b>0.01</b>	0.03	0.06
	$M_{SP}$			$M_{SP}$		
	<b>0.80</b>	0.84	0.91	<b>0.80</b>	0.84	0.91
0.00	<b>8,363</b>	6,884	5,208	<b>0</b>	0	0
0.05	<b>6,927</b>	5,762	4,426	<b>3.3</b>	2.7	2.0
0.10	<b>5,819</b>	4,884	3,801	<b>5.7</b>	4.8	3.6
0.15	<b>4,947</b>	4,185	3,296	<b>7.6</b>	6.3	4.8
0.20	<b>4,250</b>	3,620	2,880	<b>9.0</b>	7.6	5.8
0.25	<b>3,684</b>	3,158	2,536	<b>10.1</b>	8.5	6.6
0.30	<b>3,219</b>	2,775	2,246	<b>10.9</b>	9.3	7.2
0.35	<b>2,832</b>	2,453	2,001	<b>11.6</b>	9.8	7.7
0.40	<b>2,507</b>	2,182	1,791	<b>12.1</b>	10.3	8.1
0.45	<b>2,232</b>	1,950	1,610	<b>12.5</b>	10.7	8.5
0.50	<b>1,996</b>	1,750	1,453	<b>12.8</b>	11	8.8
0.55	<b>1,793</b>	1,578	1,316	<b>13.1</b>	11.3	9.0
0.60	<b>1,617</b>	1,427	1,196	<b>13.3</b>	11.5	9.2
0.70	<b>1,329</b>	1,179	996	<b>13.6</b>	11.8	9.6
0.80	<b>1,105</b>	985	838	<b>13.9</b>	12.1	9.8
0.90	<b>927</b>	830	710	<b>14.0</b>	12.2	10.0
1.00	<b>785</b>	705	606	<b>14.1</b>	12.4	10.2

Table D16. Biological reference points from a new per-recruit model for *Illex illecebrosus* and results of a sensitivity analysis. Reference points from SARC 29 (NEFSC 1999b), a different model, are also shown but are not comparable (see text). The new per recruit model uses different natural mortality rates for non-spawning ( $M_{NS}$ ) and spawning ( $M_{SP}$ ) individuals. Reference points from the new model are maximum values for fully-recruited individuals while reference points from SARC 29 are average values for a 31-week fishing season. Best estimates of reference points from the new model, with  $M_{SP}=0.80$  and  $M_{NS}=0.01$ , are shown in bold-faced text.

Weekly Input Data	<b>Models and Input Data</b>					
	Semelparous Life History Model			Semelparous Life History Model		Constant M Model
	SARC 37			SARC 37		SARC 29
$M_{NS}$	<b>0.01</b>	0.03	0.06	NA		NA
$M_{SP}$	<b>0.80</b>	0.84	0.91	NA		NA
$M_{TOT}$	<b>NA</b>	NA	NA	0.06		0.06
<b>Reference Points (per week)</b>						
						(estimates not comparable to SARC 37 model)
$F_{50\%}$	<b>0.21</b>	0.22	0.24	0.08		0.02
$F_{40\%}$	<b>0.27</b>	0.30	0.33	0.11		0.03
$F_{0.1}$	<b>0.45</b>	0.48	0.55	0.14		0.07
$F_{MAX}$	<b>inf</b>	inf	inf	0.20		0.14

Table D17. Comparison of landings (mt) and nominal effort (df) in the *Illex* fishery as reported in the Weighout (WO), Vessel Trip Reports (VTR), and real-time data collection (RTM) databases during 1999-2002.

	VTR		RTM		WO
	Landings (mt)	Effort (df)	Landings (mt)	Effort (df)	Landings (mt)
1999	6,211	220	5,901	150	6,987
2000	6,065	196	2,969	24	8,281
2001	2,866	76	2,594	60	3,450
2002	1,752	57	*	*	2,062

\* data not presented due to Federal law confidentiality requirements

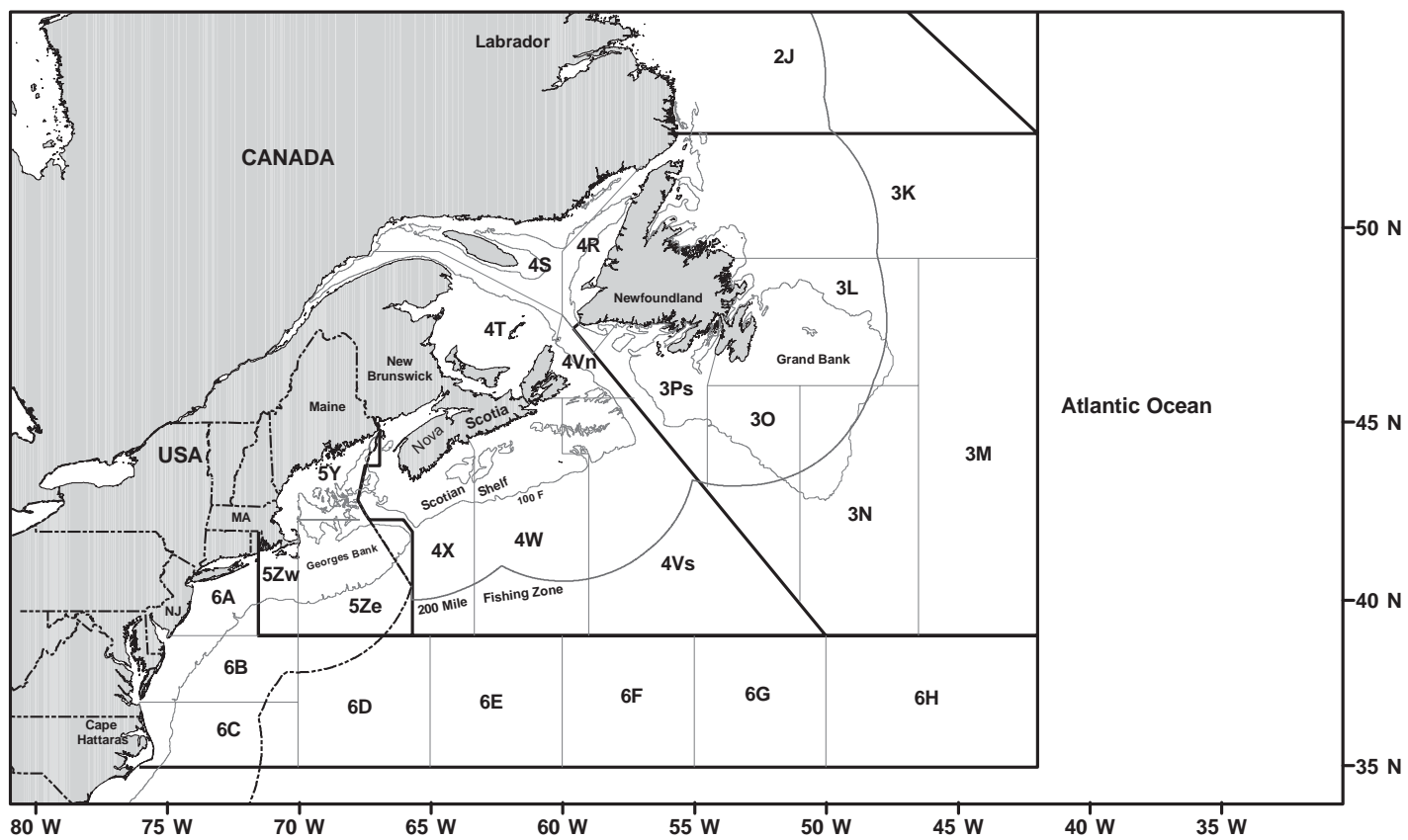


Figure D1. Northwest Atlantic Fisheries Organization (NAFO) Subareas 3-6 and Divisions in the Northwest Atlantic Ocean.



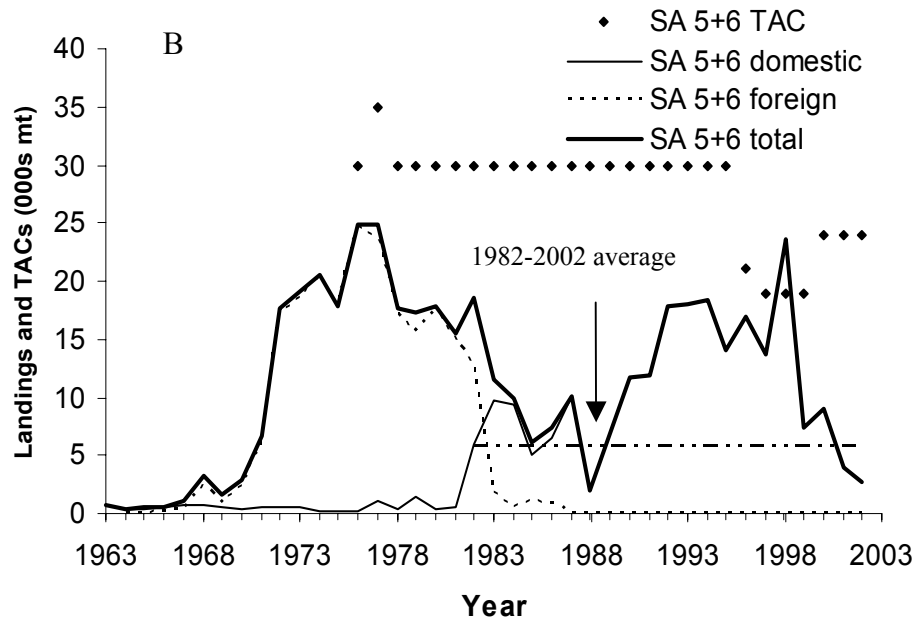
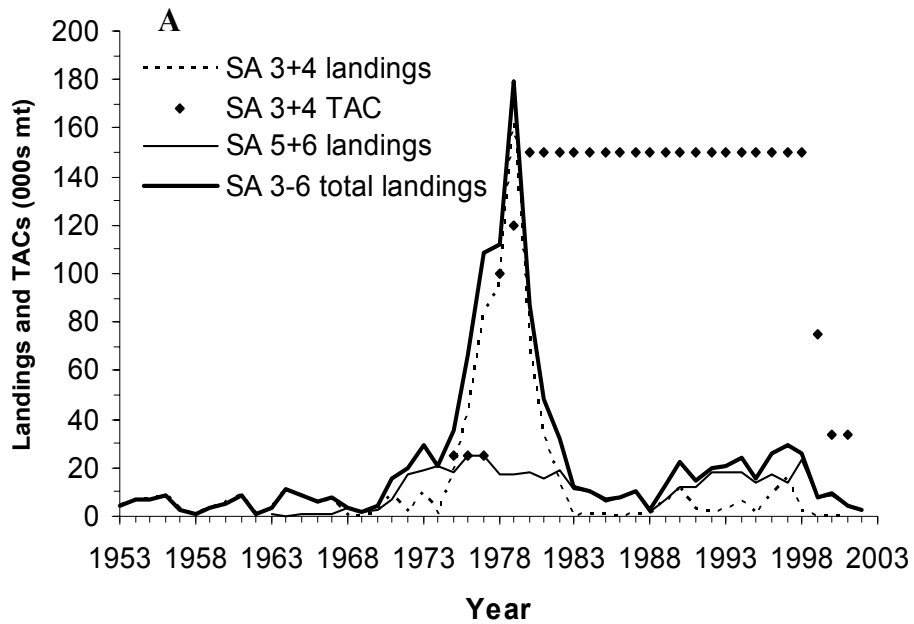


Figure D2. Landings of *Illex illecebrosus* in (A) NAFO Subareas 3-6 and (B) NAFO Subareas 5+6 (U.S. EEZ), with respect to TAC limits, during 1963-2002.

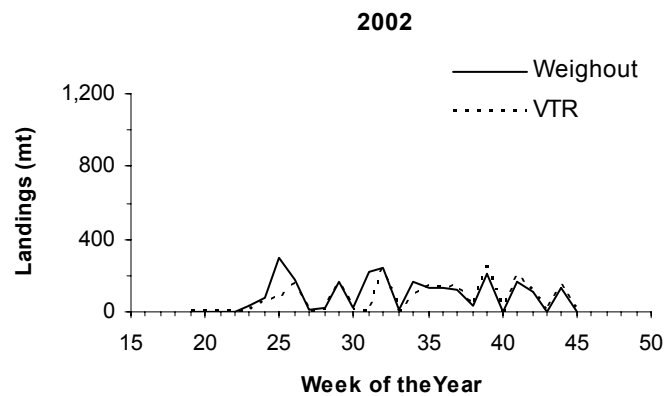
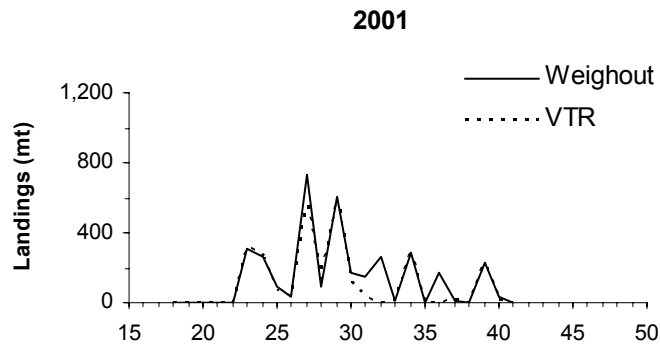
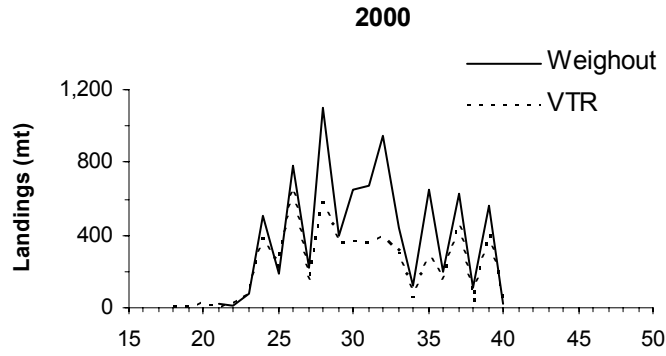
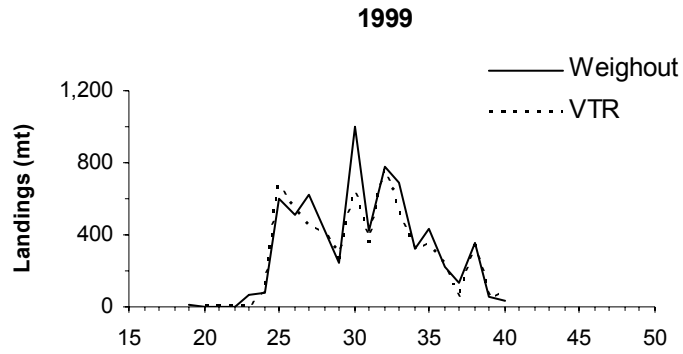


Figure D3. Trends in weekly *Illex illecebrosus* landings from the Weighout database versus the Vessel Trip Report database during 1999-2002.

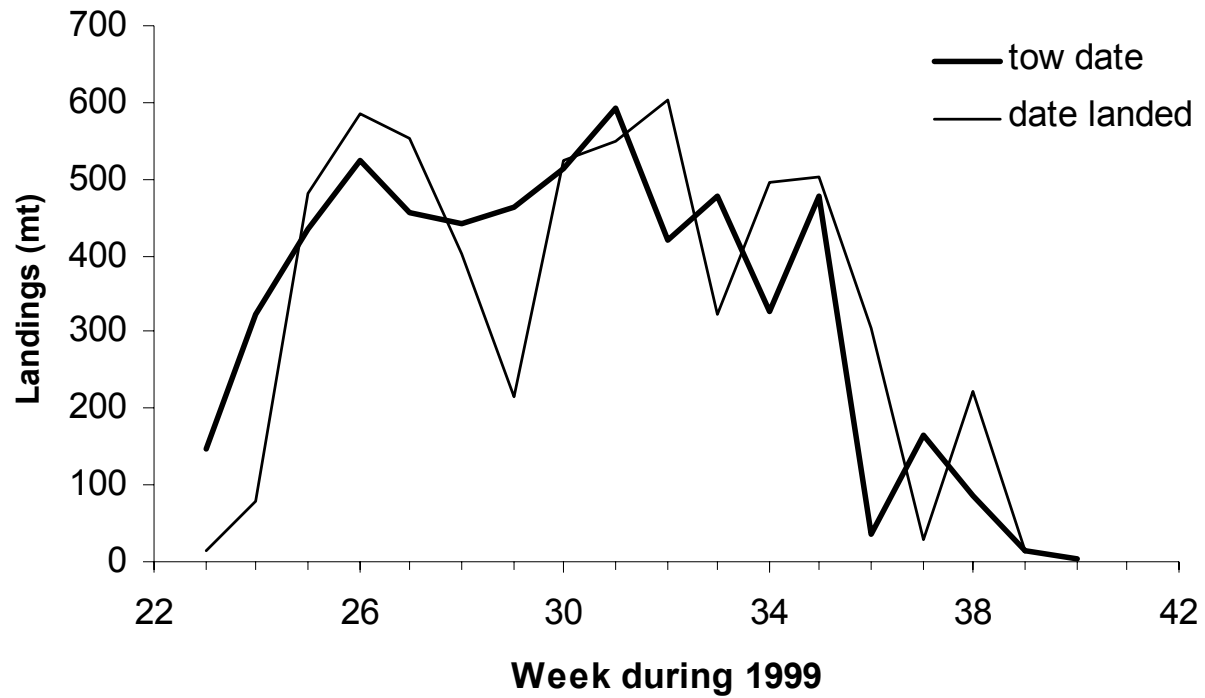


Figure D4. Weekly trends in *Illex illecebrosus* landings (mt), during 1999, from tow-based data provided by vessel operators and assigned to a week of the year based on date landed versus tow date.

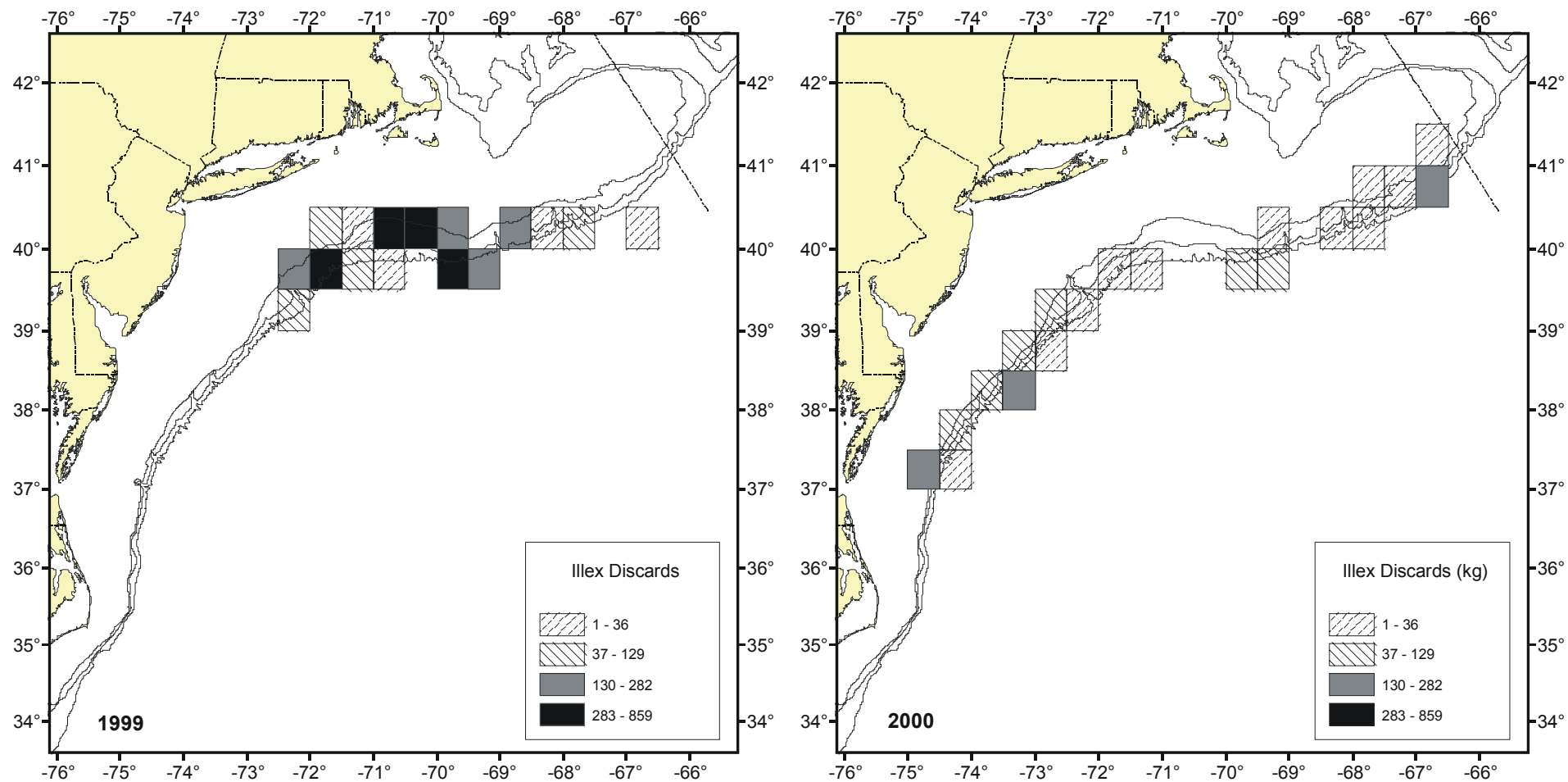


Figure D5. Spatial distribution of *Illex illecebrosus* discards (kg), by quarter-degree square, in *Loligo pealeii* trips ( $\geq 25\%$  of trip landed weight) sampled by observers from the NEFSC Observer Program during January-April and November-December, 1999-2000.

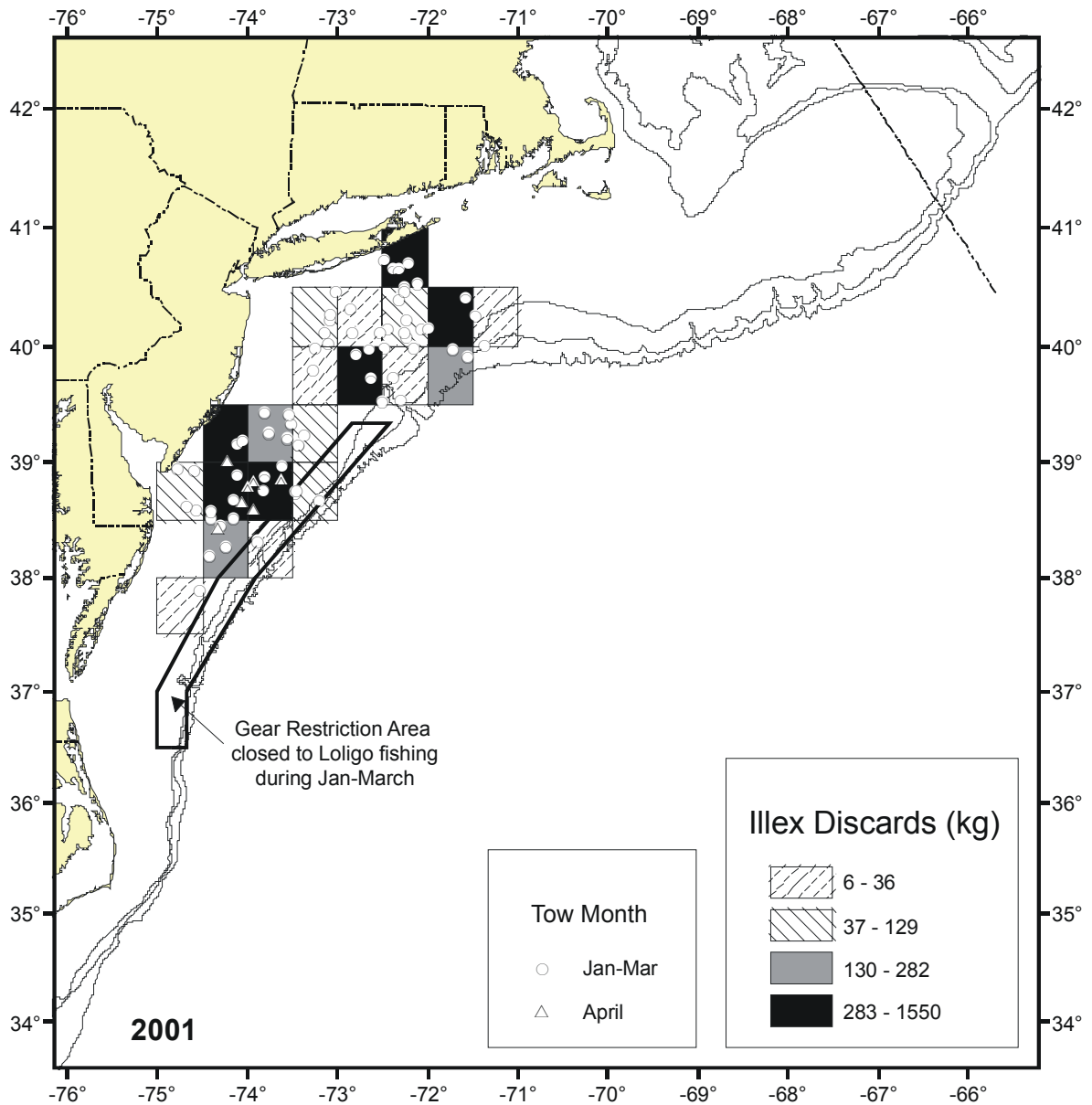


Figure D6. Spatial distribution of *Illex illecebrosus* discards (kg), by quarter-degree square, in *Loligo pealeii* trips ( $\geq 25\%$  of trip landed weight) sampled by observers from the NEFSC Observer Program during January-April and November-December, 2001. Circles and triangles indicate tow locations in relation to the small-mesh Southern Gear Restriction Area that is closed to *Loligo* and *Illex* fishing during January–March 15.

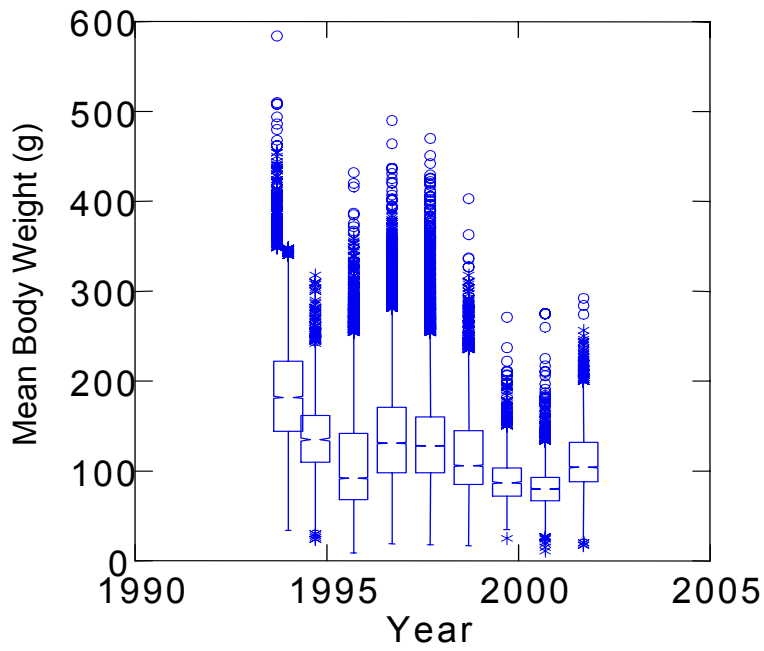
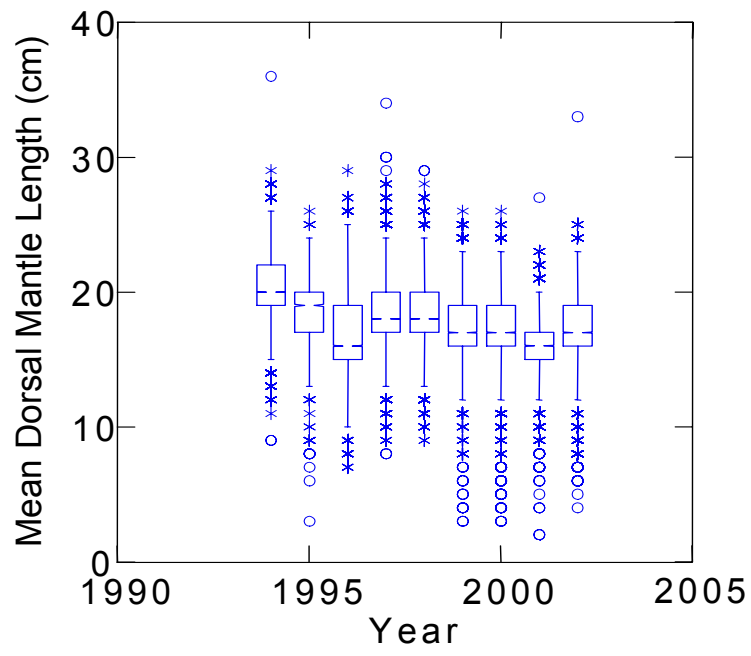


Figure D7. Annual trends in (A) mean mantle length (cm) and mean body weight (g) of *Illex illecebrosus* sampled from the landings during 1994-2002. The middle notch represents the median and the box boundaries represent the interquartile range.

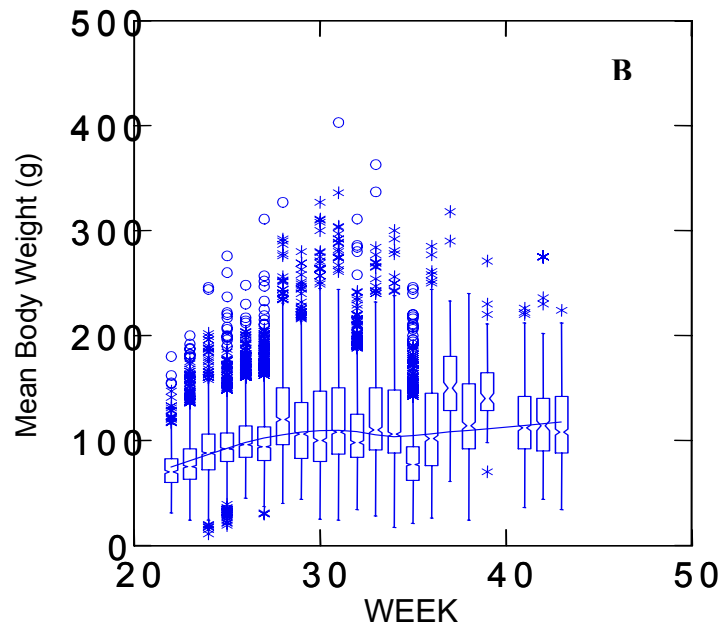
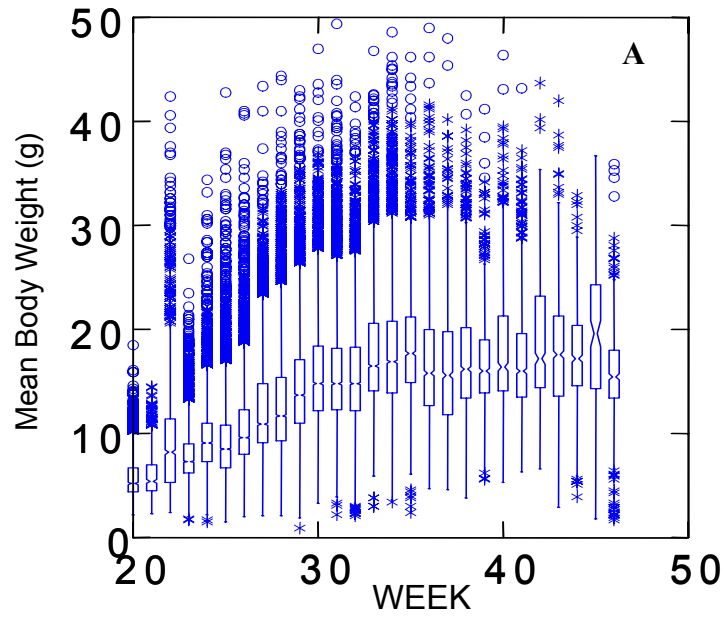


Figure D8. Weekly trends in the composite mean body weight (g) of *Illex illecebrosus* sampled from the landings during (A) 1994-1998 and (B) 1999-2002.

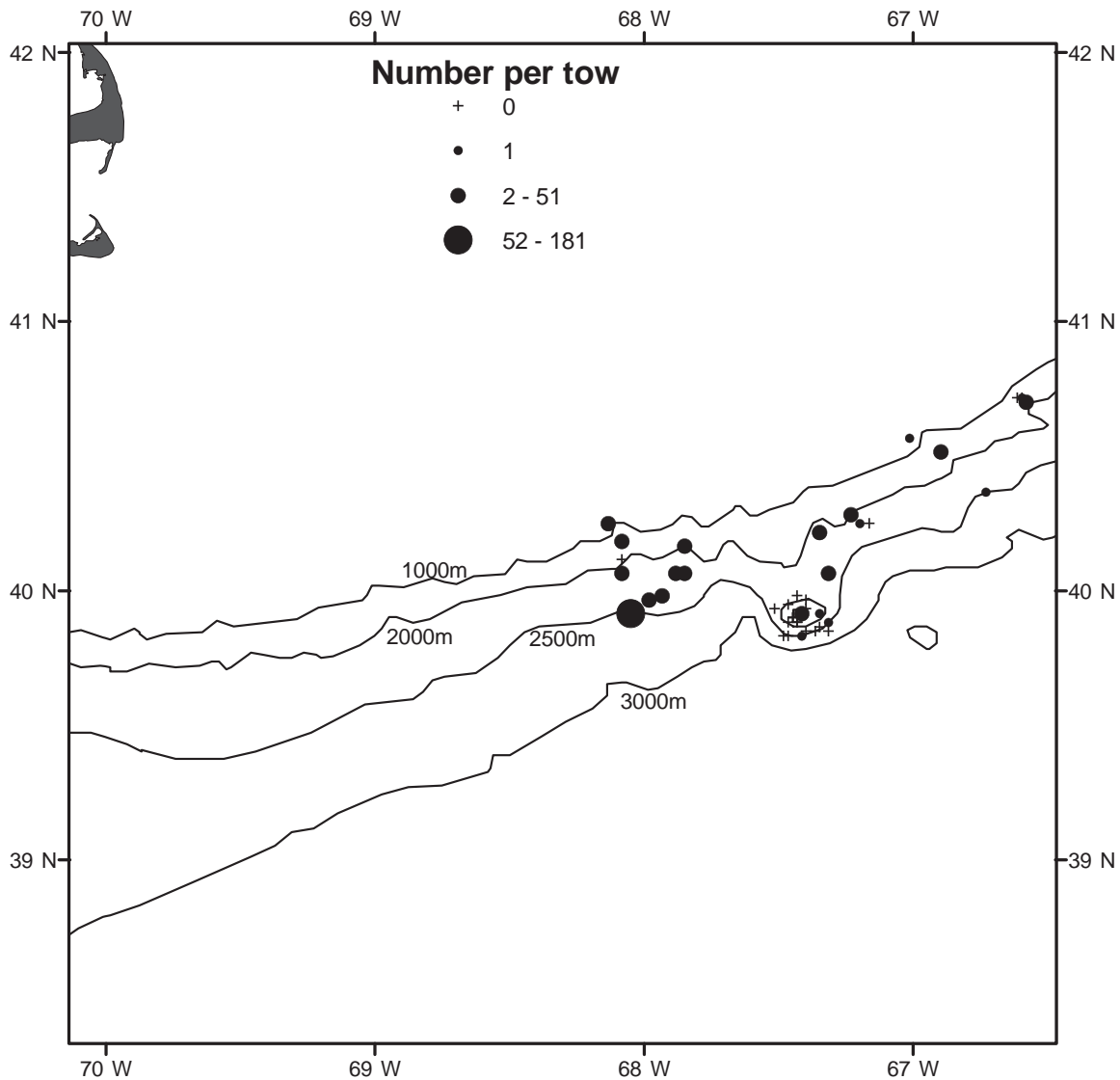


Figure D9. Distribution of *Illex illecebrosus* (number per tow) captured in a midwater trawl, by the *Delaware II*, during a research survey of the U.S. continental slope and the Bear Sea Mount during July, 2002.



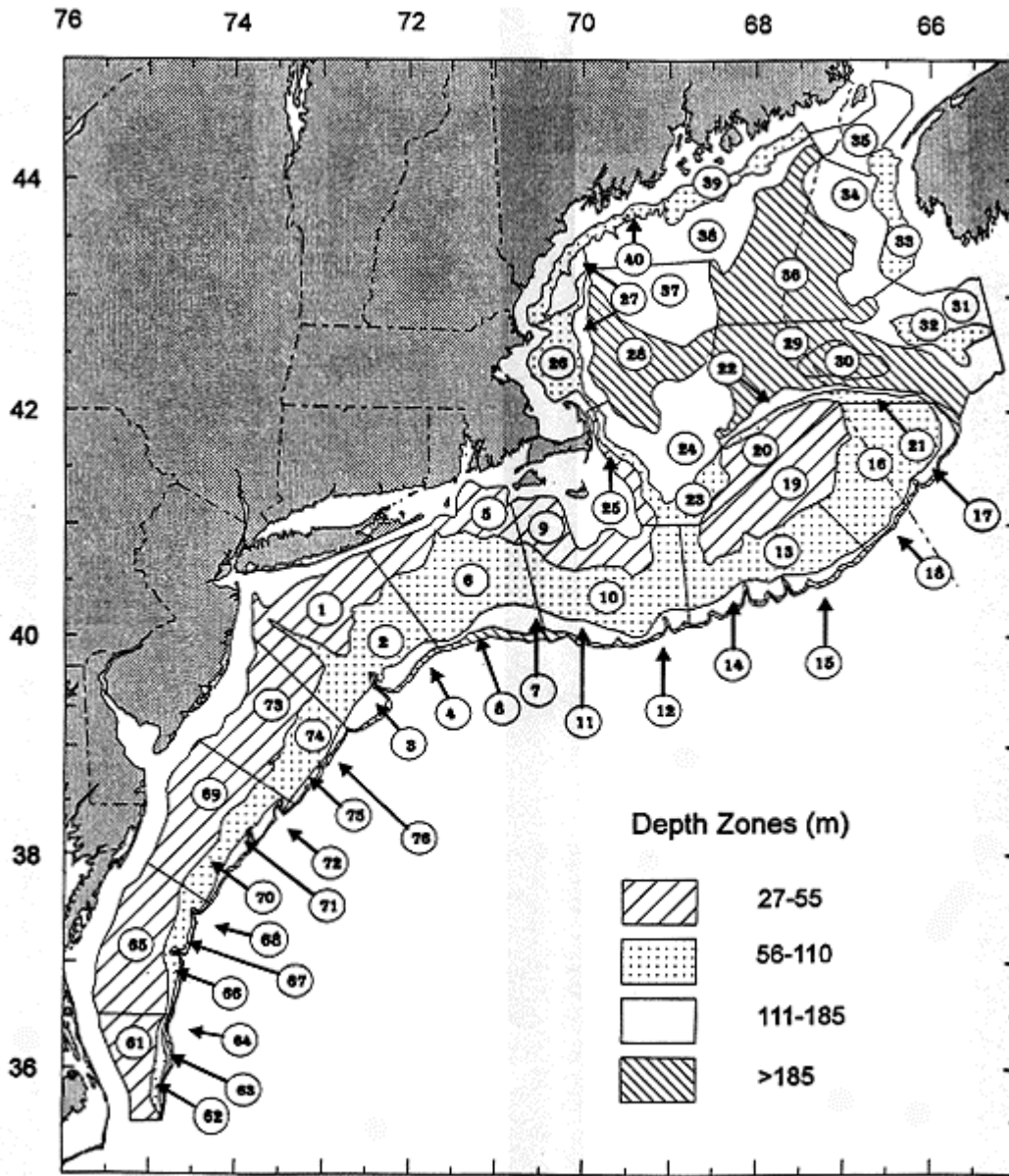


Figure D10. Offshore strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

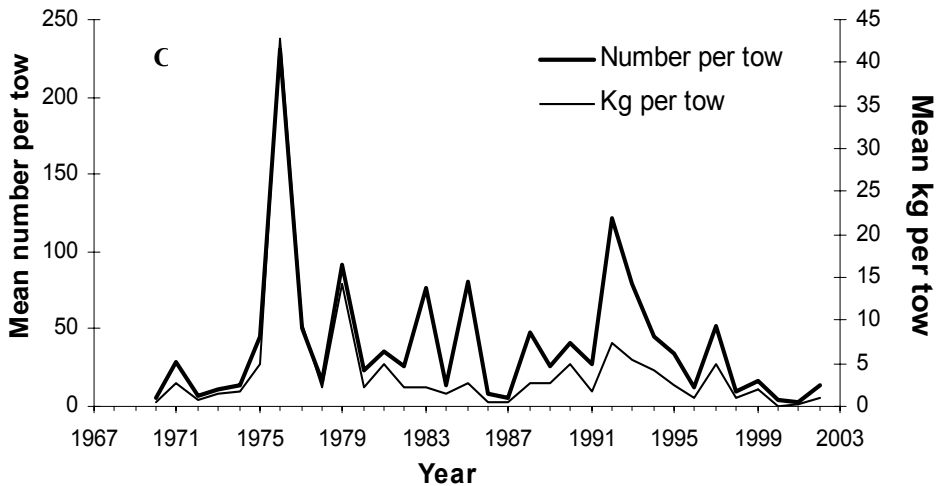
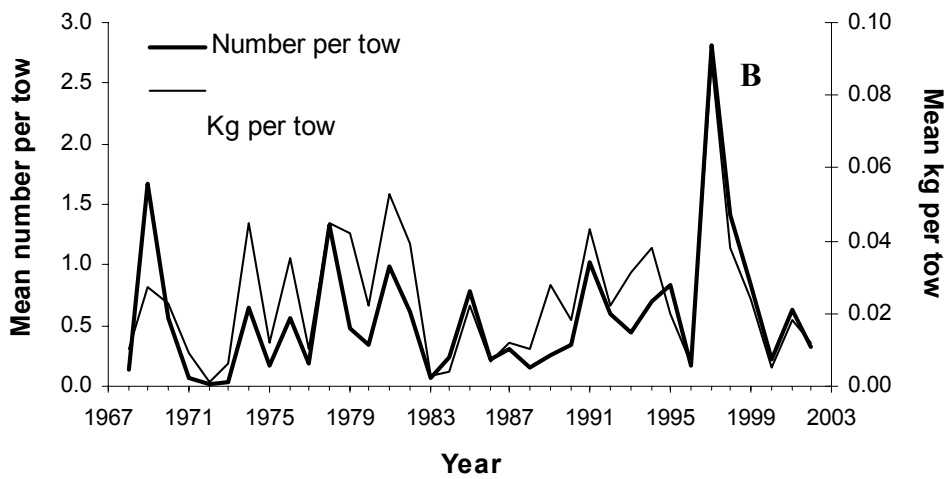
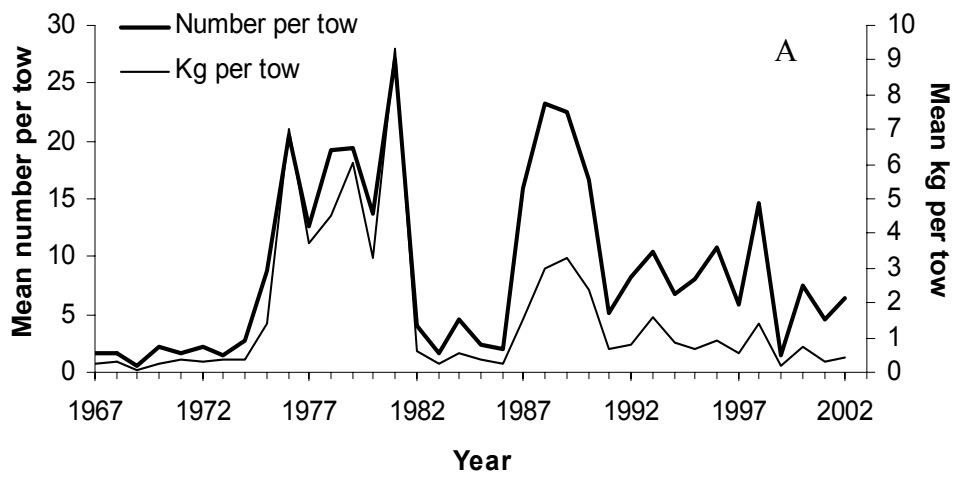


Figure D11. Trends in *Illex illecebrosus* indices of relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow) based on NEFSC (A) autumn (1967-2002) and (B) spring (1968-2002) research bottom trawl surveys and (C) the Canadian July bottom trawl survey on the Scotian Shelf (1970-2002).

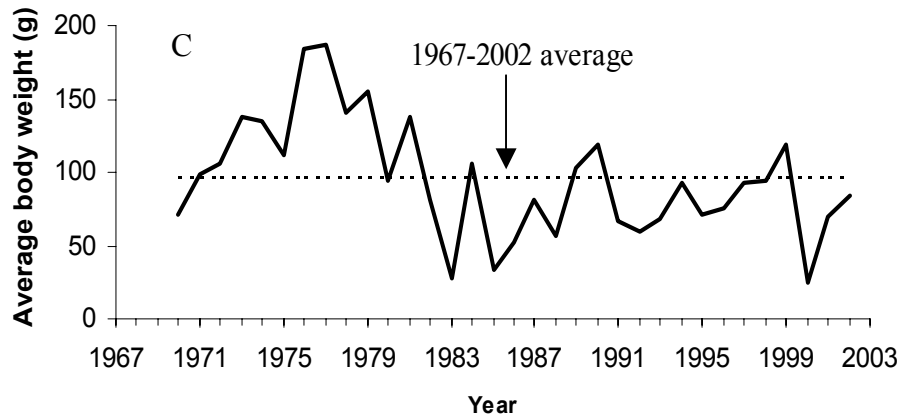
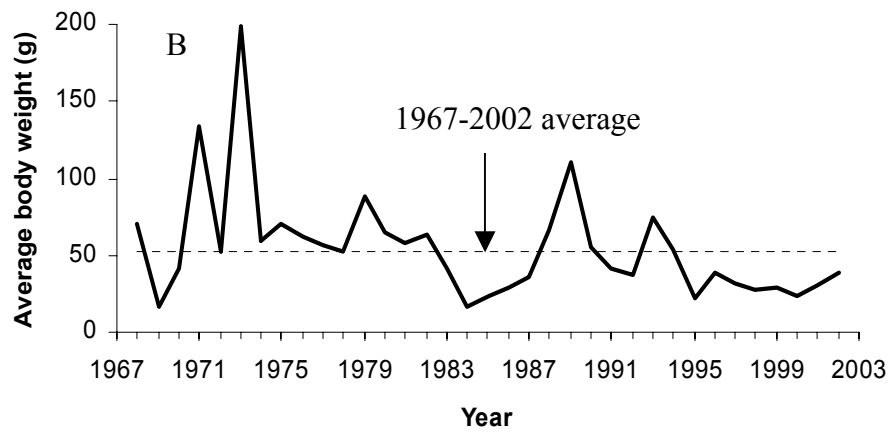
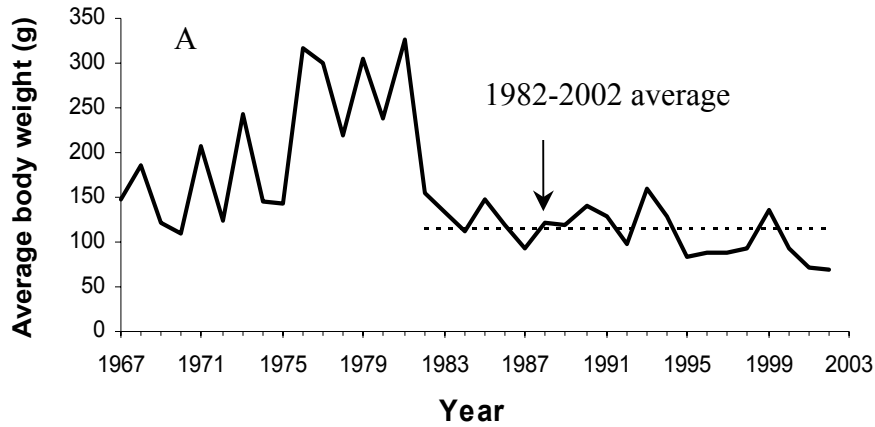


Figure D12. Trends in average body weight (g) of *Illex illecebrosus* caught during NEFSC (A) autumn (1967-2002) and (B) spring (1968-2002) research bottom trawl surveys and (C) the Canadian research bottom trawl survey conducted in July on the Scotian Shelf (NAFO Div. 4VXW, 1970-2002).

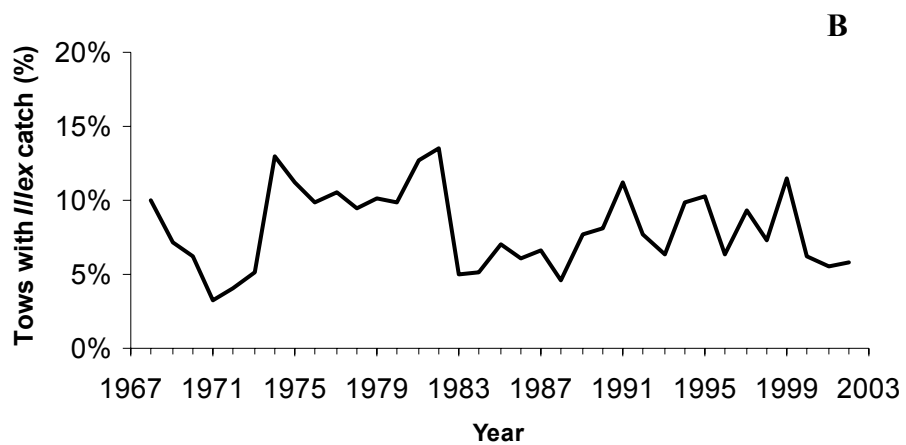
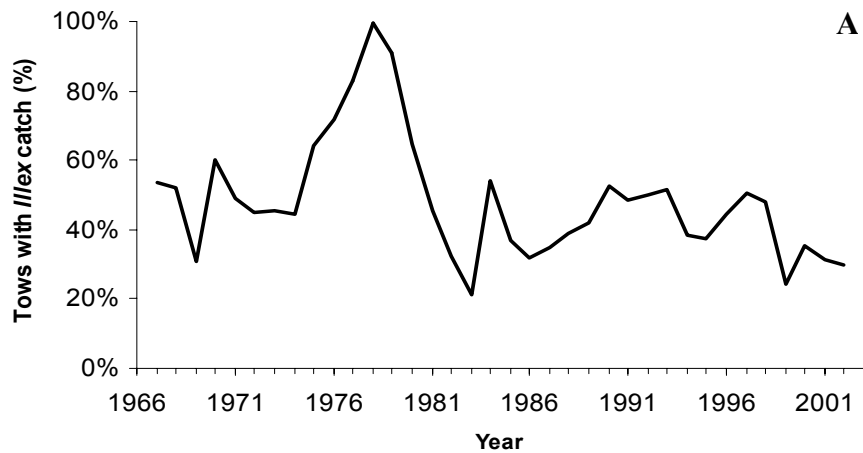
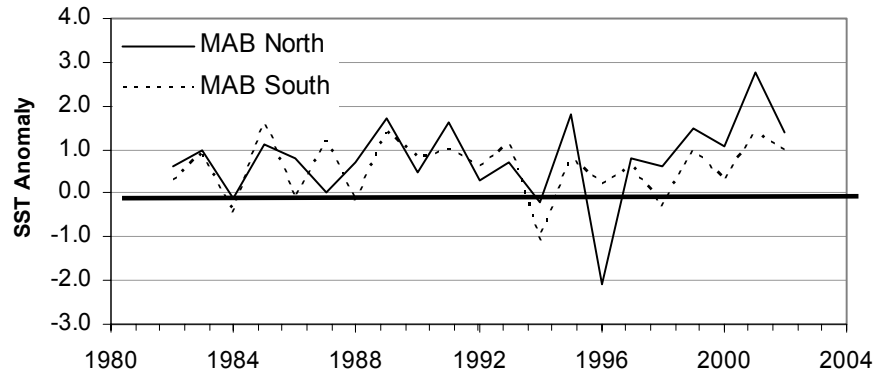


Figure D13. Trends in *Illex* dispersion indices, proportion of tows with *Illex illecebrosus* catch, from NEFSC autumn (1967-2002) and spring (1968-2002) bottom trawl surveys.

**Autumn Survey**



**Spring Survey**

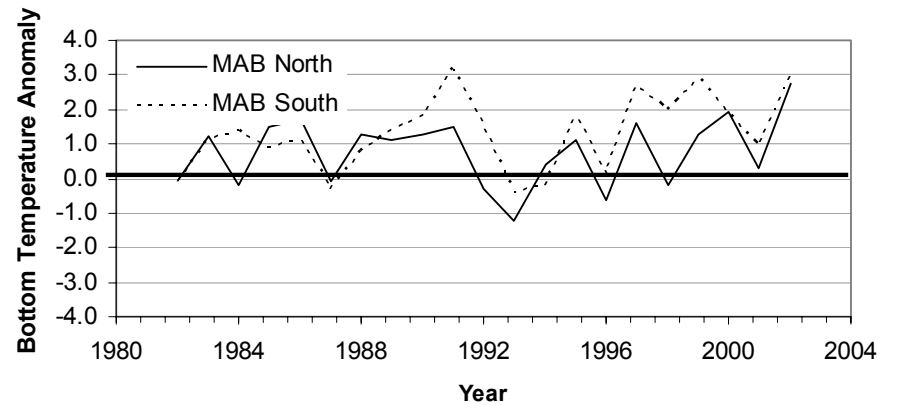
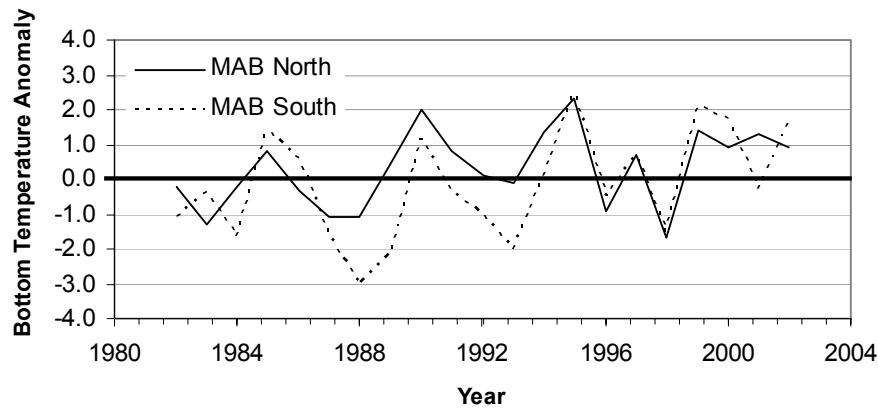
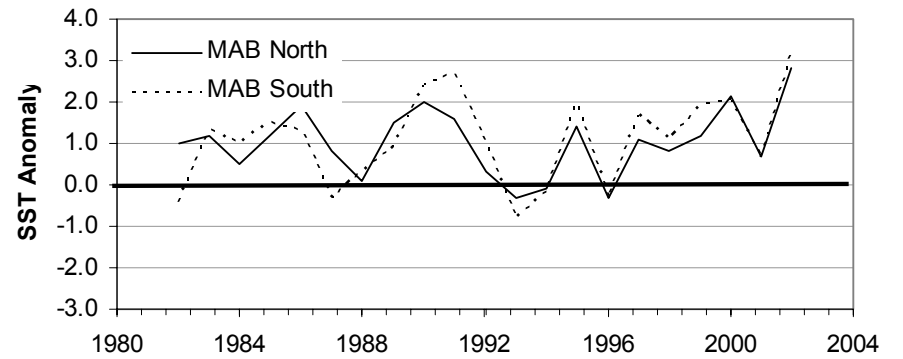


Figure D14. Areal average sea surface and bottom temperature anomalies in the Mid-Atlantic Bight, north versus south, during NEFSC autumn and spring bottom trawl surveys, 1982-2002. Anomalies were computed in relation to a reference period of 1977-1987.

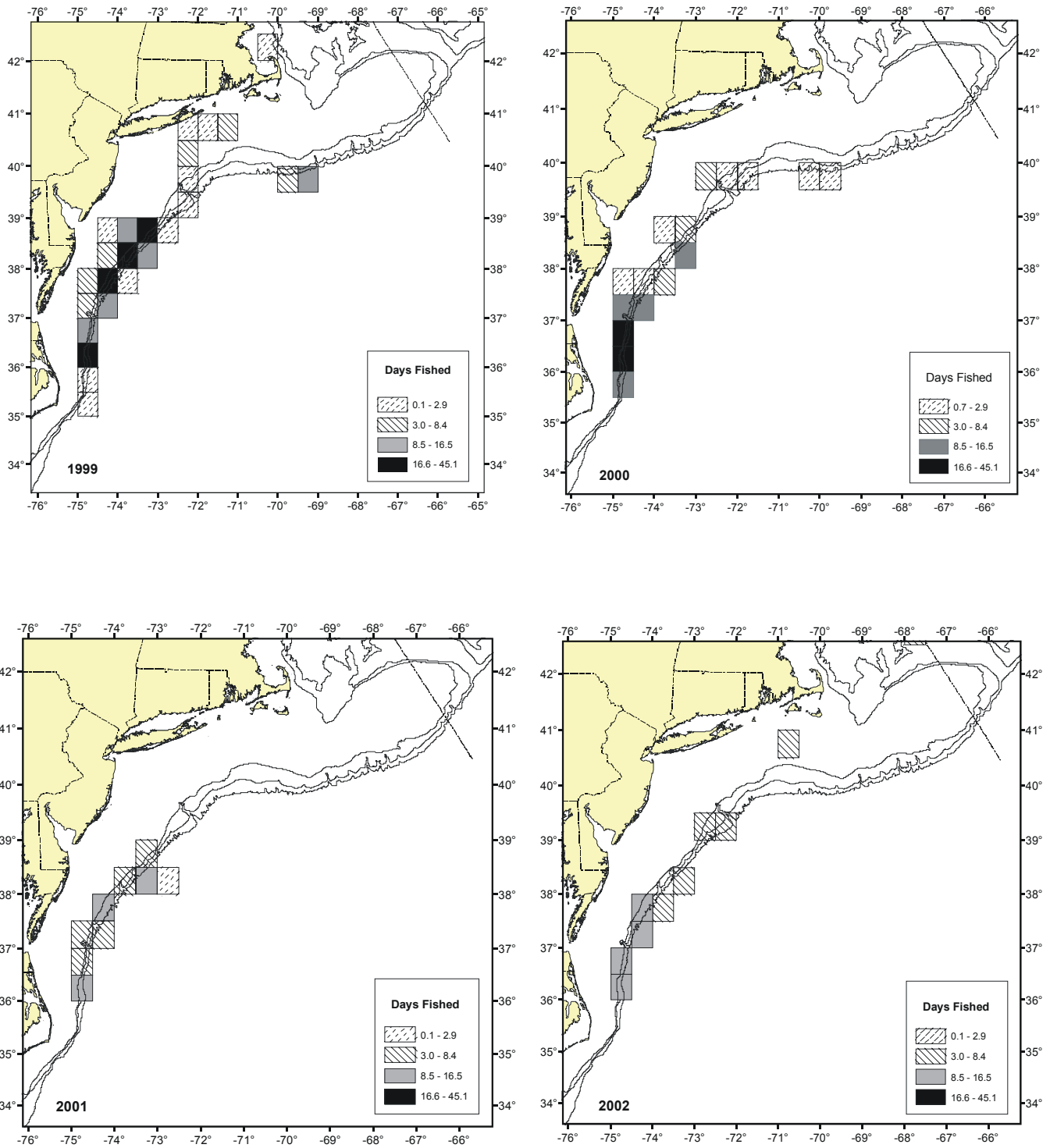


Figure D15. Distribution of fishing effort (days fished), by quarter-degree square, for otter trawlers participating in the *Illex illecebrosus* fishery during May-November, 1999-2002. Bathymetry represents 50, 100 and 500 fathoms.

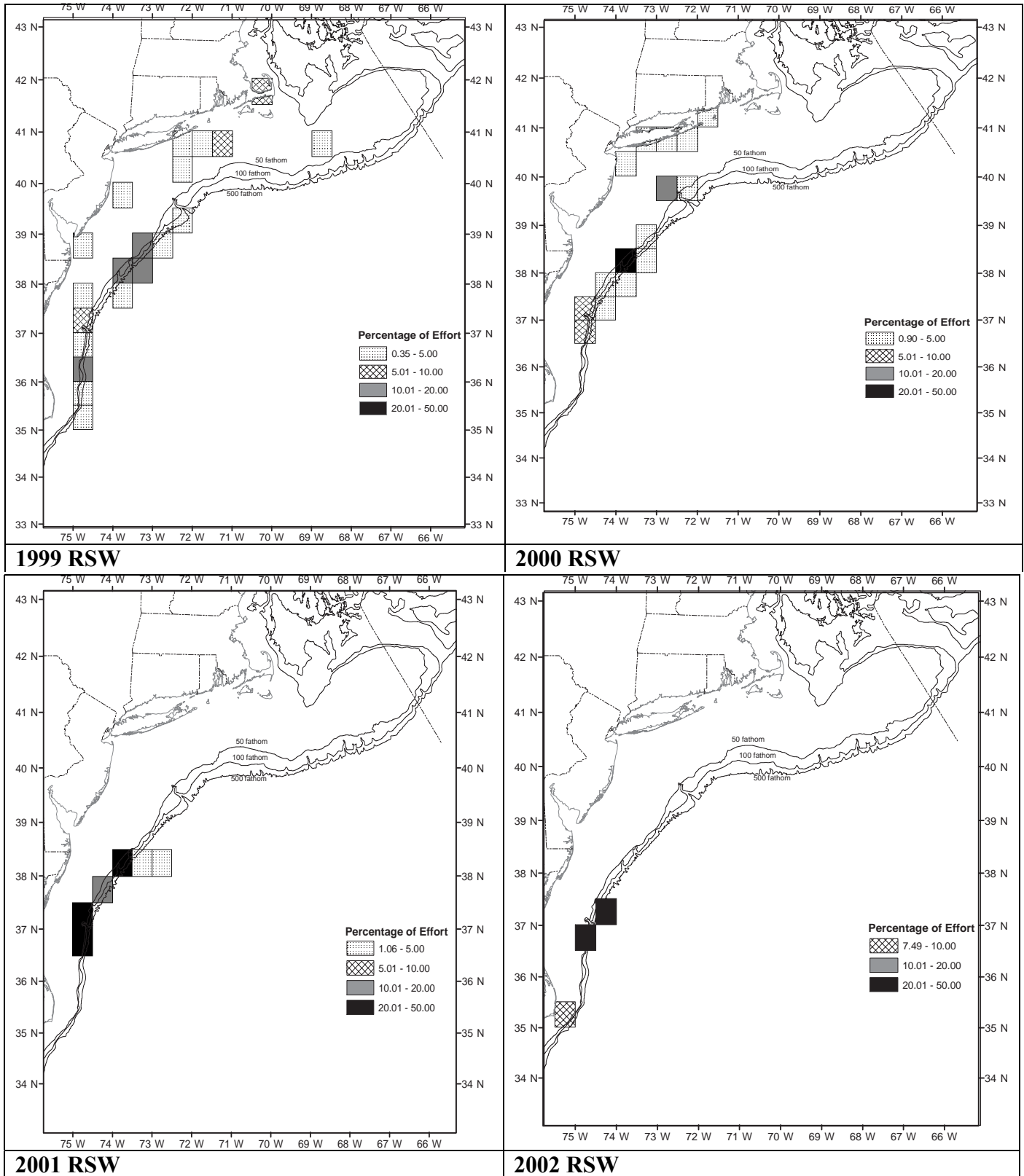


Figure D16. Percentage of fishing effort (days fished), quarter-degree square, for recirculating seawater system (RSW) trawlers participating in the *Illex illecebrosus* fishery during May-November, 1999-2002.

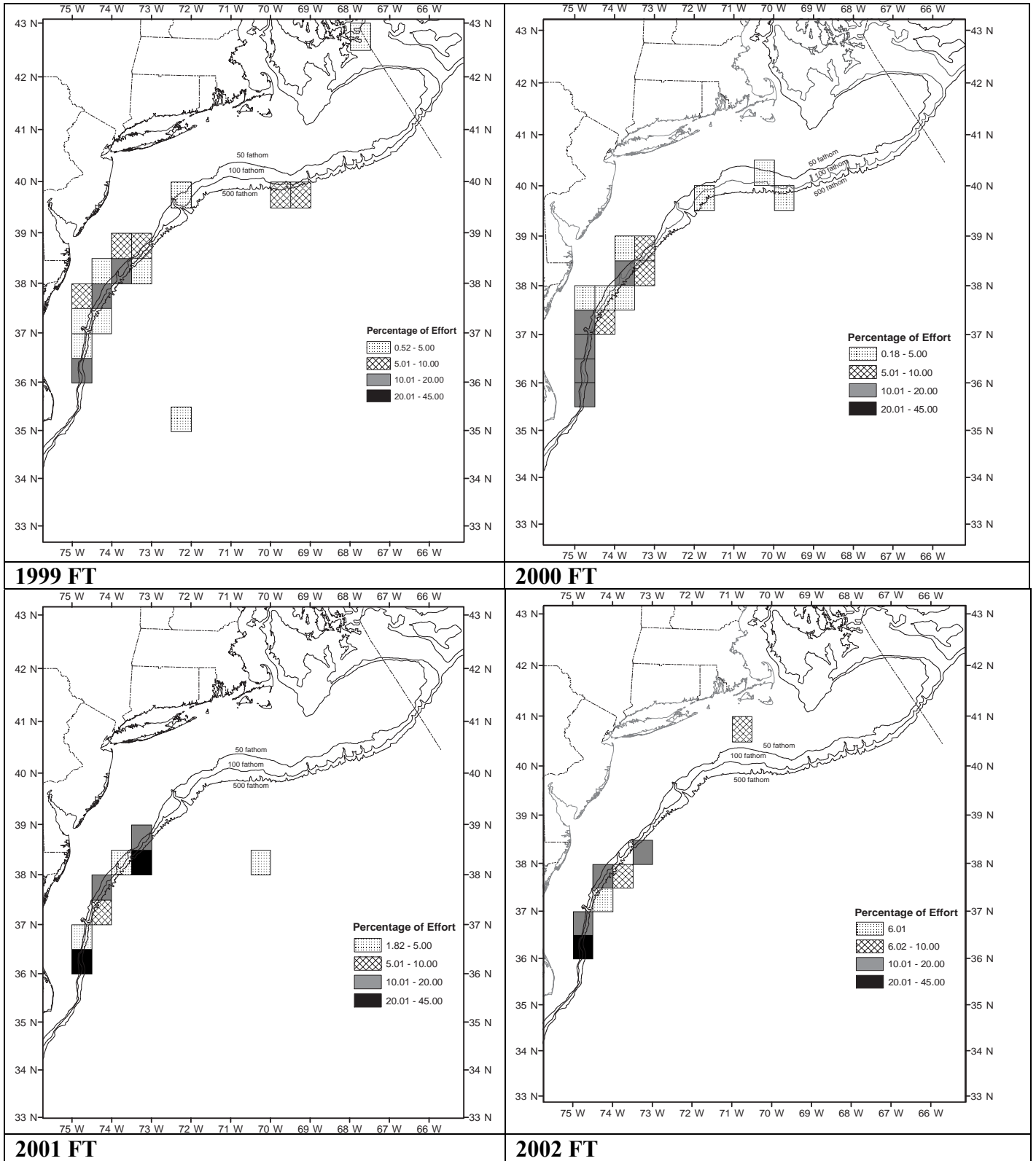


Figure D17. Percentage of fishing effort (days fished), by quarter-degree square, for freezer trawlers participating in the *Illex illecebrosus* fishery during May-November, 1999-2002.



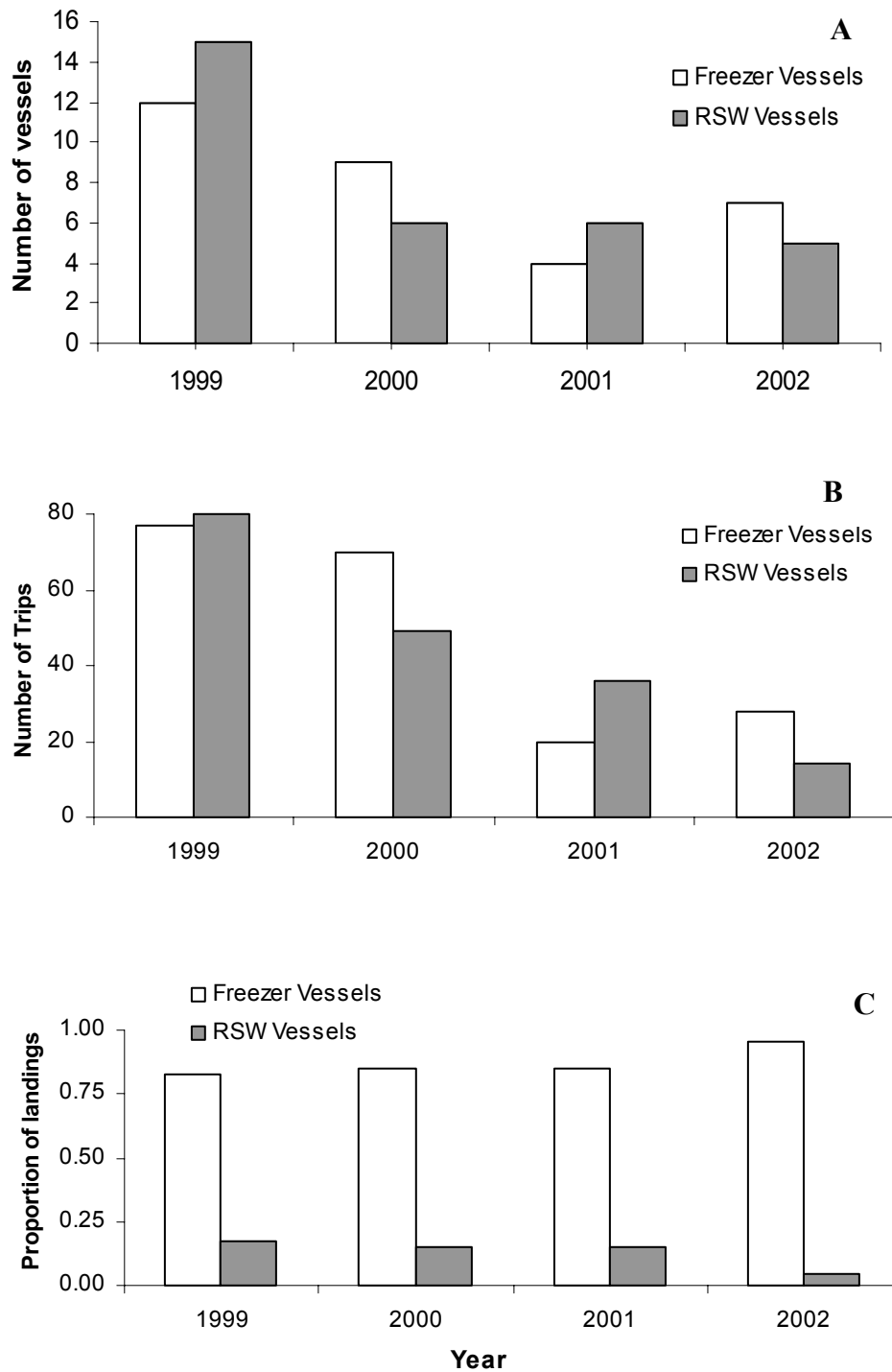


Figure D18. Number of vessels, trips and proportion of *Illex* landings in the U.S. directed fishery, by fleet sector, during 1999-2002. Data were obtained from the Weighout database.

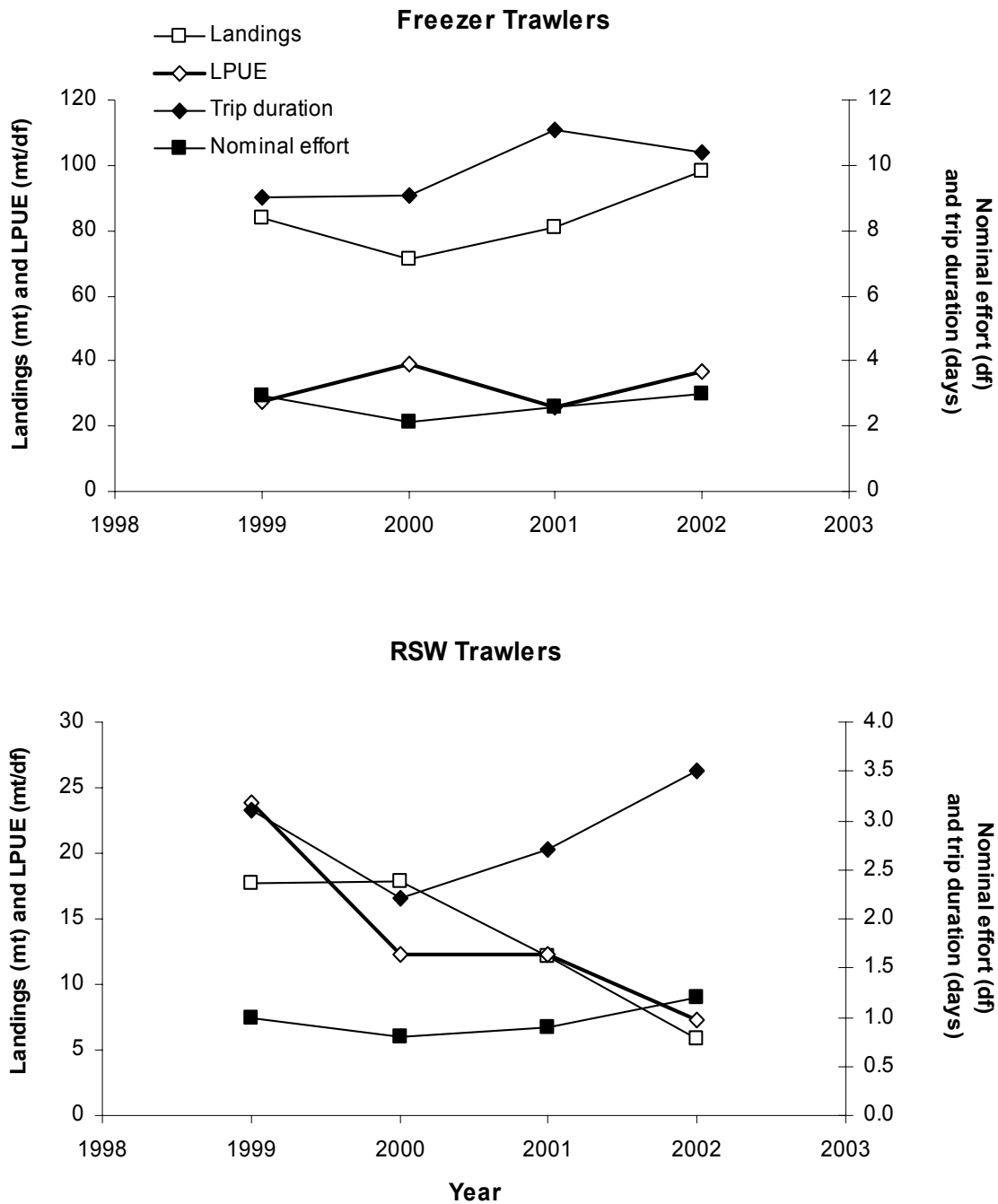


Figure D19. Trends in average trip duration, (days), nominal effort (days fished), landings (mt), and LPUE (mt/df), for (A) freezer trawlers and (B) RSW trawlers, during 1999-2002.

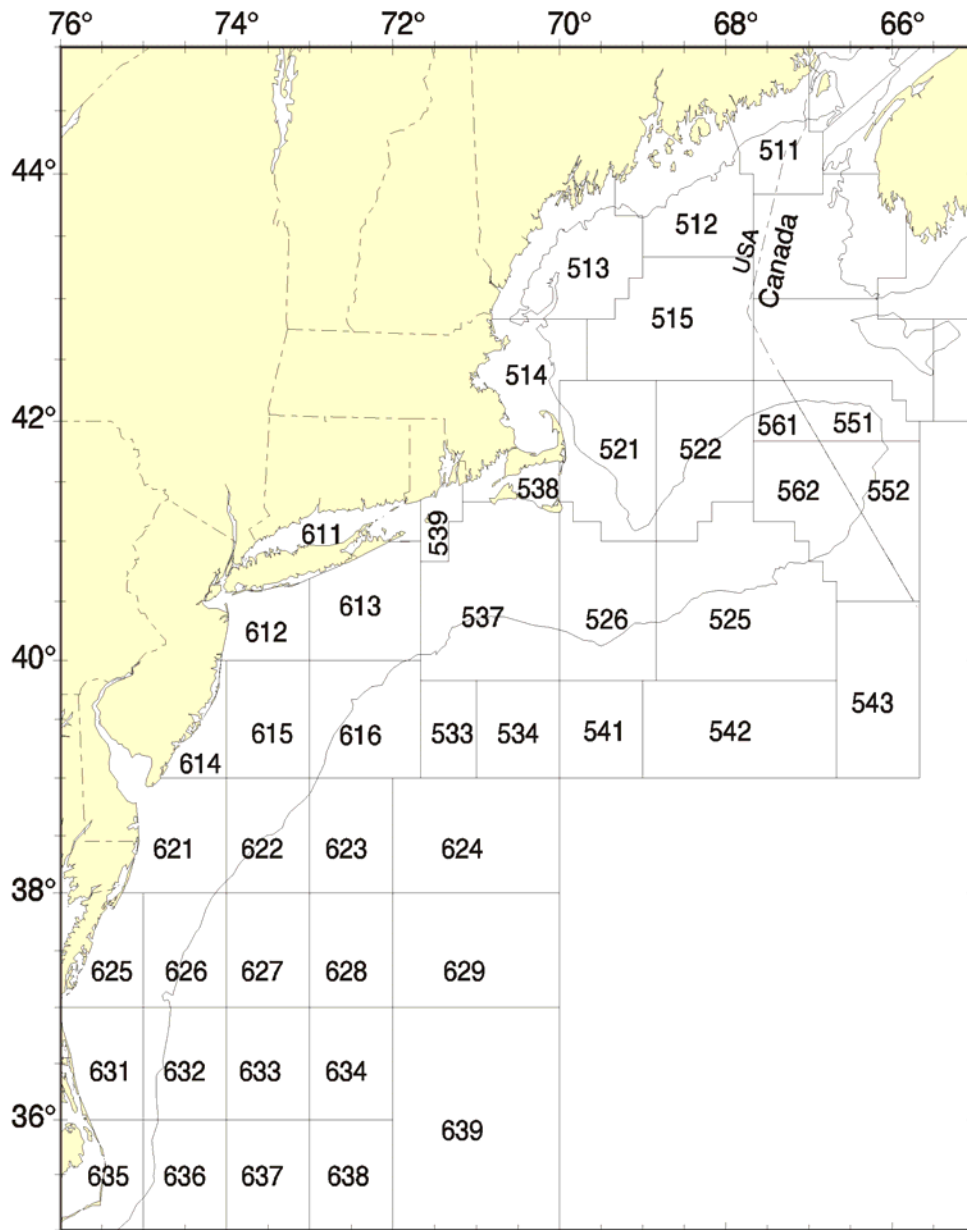


Figure D20. Statistical reporting areas for U.S. fisheries in the northwest Atlantic Ocean.

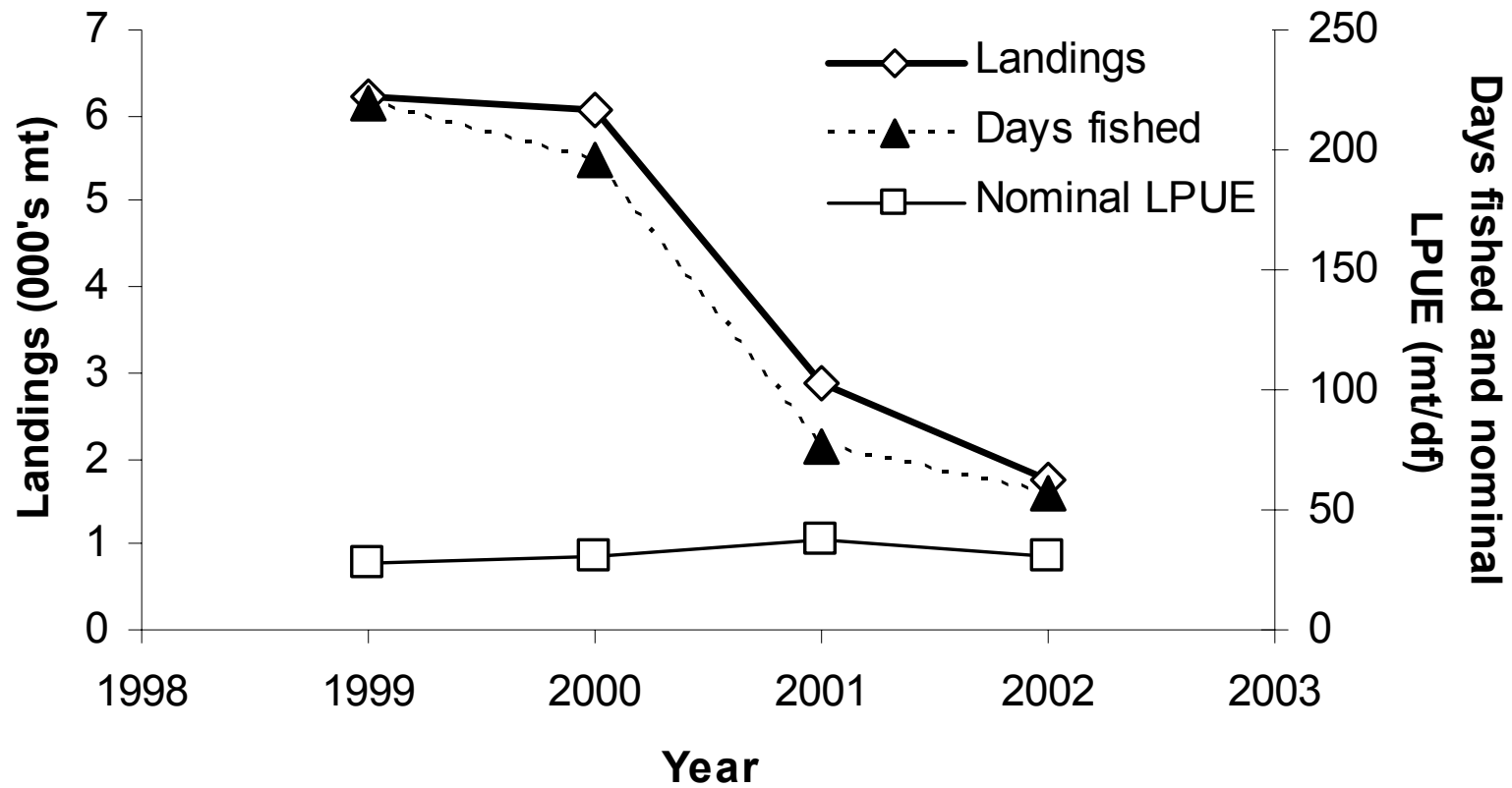


Figure D21. Trends in total landings (mt), effort (days fished) and nominal LPUE (mt per day fished) in the *Illex illecebrosus* fishery, during 1999-2002, based on Vessel Trip Reports.

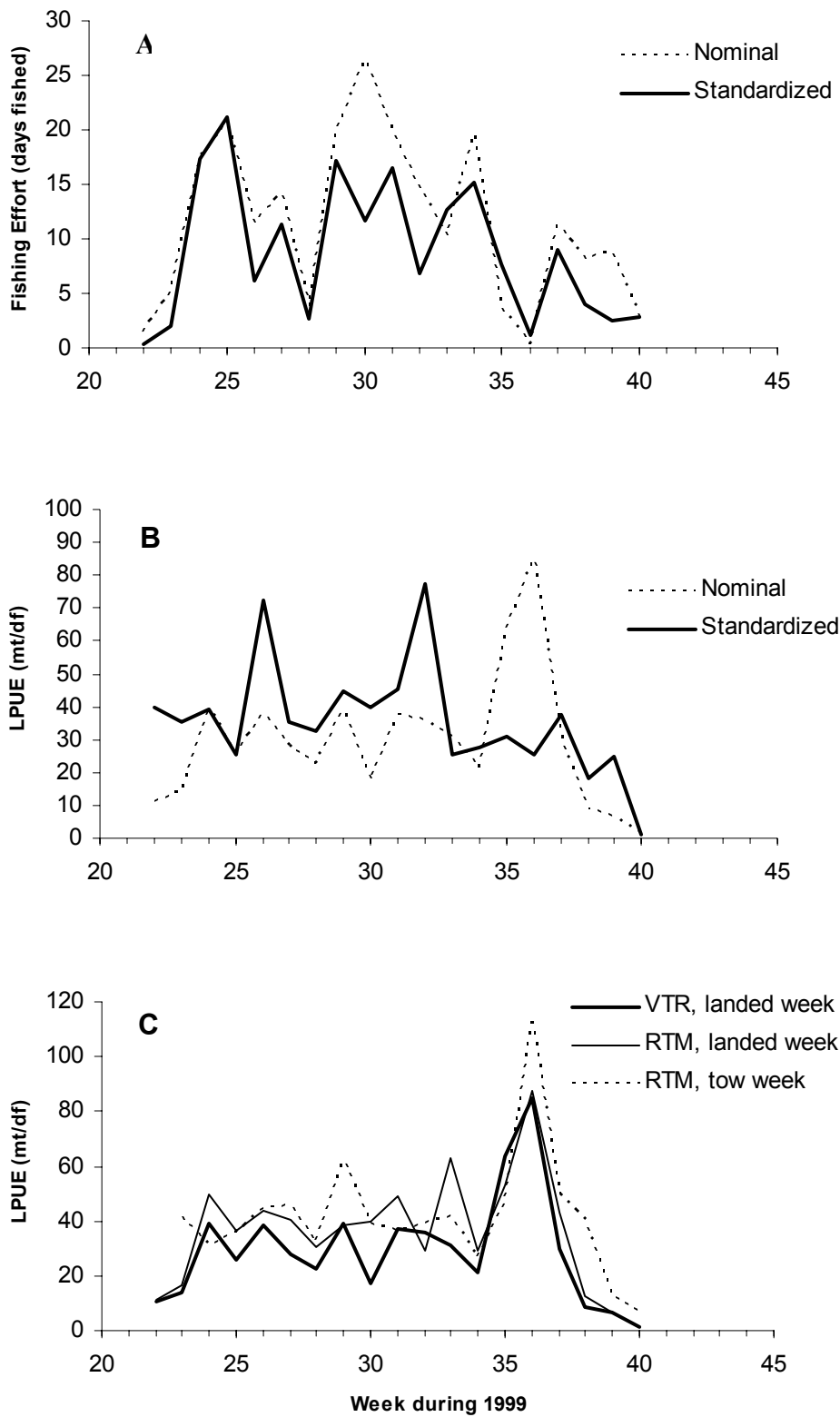


Figure D22. Seasonal trends in (A) *Illex* fishing effort (df) and (B) LPUE (mt/df) reported in the Vessel Trip Reports (VTR), and (C) nominal LPUE reported in the VTR and RTM databases during 1999.

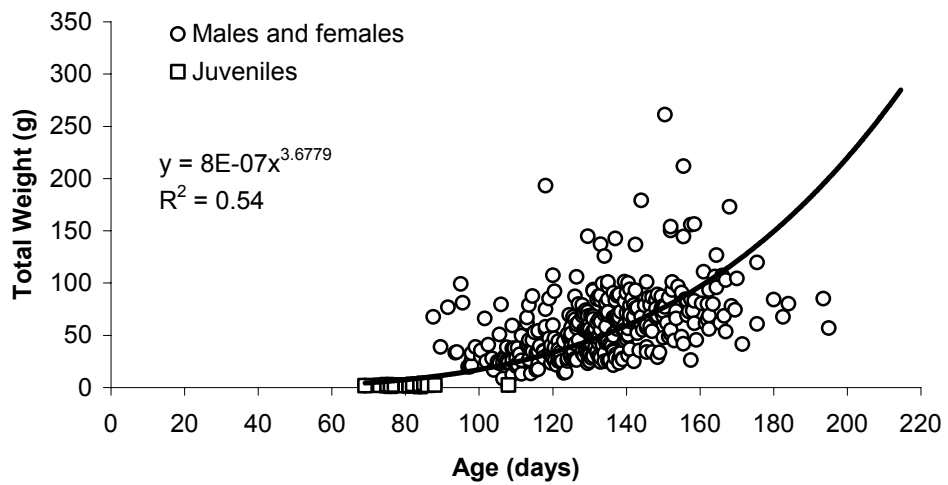
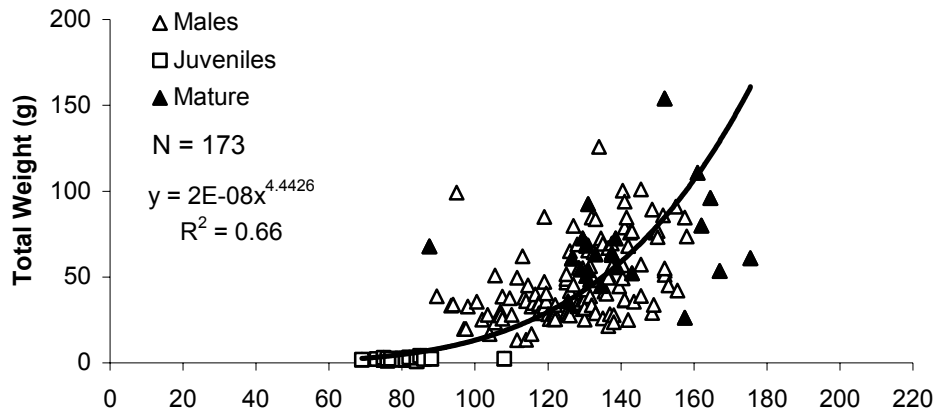
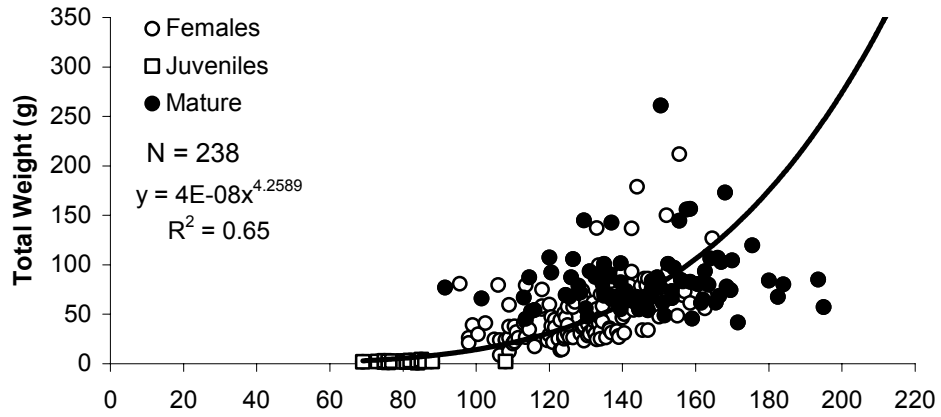


Figure D23. Observed weights-at-age and growth curves, by separate and combined sexes, for *Illex illecebrosus* caught in a bottom trawl survey conducted off the east coast of the U.S. during May, 2000 (Hendrickson *In Review*).

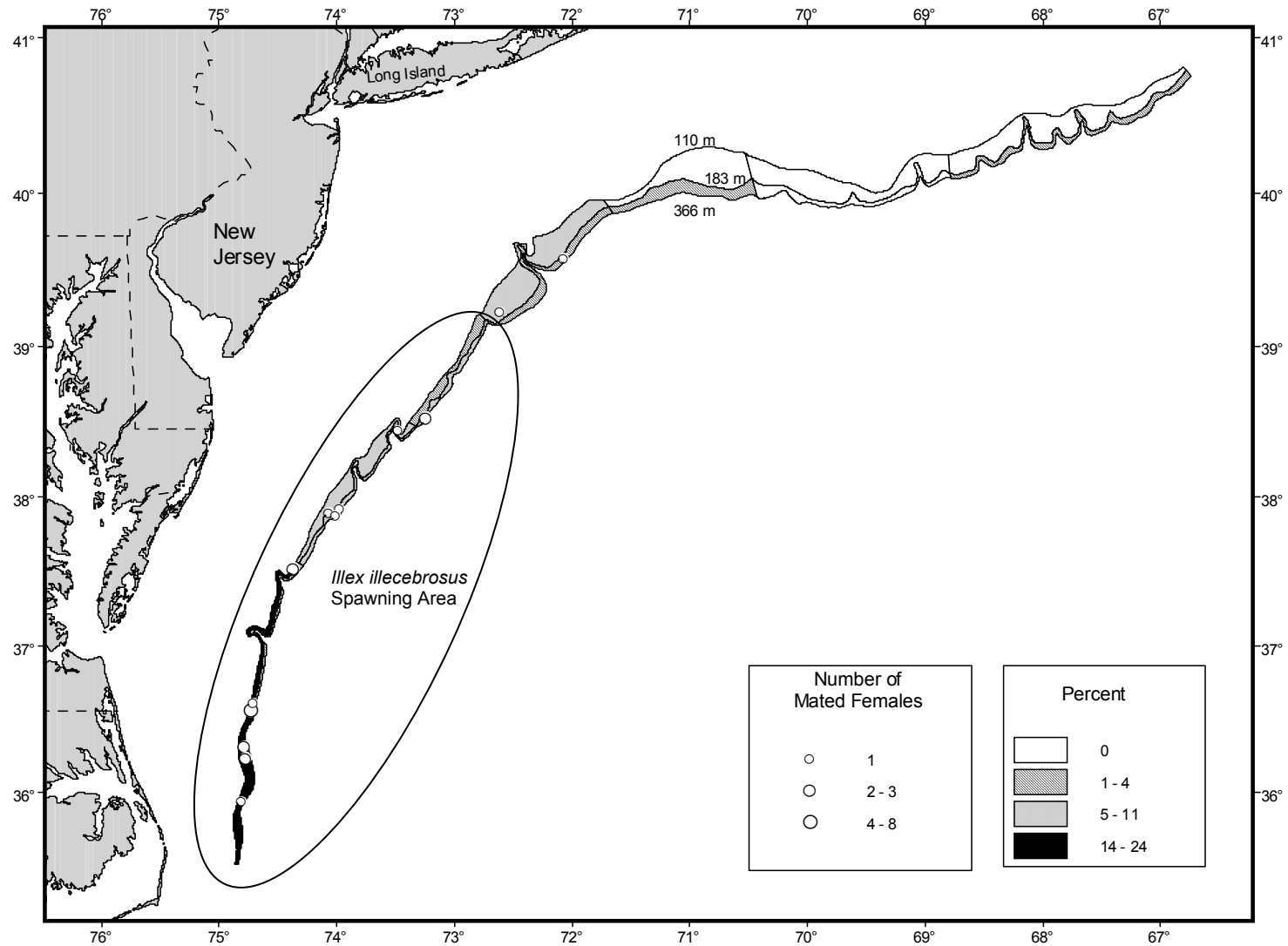
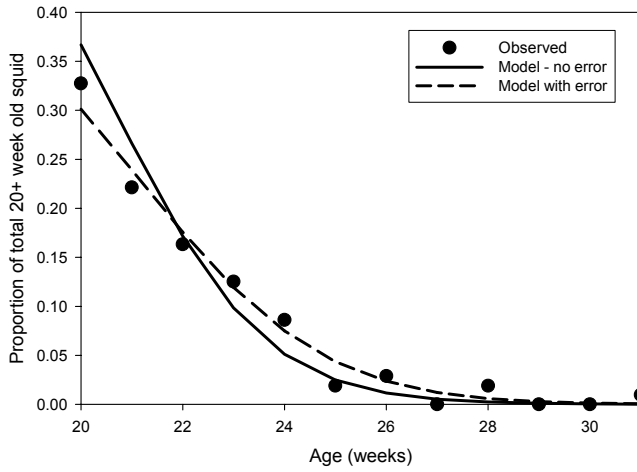
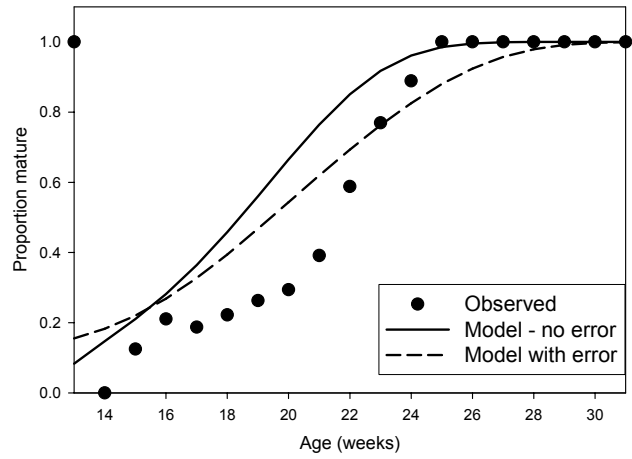


Figure D24. *Illex illecebrosus* spawning area defined as strata within which the majority of mated females and highest percentage of mature females were caught during a bottom trawl survey conducted off the east coast of the U.S. during May, 2000 (Hendrickson *In Review*).

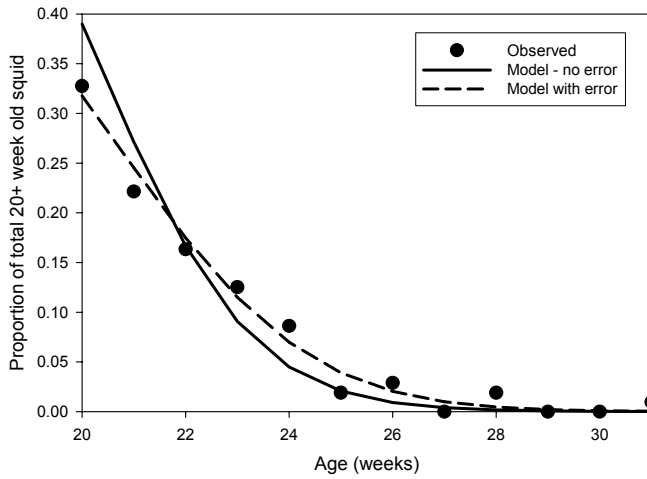
**Age structure**  
 $M_{NS}=0.01, M_S = 0.80$



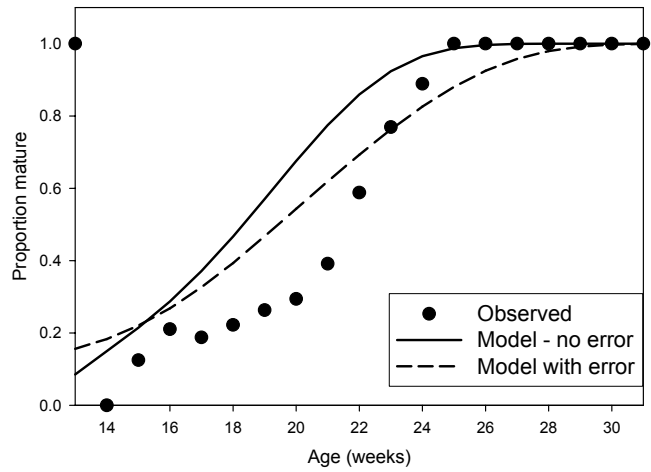
**Proportion mature with age**  
 $M_{NS}=0.01, M_S=0.80$



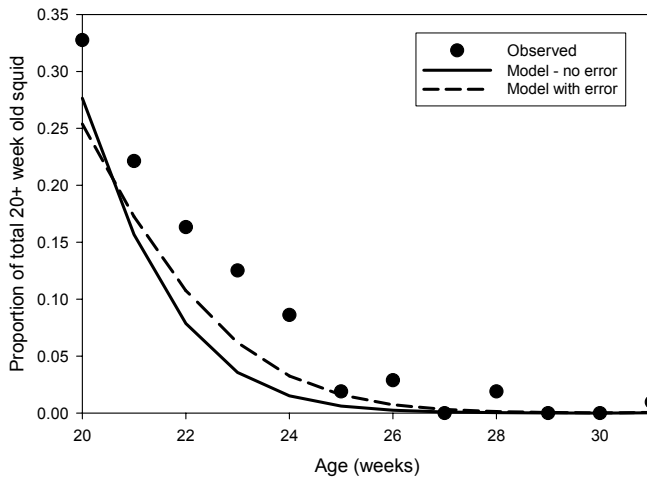
**Age structure**  
 $M_{NS}=0.03, M_S = 0.84$



**Proportion mature with age**  
 $M_{NS}=0.03, M_S=0.84$



**Age structure**  
 $M_{NS}=0.06, M_S = 0.91$



**Proportion mature with age**  
 $M_{NS}=0.06, M_S=0.91$

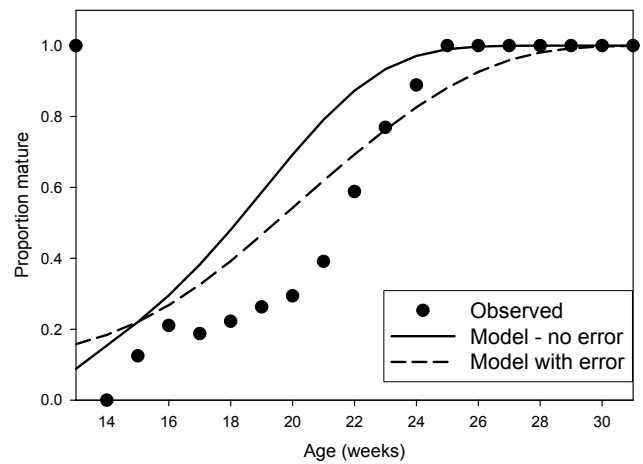


Figure D25. Observed and predicted proportions at age and proportions mature at age, for *Illex illecebrosus* sampled during May 2000, for non-spawning natural mortality rates ( $M_{NS}$ ) of 0.01, 0.03, and 0.06 and spawning mortality rates (MSP) of 0.80, 0.84 and 0.90. Model results are shown with and without the incorporation of age estimation error.



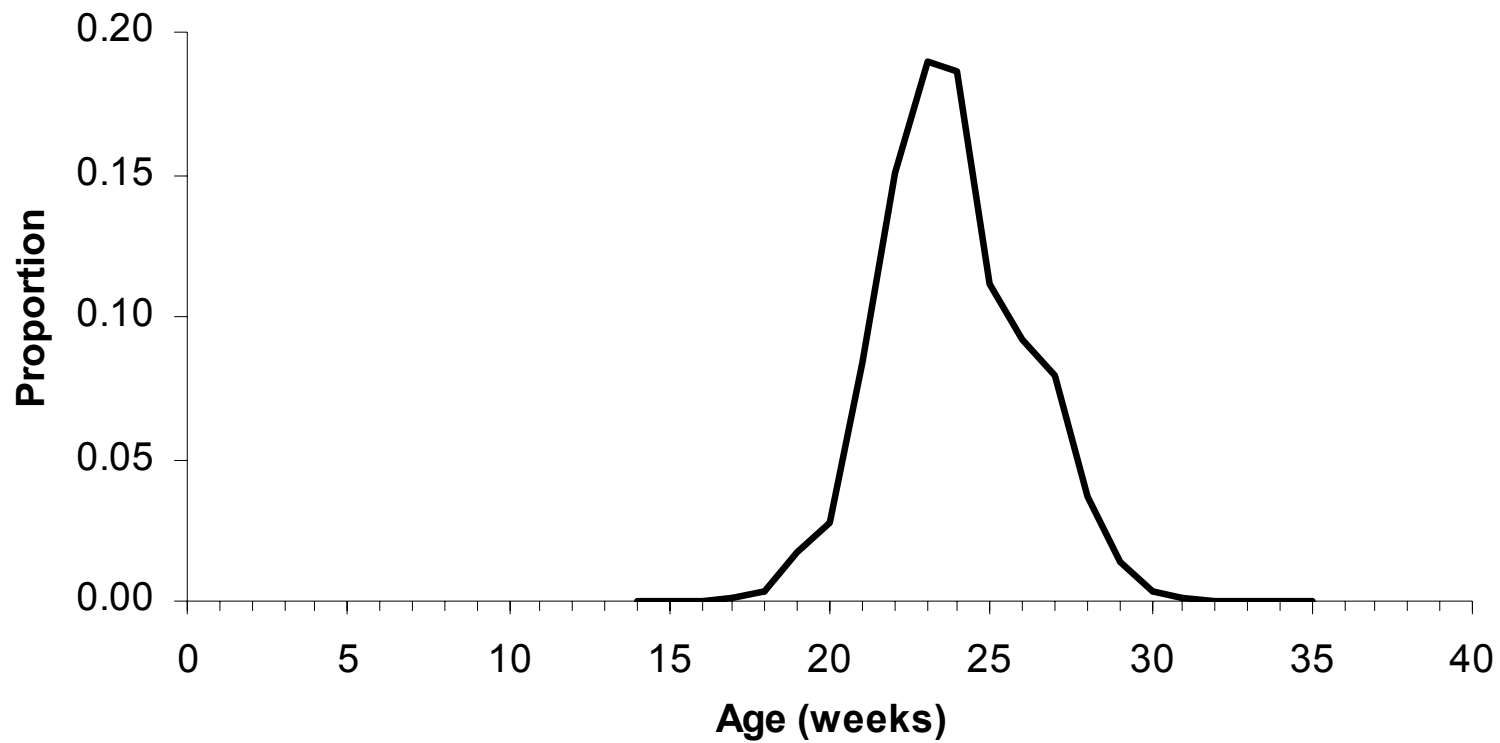


Figure D26. Composite age composition of *Illex illecebrosus* landed in the directed fishery during 1999-2002.

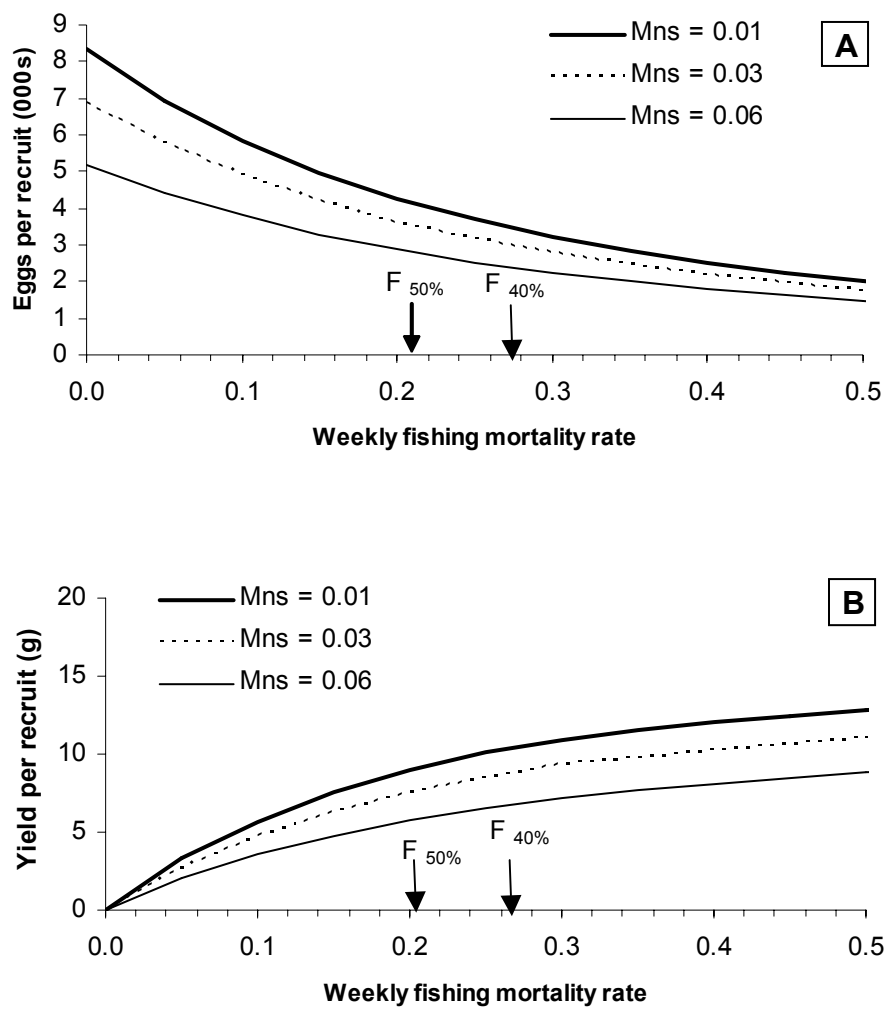


Figure D27. Estimated (A) number of eggs per recruit (000s) and (B) yield per recruit (g) versus fishing mortality rate, for non-spawning mortality rates of 0.01, 0.03 and 0.06, and biological reference point estimates for a non-spawning natural mortality rate of 0.01 and a spawning natural mortality rate of 0.80.

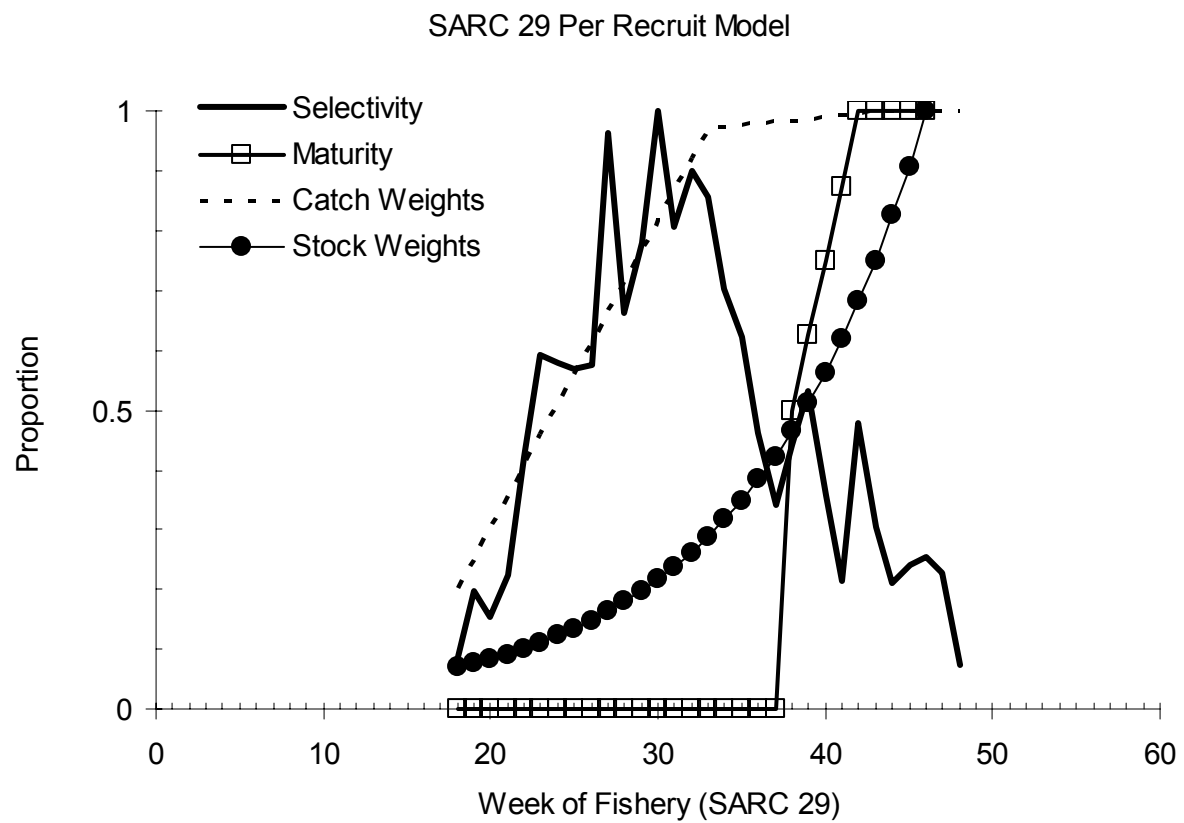
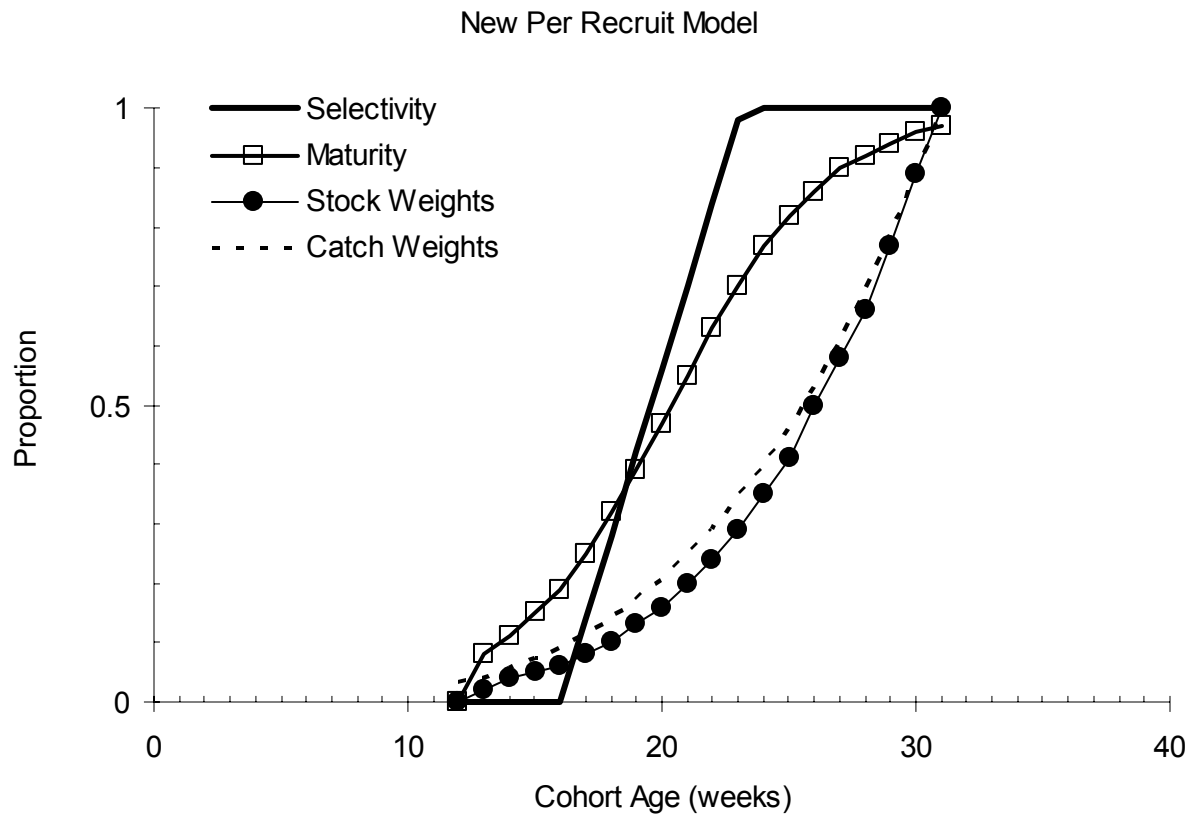


Figure D28. Input data to new *Illex illecebrosus* per-recruit models and the SARC 29 per-recruit model.

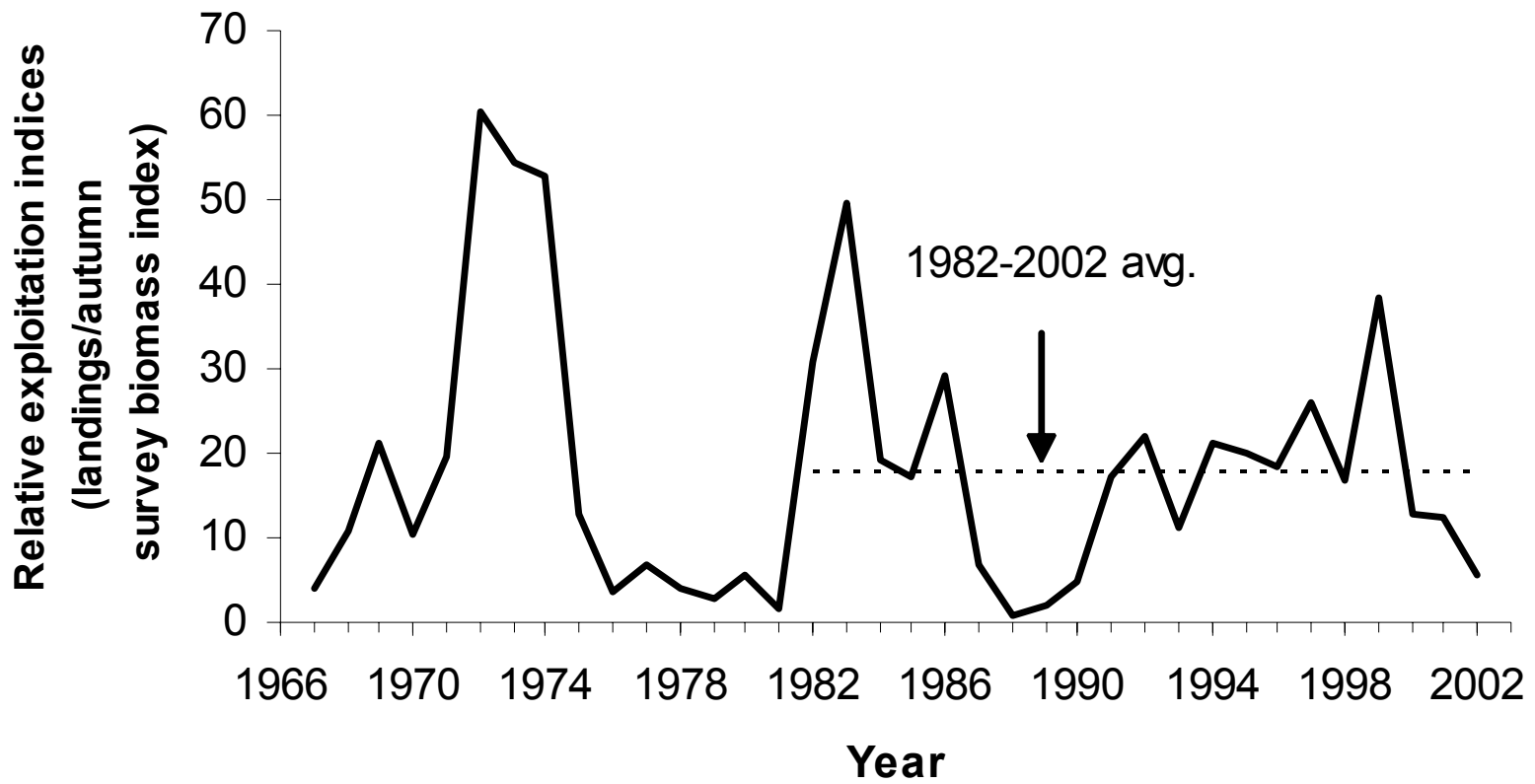


Figure D29. Relative exploitation indices (landings/NEFSC autumn survey biomass index) for the U.S. *Illex illecebrosus* fishery, during 1967-2002, in relation to the 1982-2002 mean.

**Appendix A. A preliminary in-season model for estimating stock size and fishing mortality rates of *Illex illecebrosus* in U.S. waters.**

A new model was designed to estimate stock size and fishing mortality rates of the *Illex* population (in numbers), in U.S. waters, according to the equation:

$$N_{t+1} = N_t \exp(-Z) + R_t \exp(-M_{NS}),$$

where  $N_t$  is the population numbers in week  $t$ ,  $Z$  is total mortality,  $R_t$  is recruitment to the exploitable size classes in week  $t$ , and  $M_{NS}$  is natural mortality due to causes other than spawning (e.g., predation). The predicted catch  $C_t$  (in numbers) in week  $t$  was calculated using the catch equation:

$$C_{t+1} = N_t F_t [1 - \exp(-Z)] / Z$$

The fishing mortality rate,  $F_t$ , was calculated by:

$$F_t = q S_t E_t$$

where  $S_t$  represents the proportion of  $N_t$  that is selected by the fishery,  $E_t$  is the estimated effort in week  $t$ , and  $q$  is a constant. The aggregated length composition of all landed squid was used in the calculations given above, but the individual squid lengths (fishery lengths divided by estimated selectivity, Figure A1) were used for the following purposes:

(a) to calculate the selectivity function  $S_t$  via the equation:

$$S_t = \frac{\sum_L s_L n_{L,t}}{\sum_L n_{L,t}}$$

where  $s_L$  is the estimated selectivity of the length group  $L$ , and  $n_{L,t}$  is the number of squid of length group  $L$  in week  $t$ ;

(b) to estimate recruitment, which was done by utilizing the May 2000 survey growth rate (Hendrickson, *In Review*) to estimate one week of growth for a 13-cm squid (the smallest size retained by the fishery) and assuming that recruits consisted of squid that were of lengths between 13 cm and one week of additional growth during the following week;

(c) and to estimate natural mortality, where the number,  $n_{a,t}$ , at each age group  $a$  and week  $t$  was back calculated from the length composition using the estimated growth curve. Total natural mortality,  $m_a$  (both spawning and non-spawning mortality), for each age group (in weeks) was estimated from the maturation model described previously. Total natural mortality was computed as:

$$M_t = \frac{\sum_a m_a n_{a,t}}{\sum_a n_{a,t}}$$

The Gompertz growth curve that was derived from the May 2000 *Illex* survey (Hendrickson *In Review*) was used in the calculation of equations (b) and (c) above. However, since *Illex* grow larger as the season progresses, the asymptotic size of the May growth curve was exceeded. Nearly all of the squid caught during the last few weeks of the season consisted of lengths that exceeded the estimated maximum length observed in May. In order to address the seasonal growth issue, the maximum (asymptotic) length,  $a$ , from the May growth curve was adjusted upward and estimated as the 95<sup>th</sup> percentile of the length-frequency distribution of the landings.

The model estimates the initial abundance  $N_0$ , and total fishing mortality as:

$$F_{TOT} = \sum_t qE_t$$

The model estimates the values of these two quantities by minimizing a chi-square statistic:

$$\chi^2 = \sum_t (C_t - \hat{C}_t)^2 / C_t$$

subject to the constraint

$$\sum_t \hat{C}_t = \sum_t C_t$$

where  $C_t$  is the observed catch in week  $t$ .

### Results

When both  $N_0$  and  $F_{TOT}$  were allowed to vary in the optimization routine, the best fit was found at  $N_0 = 390$  million squid and  $F_{TOT} = 1.1$ . Predicted landings fit well with the exception of week 28 (Figure A2). Examination of fishing records for that week indicated a spatial shift in effort to the southernmost fishing grounds that resulted in increased landings of larger squid (Figure A3). The spike observed in the predicted landings during week 28 was attributable to an increase in the percentage of squid that were vulnerable to the fishery during that week.

A sensitivity analysis was performed by fixing  $N_0$  at various values and fitting just  $F_{TOT}$  (Table A1). The analysis indicated that a broad range of  $N_0$  and  $F_{TOT}$  values were plausible, because the  $\chi^2$  statistic was relatively flat over large portions of parameter space. Thus, there is considerable model uncertainty regarding the exact values of these parameters.

To assess whether the model could be used to determine whether overfishing was occurring in 1999, total fishing mortality was fixed at the most stringent overfishing threshold,  $F_{50\%} = 0.21$  per week, and an  $M_{NS}$  value of 0.01 was assumed. During 1999, the duration of the fishing season was 18 weeks. Therefore, in order for overfishing to have occurred,  $F_{TOT}$  would have to have exceeded 3.8 ( $F_{50\%} = 0.21 * 18$ ). When  $F_{TOT}$  was fixed at 3.8, model fit was poor and the  $\chi^2$  statistic was more than 50% above its overall minimal value (Figure A2B, Table A1). If the criterion for overfishing is taken on an annual basis, so that the reference point is  $F_{50\%} = 0.21 * 52 = 10.9$ , then the  $\chi^2$  statistic at  $F = 10.9$  is several times its overall minimum. Thus, overfishing

was not likely to have occurred in 1999, because the model fit for the run that assumed a fishing mortality rate equal to the overfishing threshold was implausible.

#### Model Uncertainties

The model results should be examined with caution because rigorous testing of the model, with multiple years of data and under varying model assumptions, has not been conducted. A sensitivity analysis for various values of initial stock size indicated that a broad range of  $N_0$  and  $F_{TOT}$  values were plausible. A major model uncertainty is the use of a May growth curve that underestimates growth later in the fishing season. Despite scaling up the asymptotic length by using a percentile of the observed length from the fishery, empirical length-at-age data must be collected and analyzed to determine seasonal changes in growth rate. As a result of the uncertainties previously described, the Subcommittee recommended that the model results should only be considered to determine whether overfishing was occurring during 1999.

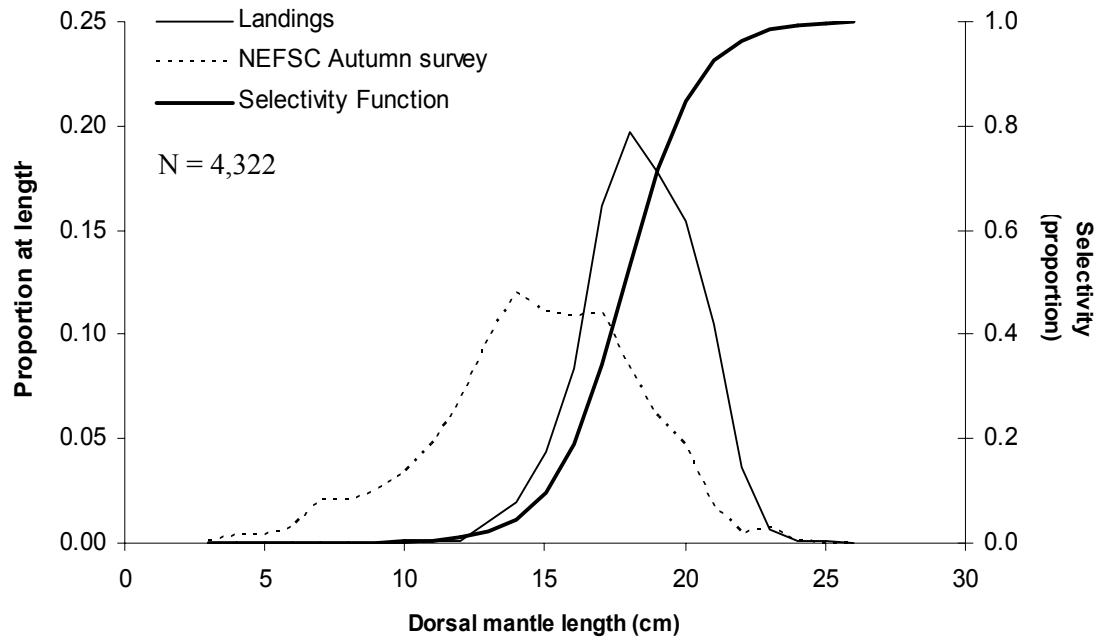


Figure A1. Composite length compositions, for 1999-2002, of *Illex* catches from the NEFSC autumn bottom trawl surveys and *Illex* landings from the directed fishery, during the same range of weeks, and the predicted selectivity curve.



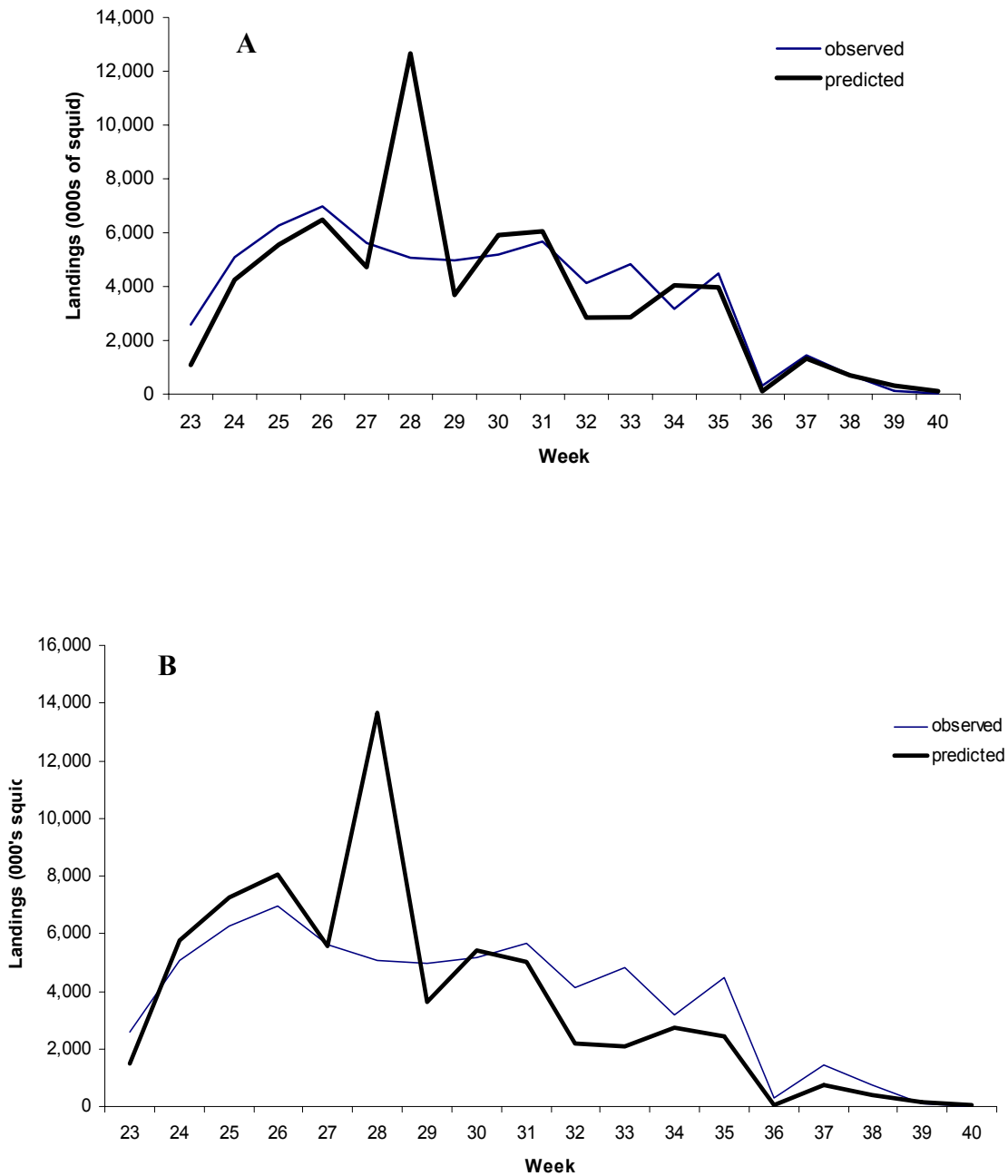


Figure A2 . Observed and predicted weekly landings of *Illex illecebrosus* (000s of squid) during 1999, based on a preliminary stock size estimation model, for (A) the best model fit and (B) and assuming a total fishing mortality rate of 3.8 (=  $F_{50\%}$ ) for an 18-week fishery.

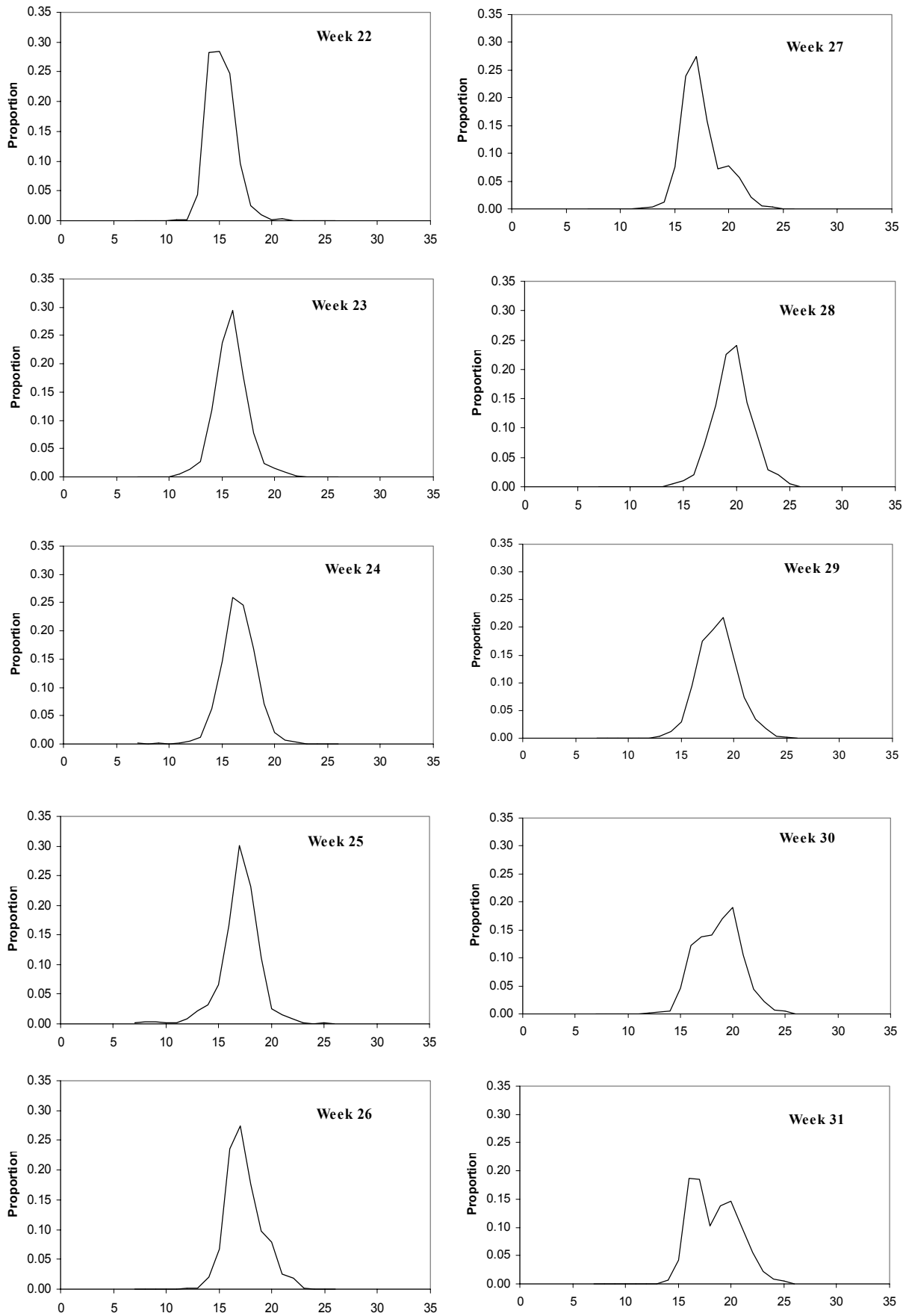


Figure A3. Length composition of *Illex illecebrosus* landings during weeks 22 through 31 of the 1999 fishing season.

## **Appendix B. Technical comments regarding the *Illex illecebrosus* stock assessment, from an external reviewer (Mike Bell from CEFAS in Lowestoft, England).**

### *Scope of the meeting*

The purpose of the meeting was to review the information and methods available for the SARC 37 short-finned squid stock assessment. The stock was last assessed in 1999 (SARC 29), using weekly landings and effort data from the Vessel Trip Records (VTR) database in the Rago Assessment Model. The main advance since 1999 has been the collection of survey data in May 2002 that has generated new information on age and size distributions in the southern part of the stock area prior to the start of the fishery. New observations on fully mature females have been particularly important in moving forward the state of understanding – 84 mature females were recorded in the survey catches, whereas only a handful have previously been observed by biologists.

This document describes my views, as an outside observer, of the effectiveness of the stock assessment process, in terms of both procedure (representation, meeting process) and scientific quality (biological and fisheries data, analytical approach).

### *Procedural aspects*

The meeting focused on three aspects of the assessments – the biological and environmental context, data on quantities and composition of fishery removals, and analytical approaches used to synthesise the available data and understanding into the best scientific appreciation of current stock status with respect to overfishing thresholds. A clear agenda covering these topics had been drawn up before the meeting, together with comprehensive supporting notes. Each topic was dealt with thoroughly, and effective chairmanship ensured that the discussions remained ‘on track’ and moved efficiently through the agenda. Those present at the meeting included the scientists responsible for each aspect of the assessment, together with a squid fishing industry representative also involved in management. Where appropriate, additional scientists were drawn in to comment on specific aspects of the assessment.

My view of the meeting process is entirely positive. The discussions were held in an atmosphere of constructive, open debate, and, as an outsider with no previous knowledge of this particular stock or species, I was very effectively made aware of the biological, fisheries and management issues relating to this assessment. The meeting would have been further enhanced by participation of more squid industry representatives, but it could not be said that the outcome of this meeting has thereby suffered. The next stage of the subcommittee process is to finalise the assessment and presentation of information. This first meeting has effectively prepared for this, and it is to be anticipated that the final outcome will represent the best scientific understanding of the current status of the *Illex* squid stock that is possible given the current state of knowledge.

### *Scientific quality – data and biological information*

Considerable uncertainty exists about the relationship of the fished portion of the *Illex* stock with the stock as a whole. The assessed part of the stock covers part of the shelf edge, onto which the squid migrate from deeper waters offshore. The assessment results are taken to apply to the whole of the shelf edge area, thus representing a ‘worst case’ scenario – an upper limit for F. In this sense the assessment is quite rightly precautionary in its approach, but it will be important in

future to determine the connectivity within the stock as a whole – both between different parts of the shelf edge and, most importantly between the shelf edge and offshore components of the stock. Critically, it will be important to determine the relationship between spawning activity and onshore migration. The assessment is, again, a worst case scenario in that it assumes that all spawning takes place on the shelf edge – i.e. the fished stock is the spawning stock, thus SSB and egg per recruit considerations are paramount in determining overfishing thresholds. Temperature has been identified as an important factor in determining the strength of the onshore migration. According to the precautionary hypothesis implicitly assumed by the assessment, this represents a control on the size of the spawning (i.e. exploited) stock by defining the extent of spawning habitat in a given year. An alternative hypothesis would be that temperature simply determines how large a fraction of the total stock becomes available to the fishery on the shelf edge. There is at least anecdotal evidence that large (i.e. reproductively mature) squid exist within the offshore component. The two hypotheses differ strongly in their implications for the vulnerability of the stock to overfishing.

These and other biological issues were very clearly highlighted during the meeting, and underline the need for further biological studies. Large strides have already been made since the previous assessment in 1999, stemming particularly from observations made from the results of the May 2002 survey. Maximal use was made of the available material from survey catches – inferences about age, growth and, most significantly, maturity – mature females had previously only been observed in small numbers, so researchers took full advantage of the opportunity to study the sample of 84 that was taken during this survey. Aside from the obvious need to study stock connectivity, biological studies should concentrate on extending observations of age, growth and maturity to other times of the year, particularly the autumn. Further studies on uncertainties in age determination are also desirable, principally so that this source of uncertainty can be accounted for in the analytical assessments.

Biological understanding of this *Illex* stock is the principal limitation for assessment, since the fishery data appear to be very good. In particular, it was notable that there is good agreement between VTR records and other sources of information on landings. More detailed analysis of CPUE records is planned in the near future, accounting for spatial and gear-specific influences in a generalised linear modelling approach.

#### *Scientific quality – analytical approach*

Excellent use is being made of the available information on the responses of *Illex* to exploitation. In particular, recent survey data are being used to generate parameters for biologically realistic ‘per recruit’ models from which biological reference points can be derived. Whilst it is true that such modelling would benefit from more species-specific information on biological parameters such as natural mortality and fecundity, and more data on changes in growth and maturity through the fishing season, these per recruit models and supporting analyses are of the highest scientific quality and represent the ‘state of the art’ for *Illex* assessment at the present time.

Likewise, the assessment approaches developed for *Illex* are of very high scientific quality – both the new and the old versions of the Rago assessment model are innovative and designed to make best use of the available observations. The science that has been applied to *Illex* assessment has clearly progressed over the years, yet the assessment scientists have not lost sight of the importance of continuity between years – the outcomes of new assessment approaches are

compared with those of previously used approaches, the outcomes of the new per recruit models are compared with those from traditional per recruit models.

### *Summary*

In summary, considered in the context of uncertainties about the relationship of the exploited to the total stock, the scientific quality of the *Illex* assessment is very high in terms of both the analytical approaches and the data (however limited) to which they are applied. A very effective synthesis is made of all available observations in drawing together an overall appreciation of stock status within a framework which is rightly precautionary in nature. Full consideration of statistical and other uncertainties is made within the quantitative analyses, and the sensitivity of assessment outcomes to feasible ranges of values of uncertain biological parameters is investigated. The final assessments presented at the SARC are thus expected to be both rigorous and defensible.

## E. ATLANTIC HAGFISH

### 1.0 EXECUTIVE SUMMARY

In New England, a growing fishery for Atlantic hagfish (*Myxine glutinosa*) has initiated science and policy discussions about the development of the fishery, its potential for future expansion, and its effect on the resource. The hagfish fishery in New England was developed in the early 1990s, with the first reported landings of around 1 million pounds in 1993. Korean buyers quickly recognized that a fishery in the New England area could provide the high quality hagfish skins used in making leather as well as hagfish meat for human consumption.

Reported hagfish landings in New England quadrupled during the first four years of the fishery (1993-1996), exceeding the highest reported landings in other North American hagfish fisheries (including British Columbia, Oregon, Washington, California and Nova Scotia) by 1994. Landings increased six-fold from 1993 to 2000, with a reported 6.8 million pounds of hagfish landed in 2000 yielding over 1.8 million dollars in revenues. Landings in 2001 and 2002 are estimated to be 3-6 million pounds in each year. There is no management program for this fishery, and consequently no permitting or reporting requirements. Thus, there is considerable uncertainty regarding the actual level of hagfish landings, as the data provided by fishers and processors may be incomplete. Moreover, the level of discards and discard mortality of hagfish culled at sea or rejected by the dealer in port is unknown. Landings are highest during the summer and fall months.

The number of active vessels in the fishery has fluctuated between 1993 and the present, ranging from 5 to more than 30 vessels reporting landings per year. These vessels use specialized hagfish traps and land their catch primarily in Gloucester, Massachusetts. Hagfish are no longer landed in Maine. The average size of active vessels in the fishery has increased since 1993, with new entrants as large as 165 feet. The fishing capabilities and efficiency of these larger vessels has increased even over the past year, as fishermen have developed more effective means of sorting and storage of hagfish at sea, an enhanced awareness of localized aggregations of hagfish, and improved product quality control.

The fishery is prosecuted throughout the Gulf of Maine, from Nantucket to Downeast Maine and east to the Hague line, with the majority of landings from trips in the inshore Gulf of Maine between Gloucester and Portland. The vast majority of hagfish trips occur in the deeper waters (greater than 40 fathoms) of the Gulf of Maine, within a 60 nautical mile range of Gloucester, MA. The geographic range of the fishery and spatial distribution of hagfish trips have expanded since 1994, with vessels moving further offshore and trips more broadly distributed across the range of the fishery. Average trip duration, as reported via vessel trip reports, has generally increased since 1994. Nominal and standardized estimates of landings per unit of effort (LPUE) fluctuated from 1994 to 2002, with distinctions among LPUE trends for different seasons and statistical areas across the time period.

Hagfish have been captured in low numbers in the Northeast Fisheries Science Center groundfish bottom trawl surveys since 1963 from the Gulf of Maine to Cape Hatteras. Based on these trawl survey data and Gulf of Maine shrimp survey data, it appears that hagfish abundance in the Gulf of Maine decreased from the mid-1970s through the mid-1980s and remained at a fairly consistent low level until the early to mid-1990s, with an increase during the late 1990s. The factors which contributed to the apparent decline in the 1970s are unknown. Hagfish captured in the Gulf of Maine groundfish trawl survey are generally larger than those captured in the deeper offshore survey strata south of Cape Cod. Mean lengths of hagfish from the spring and fall groundfish surveys were 40.5 cm and 42.6 cm, respectively. In the offshore survey area, hagfish averaged 34.7 cm in the spring and 34.6 cm in the fall. Hagfish are most commonly captured in the survey at depths of 150-250 meters and at temperatures of 5-10°C, but are found across a broader range of depths and temperatures.

Little is known about the life history of hagfish. The age at maturity and lifespan of *Myxine* (in the Gulf of Maine and elsewhere), as well as timing, conditions and location of reproduction are not known. Hagfish have a limited reproductive potential, as evidenced by the small number of large, yolky eggs carried by the females. Hagfish serve an important ecological role, contributing to nutrient cycling, substratum turnover and removal of dead or dying organisms on the sea floor.

Developing a comprehensive understanding of the hagfish fishery and resource will require new scientific and fishery-dependent research and data collection efforts. A one-day working group that met to discuss hagfish science and management identified important information gaps and discussed a number of potential approaches to acquiring the data and information needed to fill them. Among these are the initiation of an at-sea observer program and port sampling for estimating discard levels and collecting length/weight data, tagging studies to estimate growth rates and examine movement of localized populations of hagfish, age and growth studies conducted in the laboratory, specialized broad-scale surveys of hagfish, investigation of spatial movement of the fishery through interviews with fishermen. Several potential approaches for stock assessment modeling were also described. However, it is unlikely that conventional stock assessment approaches will provide significant information in the near future due to lack of data. There are many opportunities for development of industry-based research projects and further collaborative efforts among scientists, fishermen, administrators and policy analysts. Implementation of some of these recommendations may require adoption of a formal fishery management plan.

## **2.0 INTRODUCTION**

### **2.1 Background**

On March 28, 2003, a working group of scientists, fishery analysts, fishermen and administrators met at the New England Fishery Management Council office to review biological and fishery information for Atlantic hagfish. This report is a result of the group's efforts to address informational needs of the Stock Assessment Review Committee (SARC) in its peer review meeting in June, 2003, and represents the best available fishery and stock information on the Atlantic hagfish.

#### **Participants**

The following individuals participated in the working group meeting and the production of this report.

Anne Beaudreau – New England Fishery Management Council  
Mark Boulay – F/V Camano  
Andrew Cooper – University of New Hampshire  
Chad Demarest – New England Fishery Management Council  
Larry Jacobson – Northeast Fisheries Science Center  
Chad Keith – Northeast Fisheries Science Center  
Christopher Kellogg – New England Fishery Management Council  
Frederic Martini – University of Hawaii  
Steve Nippert – F/V Kristin & Michael  
Mickie Powell – Birmingham-Southern College  
Terry Smith – Northeast Fisheries Science Center

## 2.2 Working Group Objectives (Terms of Reference)

1. Characterize and describe the Atlantic hagfish fishery currently and historically, including fleet characteristics (number and size of harvesting vessels), harvesting techniques and gear, major ports of landing, landings and revenue trends, changes in landings per unit of effort (LPUE), and distribution of fishing effort.
2. Describe discarding in the hagfish fishery and identify other sources of uncertainty in fishery-dependent data. Discarding includes discarding at sea (culling), and discarding at the processing plant due to quality concerns.
3. Provide a description of what is known about hagfish life history. Include current information pertaining to growth rates, size at age, fecundity and reproduction.
4. Discuss strategies for determining stock abundance and trends in abundance using survey data available from the Northeast Fisheries Science Center (NEFSC) trawl surveys, and other fishery-independent measures of abundance and density.
5. Determine the utility of existing biological and fishery data for assessing the Atlantic hagfish stock and discuss general strategies for assessing hagfish.
6. Identify high priority data needs for hagfish assessment and management and discuss methods for collecting essential data about the stock and fishery.

## 3.0 HAGFISH LIFE HISTORY AND ECOLOGY

### 3.1 Morphological/Physiological Characteristics and Taxonomy

Hagfishes are recognized as the most primitive extant craniates and have been studied primarily in the context of vertebrate evolutionary history. Hagfish possess an entirely cartilaginous skeleton and are eel-like in form. While their olfactory capabilities are quite keen, they have limited sensitivity to light and possess reduced or degenerative eyes. Unlike most bony fish, hagfish lack scales. The pink-gray skin of the Atlantic hagfish is smooth and lined with slime glands along the ventral midline. Known commonly as the slime eel, the hagfish is capable of producing massive quantities of mucous when provoked or threatened. The slime likely protects hagfish from attacks by suffocating, trapping or diverting predators. A hagfish will avoid suffocation in its own slime by forming its body into a knot and through muscular contraction, passing this knot down the length of its body to draw off excess mucous. Knotting may also aid hagfish in predator evasion and provide leverage for the animals while feeding on carcasses of larger fish or marine mammals.

Hagfish are jawless, possessing an evertible toothplate lined with tiny denticles which allows them to attach to other fish and bore into body cavities, eating the flesh and viscera and leaving behind the tougher skin and bony structures. Hagfish are an irritant to hook and gillnet fisheries which target species such as haddock, hake, and cod, because of their proclivity for feeding on hooked or gilled fish. Though considered scavengers of dead or dying organisms, hagfish feed primarily on invertebrates. (For more information on their feeding habits, see Section 3.4.) Hagfishes are ubiquitous, with about 60 species of hagfish in two subfamilies found across the world's oceans. The Atlantic hagfish is a member of the family *Myxiniidae*, which is characterized by one pair of gill openings. The second family, *Eptatretinae*, is identified by multiple pairs of gill openings. *Myxine glutinosa* is the only hagfish species in the



Atlantic Ocean. Wisner and McMillan (1995) suggested that two species of hagfish may exist, differing in size at maturity and color of preserved specimens – *Myxine glutinosa* in the western Atlantic and *Myxine limosa* in the eastern Atlantic. However, in the absence of substantial supporting morphological data, this idea was dismissed and *M. limosa* has not been classified as a distinct species (Martini et al. 1998).

*Reference:* Martini & Flescher in Collette & Klein-MacPhee 2002

### **3.2 Geographic Range and Habitat**

*M. glutinosa* are very common in the Gulf of Maine and occur as far south as Cape Fear, North Carolina. Up until the early 1990s, they were reported in large numbers in deeper parts of Massachusetts Bay and in the waters surrounding the Isles of Shoals and Jeffreys Ledge in the Gulf of Maine (Martini & Flescher in Collette & Klein-MacPhee 2002). It is suggested that the stock has substantially diminished in these inshore areas since the early 1990s (Boulay, Hill, Nippert, Palumbo, pers. comm. 2003). Habitat suitable for hagfish covers 60-70% of the bottom in the Gulf of Maine, but in several density studies which used trap survey data collected over a five year period in a part of the Gulf of Maine, hagfish were found in only 5% of the suitable habitat area in densities of 1:16.75 m<sup>2</sup> to 1:2 m<sup>2</sup> (based on the biomass estimate of 8119 kg/km<sup>2</sup> derived from the survey) (Martini et al. 1997b).

A bottom-dwelling species, the Atlantic hagfish spends most of its time embedded in soft clay or mud substrates with the tip of the snout protruding. The burrows of Atlantic hagfish are transient, collapsing as the animal moves through the flocculant substrate (Martini & Flescher in Collette & Klein-MacPhee 2002). Hagfish have been reported on almost all substrate types from muddy bottoms to sand, gravel and rock. Although they can swim in rapid bursts while feeding, hagfish generally remain very sedentary in their natural environment. Swimming speeds have been estimated to be under 2 knots over short distances (Martini & Flescher in Collette & Klein-MacPhee 2002). Migratory behavior has only been observed in one species of hagfish, the Japanese hagfish *Eptatretus burgeri* (Fernholm 1974, cited in Martini et al. 1998).

### **3.3 Preferred Depth, Temperature, and Salinity**

Hagfish distribution is determined by three factors, listed in order of importance: salinity, temperature and substrate type (Martini & Flescher in Collette & Klein-MacPhee 2002). Hagfish have been found at depths of 15 to 524 fathoms (27.4 to 958.3 m) in the Gulf of Maine (Bigelow & Schroeder 1953). They prefer low temperatures probably cooler than 50°F, confining them to depths of at least 15-20 fathoms (27.4-36.6 m) or greater in the Gulf of Maine during the summer (Bigelow & Schroeder 1953). Hagfish are exclusively marine organisms, requiring full salinity sea water to function (33-35 ppt). Sudden changes in temperature and salinity will render the animals moribund (Martini & Flescher in Collette & Klein-MacPhee 2002). Because of their extreme sensitivity to shifts in temperature and salinity, it is suggested that mortality of hagfish culled at sea may be high (Martini et al. 1997a).

### **3.4 Feeding, Adaptability and Ecological Role**

In hagfish, cutaneous respiration and a large blood volume, at 18% of its body weight, have allowed these organisms to adapt to hypoxic benthic environments. Other characteristics, such as a low energetic requirement and opportunistic feeding habits, allow hagfishes to thrive across a wide range of habitat (Lesser et al. 1996). The bulk of their diet is made up of invertebrates such as shrimp and polychaetes and supplemented with dead or dying organisms, including discarded bycatch, hooked or gilled groundfish, and dead marine mammals. It is suggested that hagfish may have a particular predatory influence on northern (Pandalid) shrimp in the Gulf of Maine. They contribute to the diet of marine mammals and many species of fish (Martini, Lesser et al. 1997). Hagfish play a significant ecological

role in their natural environment, contributing to nutrient cycling, substratum turnover and removal of bycatch (Martini et al. 1997b).

### 3.5 Reproduction and Development

Little is known about the life history of hagfish. The age at maturity and lifespan of *Myxine* (in the Gulf of Maine or elsewhere) are not known. The timing, conditions and location of reproduction and egg deposition are not known (Martini et al. 1997a). However, it is evident that the reproductive potential of hagfish is extremely limited. The potentially small spawning stock increases the susceptibility of hagfish to overfishing.

Female hagfish produce small clutches of relatively large, yolky eggs encased in a leathery shell. Research on Pacific hagfish has shown that, on average, only 23.4 fully developed or developing eggs are found in the body of an adult female hagfish at any given time (Nakamura 1991, cited in Hultin et al. 1996). The average number of mature eggs typically found inside the female Atlantic hagfish is between 20-30 eggs, each about 22-28 mm in length and 10 mm in diameter (Martini et al. 1997a, Sower & Powell pers. comm. 2002). While the timing and location of fertilization and egg deposition is unknown, eggs have been trawled at depths of 50 to 150 fathoms (91.4 to 274.3 m) on mud, clay and sand bottoms (Martini & Flescher in Collette & Klein-MacPhee 2002). The time required to produce a crop of eggs has not been determined but is thought to be 1-2 years. Circumstantial evidence suggests that the eggs are deposited within burrows, and that breeding animals do not feed (Martini & Flescher in Collette & Klein-MacPhee 2002). The development time is not known, but the volume of yolk present suggests a period of several months. Hagfish do not have a larval stage (Worthington 1905). Only 4 embryos of *M. glutinosa* have been collected, none within the last 60 years, and only one of these was from the western North Atlantic (Dean 1899, Holmgren 1946, Fernholm 1969, Martini et al. 1997a); all were collected by trawling and were damaged as a result. At hatching, individuals are reported to be approximately 65 mm in length. Trapping surveys and trawls on both sides of the Atlantic have failed to collect animals below 150 mm in length, and there is no information available regarding the habitat and ecology of juvenile hagfish in the 65-150 mm size range (Martini et al. 1997a). Hagfish are up to 1.5-2 feet long at maturity (Martini & Flescher in Collette & Klein-MacPhee). For more information on size distribution in the Gulf of Maine, see Section 4.2.

There are no external characteristics that can be used to distinguish males and females. Varying stages of oocytes and developing eggs have been found in males, and rudimentary testicular tissue is commonly found in animals with large developing eggs. Whether eggs found in males develop into mature eggs is unknown. Although stages of maturing eggs and the occurrence of spermatogenesis have been found simultaneously in a single hagfish (Walvig 1963, Patzner 1982, Sower & Powell pers. comm. 2002), there is no definitive evidence of functional hermaphroditism in hagfish (Martini & Flescher in Collette & Klein-MacPhee 2002). Mature eggs and mature sperm have not been found in the same individual. The female gonad will contain eggs in all stages of development, from primary oocytes to very mature eggs. However, at any one time only 20-30 eggs will reach maturity while the remaining eggs appear to be “arrested” in their development during this time (as in frogs, the eggs mature in clutches) (Sower & Powell pers. comm. 2002). The number of eggs produced has no relationship to the size of the female.

There is preliminary evidence of seasonal cycles of reproductive hormone production in Atlantic hagfish (Schutzinger et al. 1987, Powell & Sower unpub.), but no evidence of a synchronous breeding cycle in this species. Attempts to induce egg maturation and spawning through hormonal manipulation of captive hagfish have been unsuccessful (Tsuneki 1976). Inside the Gulf of Maine, gonadal development appears to begin when animals reach 400-450 mm in length. The sex ratio is strongly biased in favor of females; depending on the study and the collection site, the female:male ratio ranges from 5:1 to 10:1. The total lifespan has not been determined, nor has the duration of reproductive function, but large males and females (over 700 mm in length) contain functional gonads (Martini et al. 1997a). Surveys conducted on

both sides of the Atlantic report that 15-25% of adult hagfish lack any macroscopically identifiable gonadal tissue (Martini et al. 1997a). The high proportion of non-reproductive adults further reduces the reproductive potential of the population.

#### **4.0 FISHERY-INDEPENDENT INFORMATION**

##### **4.1 Hagfish Abundance**

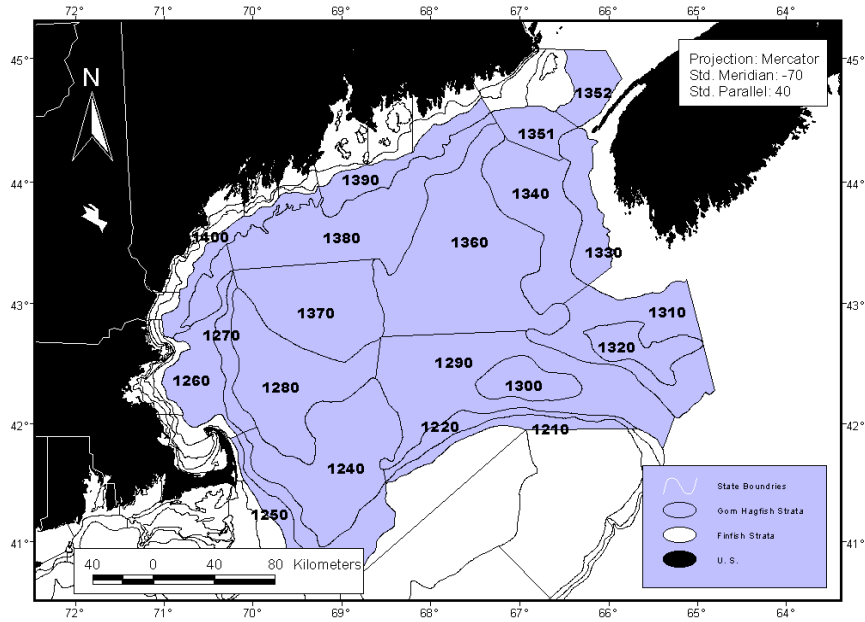
###### **4.1.1 Data Sources and Caveats**

Atlantic hagfish have been collected in limited numbers throughout the 40 years of the NOAA Fisheries Northeast Fisheries Science Center (NEFSC) groundfish trawl survey. In general, hagfish are poorly represented in trawl surveys and trawl-based estimates of hagfish population density and abundance are likely to be substantially underestimated (Wakefield 1990, cited in Martini et al. 1998). However, trends in the population over an extended time period may be evident from these trawl survey data, and the NEFSC time series is a valuable indicator of presence and absence of hagfish in specific areas of the survey from the Gulf of Maine to Cape Hatteras over the past several decades.

Survey data in this report are presented for three areas in which the NEFSC groundfish and shrimp surveys are conducted:

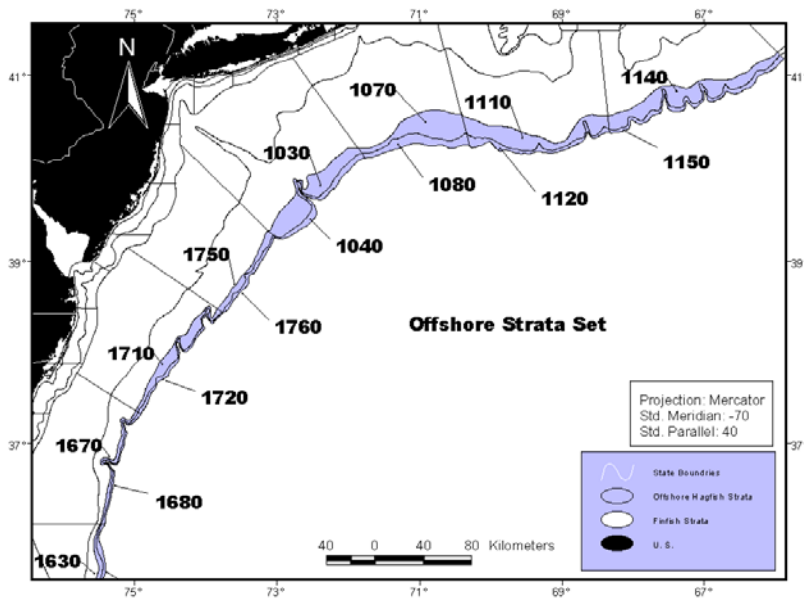
- Two primary areas of the NEFSC groundfish trawl survey –
  - (1) Gulf of Maine (Figure E1)
  - (2) Offshore Area – deep water offshore area between Georges Bank and Cape Hatteras (Figure E2)
- One area of the NEFSC shrimp survey – Gulf of Maine (Figure E3)

Abundance data for hagfish in these analyses were from NEFSC spring (1968-2002) and fall (1963-2002) bottom trawl surveys for groundfish, and from NEFSC summer shrimp surveys from 1982 to 2002. Groundfish surveys covered the area between Cape Hatteras and the northern edge of Georges Bank (Offshore survey area) at depths of 110-183+ m and in the Gulf of Maine (GOM) at depths of 55-183+ m. The shrimp survey used shrimp bottom trawl gear in the GOM at depths of 55-100+ m. These NEFSC surveys provide the best available stock abundance information but none of the surveys covers the entire range of hagfish habitat, which extends over depths of 25-1000+ m. This report presents the first analysis of hagfish taken in the NEFSC shrimp survey. Relative abundance data for hagfish were either mean numbers per tow or the proportion positive tows (i.e. the proportion of tows with at least one hagfish).



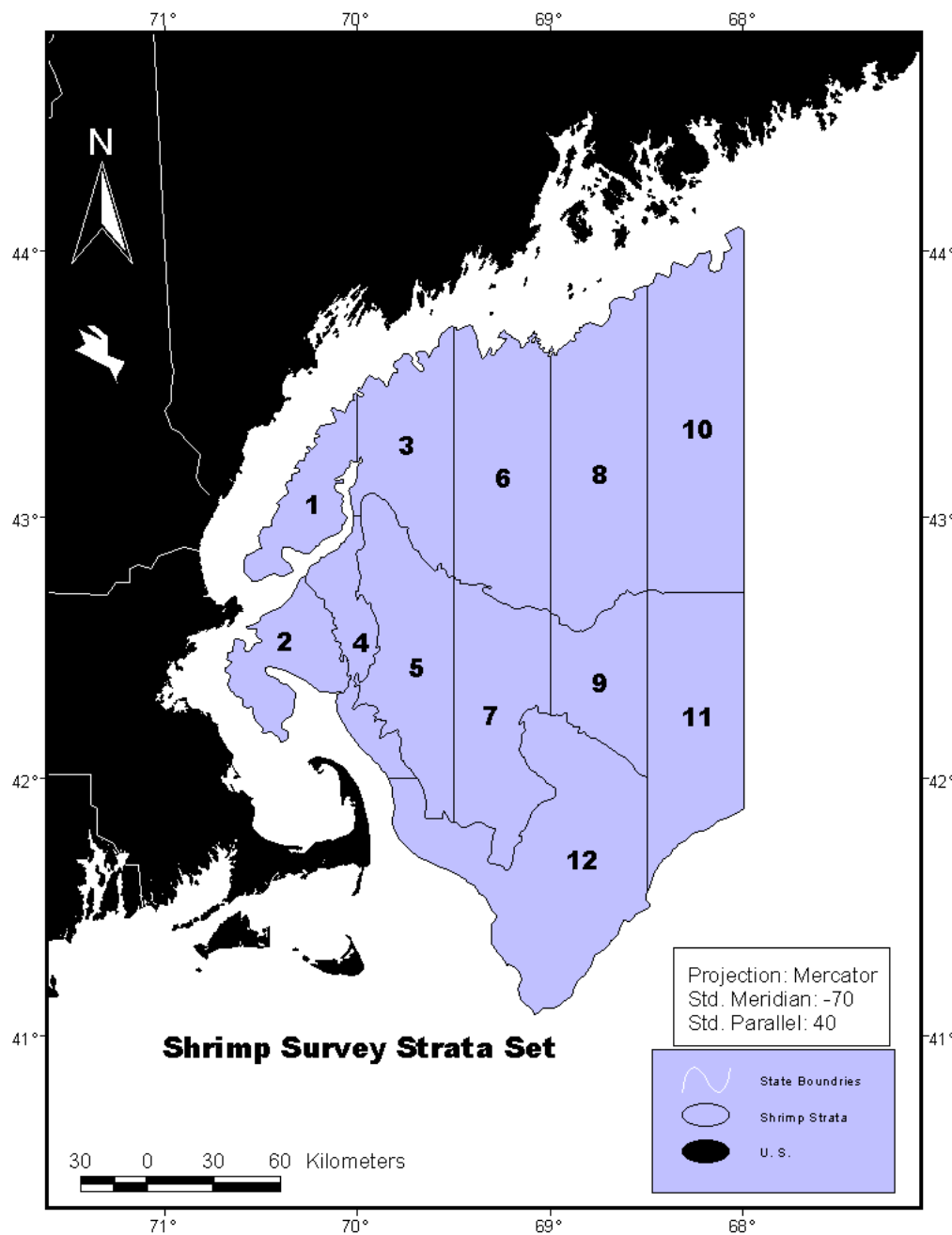
**Figure E1 - Gulf of Maine (GOM, NEFSC finfish survey strata 21-40)**

*Source: Northeast Fisheries Science Center*



**Figure E2 - Offshore Southern New England (OFF, NEFSC finfish survey strata 3-4, 7-8, 11-12, 14-15, 63-64, 67-68, 71-72, and 75-76)**

*Source: Northeast Fisheries Science Center*



**Figure E3 - Gulf of Maine Shrimp (NEFSC shrimp strata 1-12)**

*Source: Northeast Fisheries Science Center*

#### **4.1.2 Groundfish bottom trawl survey**

Hagfish are captured in the fall and spring groundfish bottom trawl surveys and rarely taken during the winter survey. (Table E1 and Table E2) They are captured most frequently in the deeper strata of the Gulf of Maine survey area and along the shelf break of the Offshore survey area. Hagfish are rarely found on Georges Bank. Figure E4, Figure E5, Figure E6, and Figure E7 visually represent the number of hagfish captured in the fall survey from 1963-2002 and in the spring survey from 1968-2002. More hagfish were captured in fall surveys in both the Gulf of Maine and Offshore area than in spring surveys. Because so few individuals were captured in the bottom trawl surveys, these data were examined in terms of (a) the mean number of hagfish per tow, and (b) the proportion of total tows in which at least one hagfish was captured (proportion of positive tows). The latter method is useful for examining survey data in which a low number of individuals was captured and tows which capture no individuals (zero tows) occur relatively often. Mangel and Smith (1990) described the use of presence-absence sampling of eggs and larvae as a means of estimating adult biomass for pelagic species, focusing on the California sardine as a case study. While this sampling methodology is not directly applicable to hagfish, this study suggests that presence-absence data may be used to supplement other survey methods for species that are rare or difficult to sample. The percentage of tows in which at least one hagfish was captured was 11% for the Gulf of Maine fall survey. The proportion of positive tows was lowest for the Offshore fall survey, with only 5% of all tows capturing hagfish.

Year	Gulf of Maine area					Offshore area					Combined Areas				
	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows
1968	0.199	46	7	95	0.07	0.038	100	1	50	0.02	0.179	45	8	145	0.06
1969	0.114	32	10	95	0.11	0.118	66	3	41	0.07	0.115	29	13	136	0.10
1970	0.123	38	9	106	0.08	0.220	36	8	49	0.16	0.135	31	17	155	0.11
1971	0.296	26	17	123	0.14	0.185	48	3	40	0.08	0.284	25	20	163	0.12
1972	0.280	32	9	106	0.08	0.064	55	4	47	0.09	0.256	31	13	153	0.08
1973	0.072	32	7	96	0.07	0.088	54	4	43	0.09	0.074	29	11	139	0.08
1974	0.672	32	18	91	0.20	0.794	26	11	36	0.31	0.687	28	29	127	0.23
1975	0.563	32	18	93	0.19	0.394	32	8	36	0.22	0.541	29	26	129	0.20
1976	1.017	24	18	109	0.17	0.754	41	11	41	0.27	0.985	22	29	150	0.19
1977	0.028	62	11	117	0.09	0.000	0	7	40	0.18	0.025	62	18	157	0.11
1978	0.203	33	12	125	0.10	0.272	57	6	40	0.15	0.211	30	18	165	0.11
1979	0.097	48	8	142	0.06	0.000	0	0	39	0.00	0.086	48	8	181	0.04
1980	0.103	36	8	95	0.08	0.374	76	4	39	0.10	0.137	35	12	134	0.09
1981	0.140	36	11	93	0.12	0.214	19	7	36	0.19	0.149	30	18	129	0.14
1982	0.007	100	1	99	0.01	0.026	77	2	41	0.05	0.009	70	3	140	0.02
1983	0.051	51	4	97	0.04	0.213	83	2	40	0.05	0.071	44	6	137	0.04
1984	0.019	100	1	93	0.01	0.057	100	1	40	0.03	0.023	76	2	133	0.02
1985	0.000	0	0	87	0.00	0.026	100	1	39	0.03	0.003	100	1	126	0.01
1986	0.000	0	0	96	0.00	0.015	100	1	40	0.03	0.002	100	1	136	0.01
1987	0.012	100	1	90	0.01	0.007	100	1	40	0.03	0.011	92	2	130	0.02
1988	0.182	57	7	85	0.08	0.220	0	3	25	0.12	0.187	48	10	110	0.09
1989	0.017	100	1	77	0.01	0.026	0	1	25	0.04	0.018	79	2	102	0.02
1990	0.094	34	7	85	0.08	0.000	0	0	25	0.00	0.081	34	7	110	0.06
1991	0.008	100	1	81	0.01	0.000	0	0	26	0.00	0.007	100	1	107	0.01
1992	0.042	55	4	77	0.05	0.000	0	0	23	0.00	0.036	55	4	100	0.04
1993	0.000	0	0	82	0.00	0.031	0	1	23	0.04	0.004	0	1	105	0.01
1994	0.000	0	0	83	0.00	0.000	0	0	25	0.00	0.000	0	0	108	0.00
1995	0.237	52	5	84	0.06	0.093	0	1	24	0.04	0.217	49	6	108	0.06
1996	0.036	50	3	76	0.04	0.000	0	0	30	0.00	0.031	50	3	106	0.03
1997	0.096	77	3	85	0.04	0.016	0	1	23	0.04	0.086	76	4	108	0.04
1998	0.063	38	8	111	0.07	0.000	0	0	25	0.00	0.054	38	8	136	0.06
1999	0.083	47	5	81	0.06	0.000	0	0	25	0.00	0.071	47	5	106	0.05
2000	0.044	57	4	84	0.05	0.000	0	0	25	0.00	0.038	57	4	109	0.04
2001	0.216	27	14	85	0.16	0.000	0	0	25	0.00	0.186	27	14	110	0.13
2002	0.448	44	9	86	0.10	0.030	0	1	25	0.04	0.391	44	10	111	0.09

**Table E1 - NEFSC spring bottom trawl survey data for hagfish in the Gulf of Maine area, offshore area, and the combined Gulf of Maine and offshore areas**

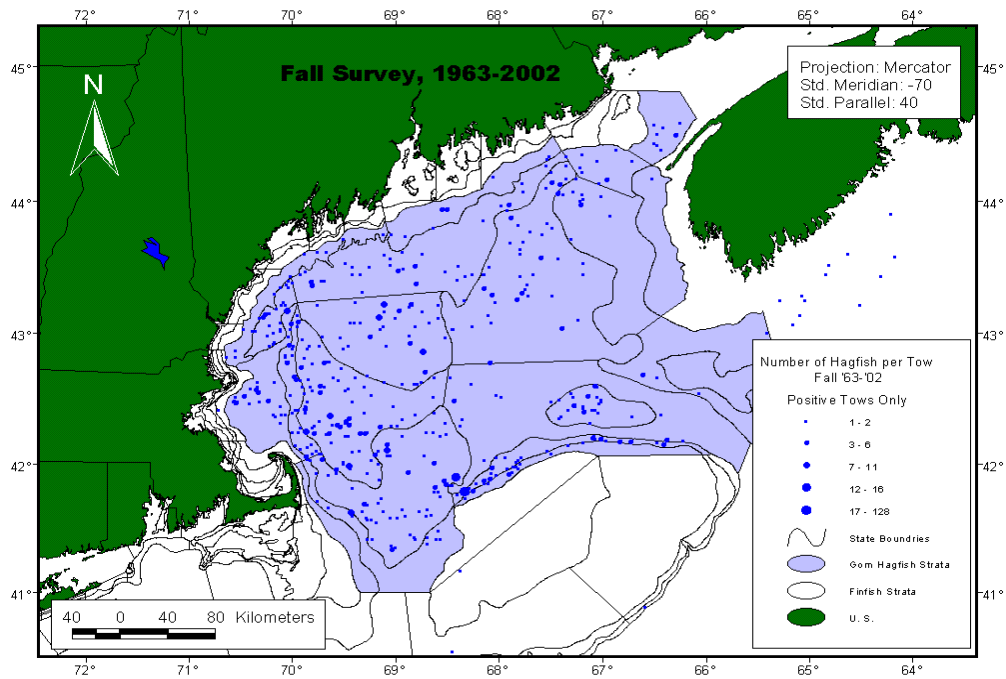
The Gulf of Maine area consists of NEFSC offshore survey strata 01210-01400 excluding stratum 01351. The offshore area consists of NEFSC offshore survey strata 01030-01040, 01070-01080, 01110-01120, 01140-01150, 01630-01640, 01670-01680, 01710-01720, and 01750-01760. All data are for "successful" tows only (database SHG code <= 136).

Year	Gulf of Maine area					Offshore area					Combined Areas				
	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows	Mean Number per Tow	CV (%)	Number Positive Tows	Total Number Tows	Proportion Positive Tows
1963	0.156	55	8	105	0.08	0.000	0	1	23	0.04	0.141	55	9	128	0.07
1964	0.078	38	6	95	0.06	0.000	0	0	29	0.00	0.070	38	6	124	0.05
1965	0.024	65	3	97	0.03	0.048	73	2	32	0.06	0.026	55	5	129	0.04
1966	0.214	29	13	96	0.14	0.289	22	9	32	0.28	0.222	25	22	128	0.17
1967	0.153	40	8	92	0.09	0.082	76	2	50	0.04	0.144	38	10	142	0.07
1968	0.079	52	4	95	0.04	0.047	60	3	42	0.07	0.075	49	7	137	0.05
1969	0.303	26	18	97	0.19	0.860	62	7	42	0.17	0.371	25	25	139	0.18
1970	0.355	25	17	103	0.17	0.015	0	2	42	0.05	0.313	25	19	145	0.13
1971	0.140	38	8	103	0.08	0.023	73	2	43	0.05	0.126	37	10	146	0.07
1972	0.939	55	18	104	0.17	0.292	80	5	41	0.12	0.860	53	23	145	0.16
1973	0.441	25	19	102	0.19	0.015	100	1	41	0.02	0.389	25	20	143	0.14
1974	0.258	58	7	107	0.07	1.523	97	4	41	0.10	0.413	54	11	148	0.07
1975	0.200	46	11	115	0.10	0.115	71	2	39	0.05	0.190	43	13	154	0.08
1976	0.380	38	12	97	0.12	0.095	100	1	41	0.02	0.345	37	13	138	0.09
1977	0.112	33	11	133	0.08	0.085	100	1	39	0.03	0.109	32	12	172	0.07
1978	0.230	27	25	201	0.12	0.071	78	2	38	0.05	0.211	26	27	239	0.11
1979	0.195	25	20	212	0.09	0.021	0	1	37	0.03	0.173	25	21	249	0.08
1980	0.373	31	15	105	0.14	0.000	0	0	36	0.00	0.328	31	15	141	0.11
1981	0.309	24	18	100	0.18	0.128	89	2	37	0.05	0.287	23	20	137	0.15
1982	0.022	71	2	104	0.02	0.000	0	0	38	0.00	0.019	71	2	142	0.01
1983	0.290	33	11	90	0.12	0.046	0	2	39	0.05	0.259	32	13	129	0.10
1984	0.155	85	4	98	0.04	0.000	0	0	39	0.00	0.137	85	4	137	0.03
1985	0.150	39	12	95	0.13	0.023	100	1	38	0.03	0.134	38	13	133	0.10
1986	0.106	48	7	101	0.07	0.032	72	2	39	0.05	0.097	46	9	140	0.06
1987	0.229	43	7	83	0.08	0.000	0	0	24	0.00	0.198	43	7	107	0.07
1988	0.017	100	1	84	0.01	0.026	0	1	25	0.04	0.018	80	2	109	0.02
1989	0.312	31	14	83	0.17	0.000	0	0	25	0.00	0.269	31	14	108	0.13
1990	0.226	31	14	85	0.16	0.000	0	0	24	0.00	0.196	31	14	109	0.13
1991	0.027	71	2	85	0.02	0.015	0	1	25	0.04	0.025	65	3	110	0.03
1992	0.112	54	5	82	0.06	0.121	100	1	22	0.05	0.113	49	6	104	0.06
1993	0.185	36	9	82	0.11	0.000	0	0	24	0.00	0.159	36	9	106	0.08
1994	0.656	26	23	84	0.27	0.026	0	1	24	0.04	0.569	26	24	108	0.22
1995	0.267	27	15	89	0.17	0.026	0	1	25	0.04	0.234	27	16	114	0.14
1996	0.118	41	8	81	0.10	0.000	0	0	25	0.00	0.102	41	8	106	0.08
1997	0.102	40	7	86	0.08	0.000	0	0	25	0.00	0.088	40	7	111	0.06
1998	0.406	32	12	99	0.12	0.000	0	0	25	0.00	0.350	32	12	124	0.10
1999	0.368	27	23	102	0.23	0.000	0	0	24	0.00	0.318	27	23	126	0.18
2000	0.602	42	14	83	0.17	0.013	0	1	26	0.04	0.521	42	15	109	0.14
2001	0.650	36	13	86	0.15	0.026	0	1	23	0.04	0.565	36	14	109	0.13
2002	0.186	28	8	81	0.10	0.179	0	5	25	0.20	0.185	24	13	106	0.12

**Table E2 - NEFSC fall bottom trawl survey data for hagfish in the Gulf of Maine area, offshore area, and the combined Gulf of Maine and offshore areas**

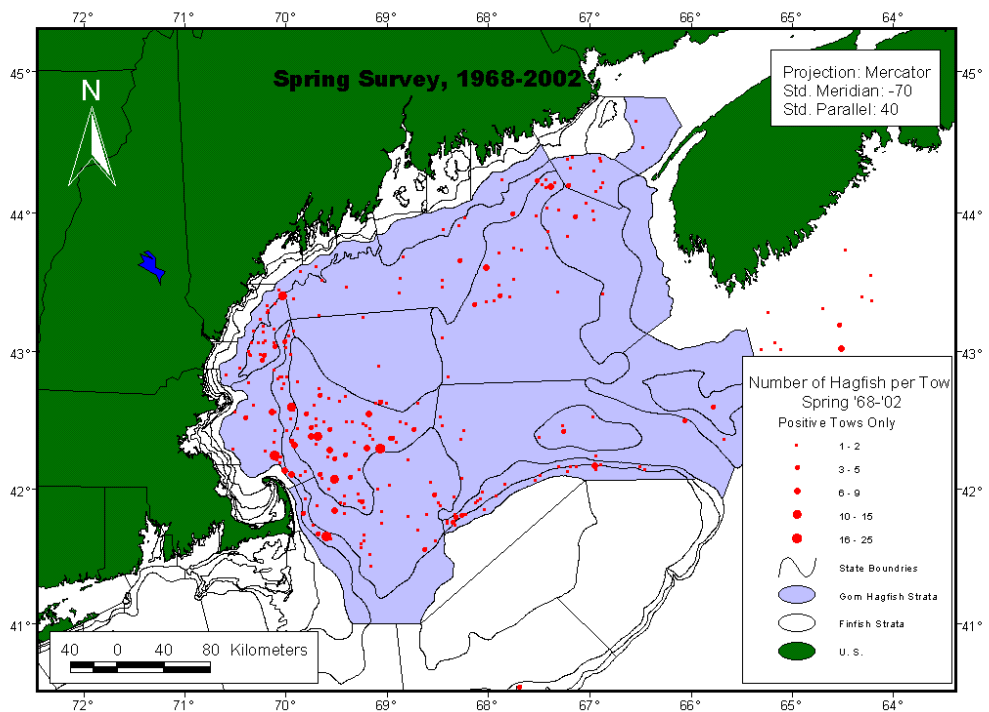
The Gulf of Maine area consists of NEFSC offshore survey strata 01210-01400 excluding stratum 01351. The offshore area consists of NEFSC offshore survey strata 01030-01040, 01070-01080, 01110-01120, 01140-01150, 01630-01640, 01670-01680, 01710-01720, and 01750-01760. All data are for "successful" tows only (database SHG code <= 136).





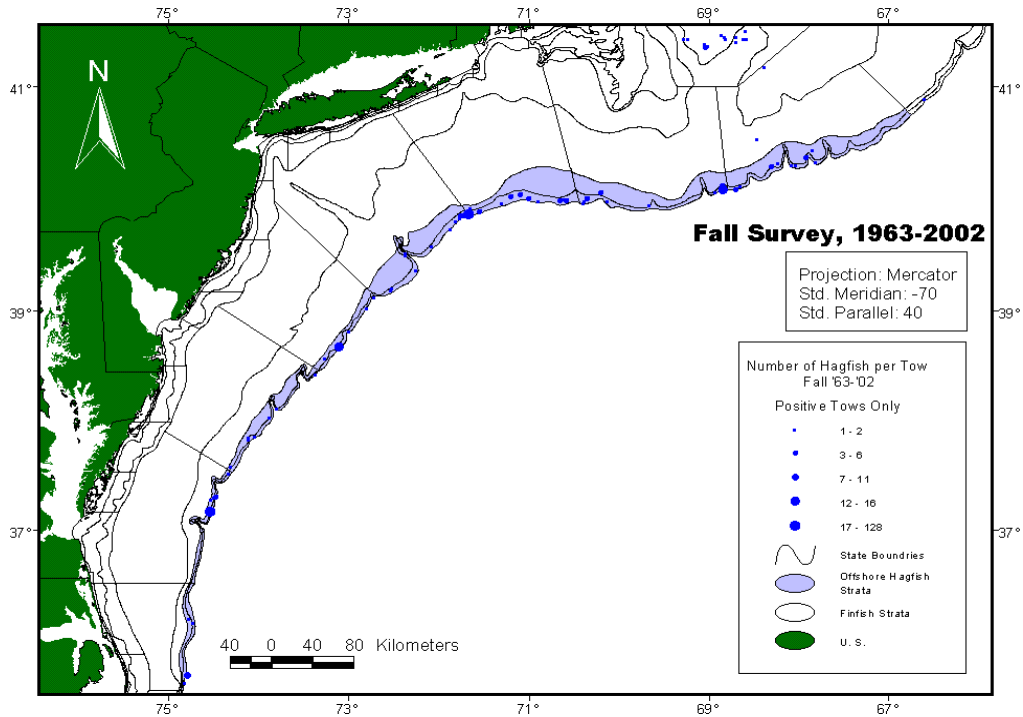
**Figure E4 - Number of hagfish per tow in NEFSC fall groundfish survey (Gulf of Maine strata), 1963-2002**

*Source: Northeast Fisheries Science Center*

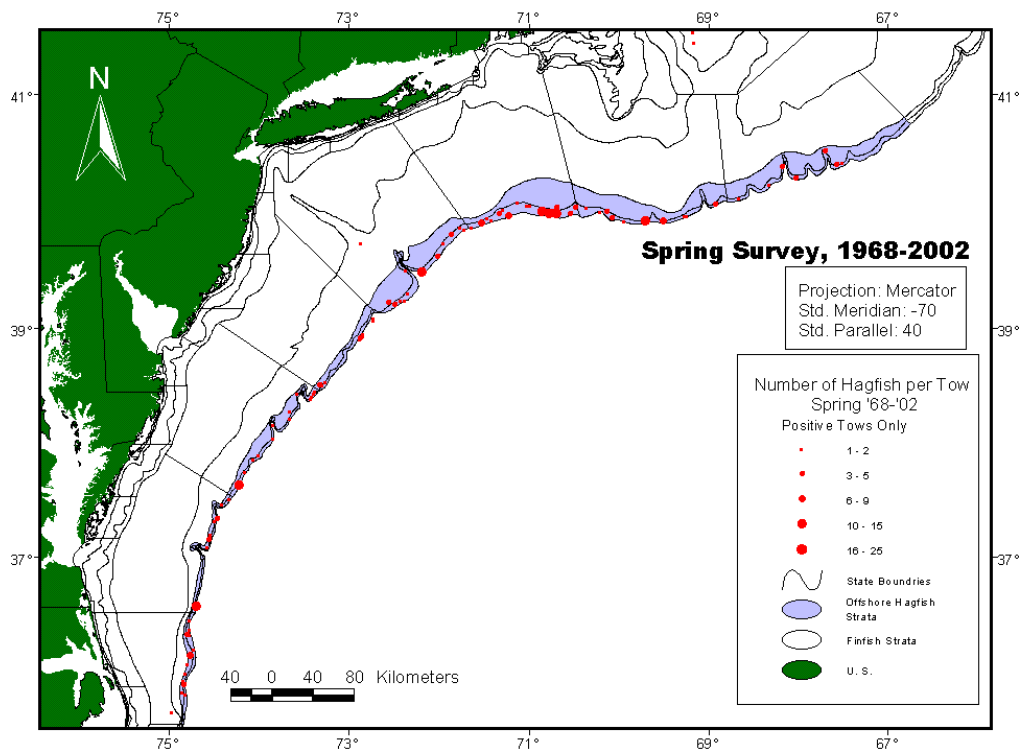


**Figure E5 - Number of hagfish per tow in NEFSC spring groundfish survey (Gulf of Maine strata), 1968-2002**

*Source: Northeast Fisheries Science Center*



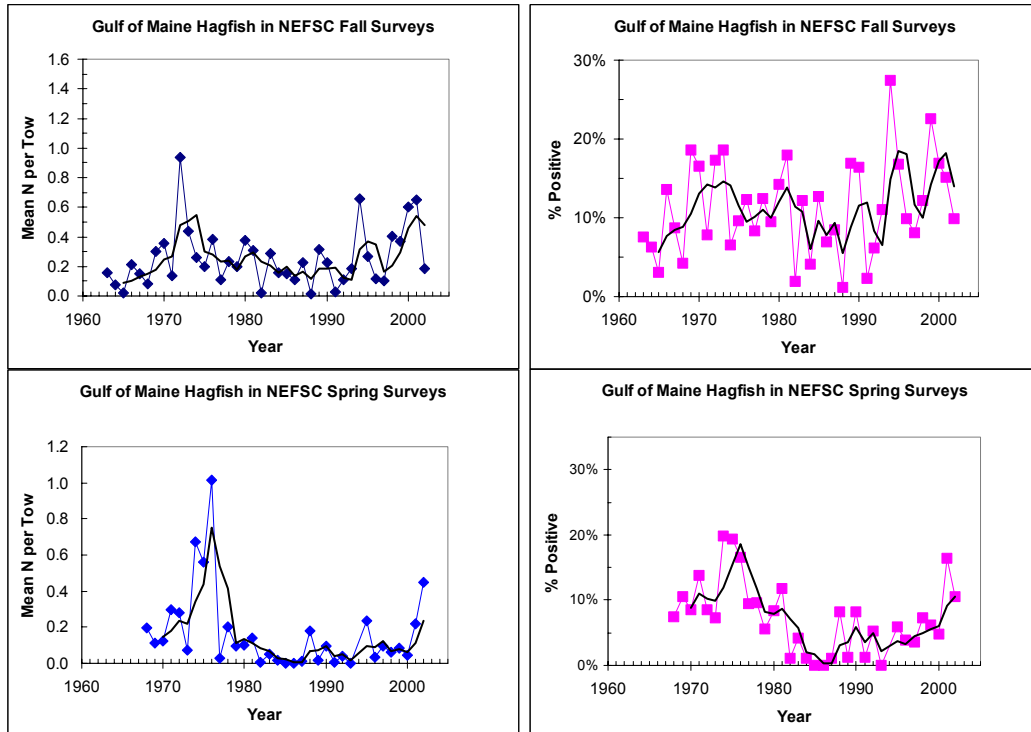
**Figure E6 - Number of hagfish per tow in NEFSC fall groundfish survey (Offshore strata), 1963-2002**



**Figure E7 - Number per tow in NEFSC spring groundfish survey (Offshore strata), 1968-2002**

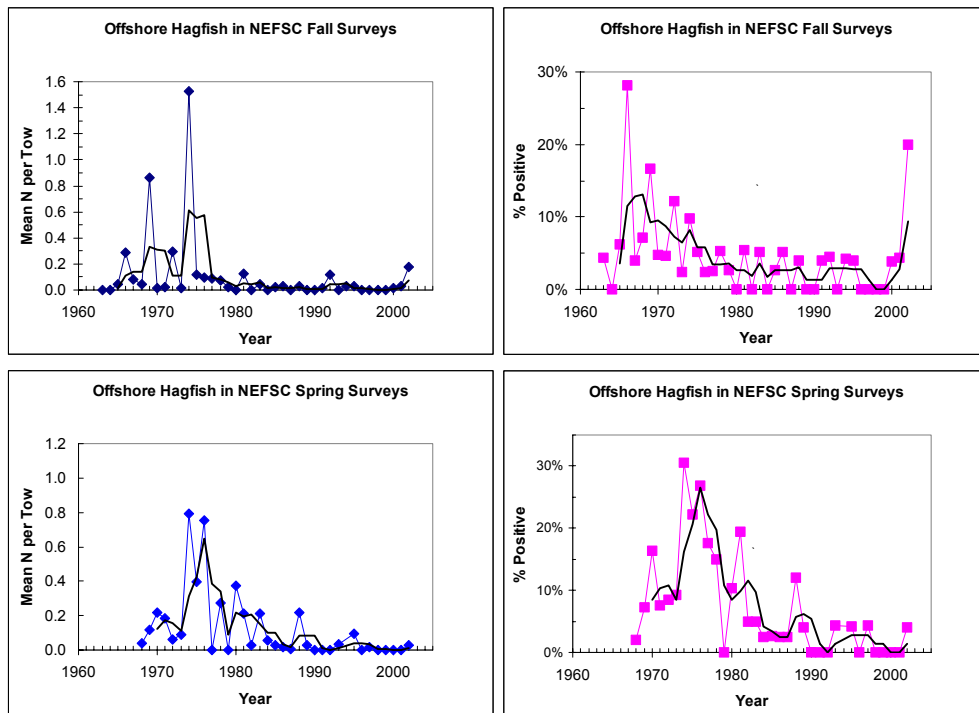
*Source: Northeast Fisheries Science Center*

For all survey areas and seasons, mean number per tow and proportion of positive tow data were “smoothed” using a 3-year moving average to show longer-term trends. The Gulf of Maine survey data indicate a decline in hagfish abundance from the mid-1970s through the early 1990s, with increases afterwards. Abundance increased slightly through the late-1990s (Figure E8). Offshore survey data demonstrate a consistent decline in hagfish abundance in both the fall and spring (Figure E9). It should be noted that this survey covers only the edge of hagfish habitat in the region south of southern New England. Combining the offshore and Gulf of Maine survey data yields trends similar to those seen in survey data from the Gulf of Maine alone (Figure E10).



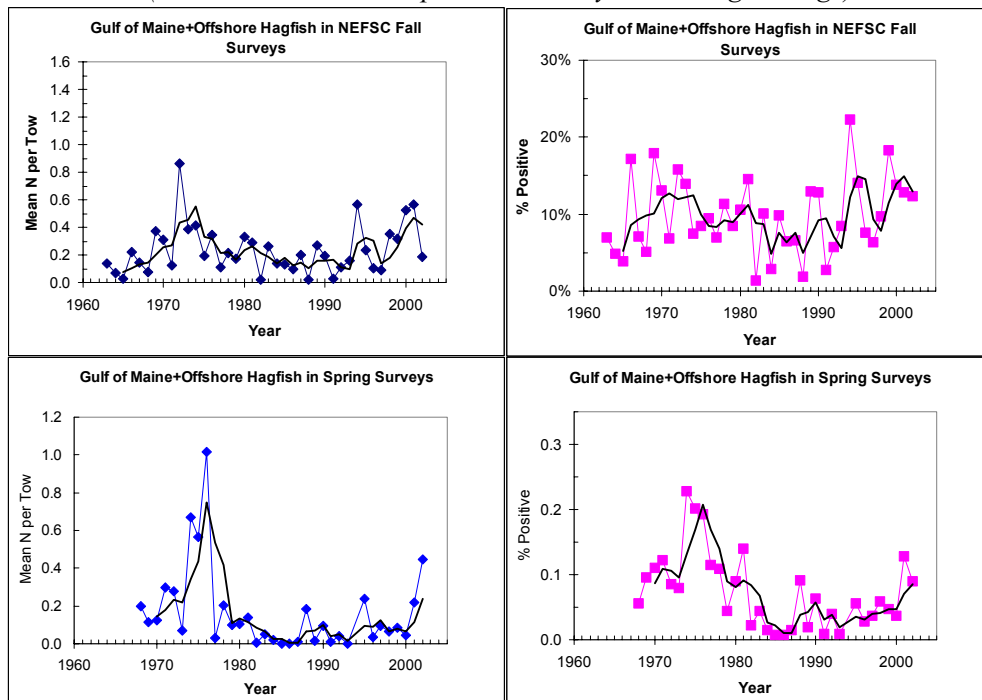
**Figure E8 - Hagfish abundance in Gulf of Maine survey area, fall (1963-2002) and spring (1968-2002)**

*Source: Northeast Fisheries Science Center  
(smoothed trend line represents three-year moving average)*



**Figure E9 - Hagfish abundance in offshore survey area, fall (1963-2002) and spring (1968-2002)**

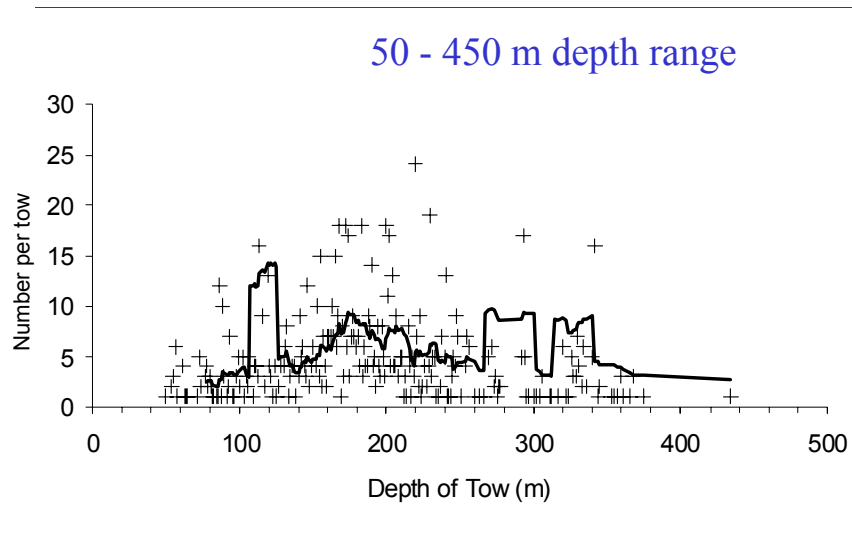
*Source: Northeast Fisheries Science Center  
(smoothed trend line represents three-year moving average)*



**Figure E10 - Hagfish abundance in Gulf of Maine and offshore survey areas, fall (1963-2002) and spring (1968-2002)**

*Source: Northeast Fisheries Science Center  
(smoothed trend line represents three-year moving average)*

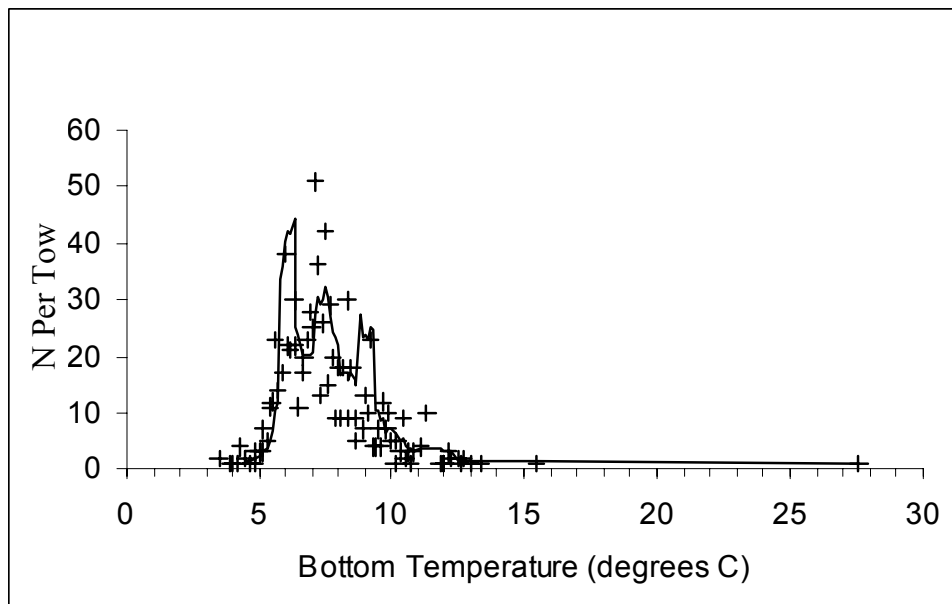
Hagfish are captured in the survey at depths of 50 to 450 meters (Figure E11), with the highest numbers of individuals per tow occurring at depths of 150-250 meters.



**Figure E11 - Depth for bottom trawl (groundfish) survey tows with hagfish**

*Source: Northeast Fisheries Science Center*

Hagfish were caught in areas with bottom temperatures ranging from 2 to 15°C but were most commonly encountered at temperatures of 5-10°C (Figure E12).



**Figure E12 - Catch and bottom temperature for bottom trawl (groundfish) survey tows with hagfish**

*Source: Northeast Fisheries Science Center*

### 4.1.3 Shrimp survey

The Gulf of Maine Northern Shrimp Survey has been conducted by the Northeast Fisheries Science Center (NEFSC) in cooperation with the Northern Shrimp Technical Committee of the Atlantic States Marine Fisheries Commission since 1983. The survey is designed to provide data required for annual stock assessments and related tasks. Hagfish are captured incidentally in this survey in low numbers. The overall trend in mean number of hagfish per tow and proportion of positive tows in the shrimp survey was highly variable with a peak during 1993-1994 (Table E3; Figure E13 and Figure E14).

Year	Total Tows	# of Hagfish	Positive Tows	Mean # / Tow	Proportion Positive
1983	22	*	*	NA	NA
1984	39	5	2	0.13	5.13
1985	55	2	2	0.04	3.64
1986	54	*	*	NA	NA
1987	57	4	3	0.07	5.26
1988	44	0	0	0.00	0.00
1989	49	2	2	0.04	4.08
1990	48	4	4	0.08	8.33
1991	56	4	4	0.07	7.14
1992	57	1	1	0.02	1.75
1993	53	10	8	0.19	15.09
1994	49	8	8	0.16	16.33
1995	53	0	0	0.00	0.00
1996	58	12	6	0.21	10.34
1997	55	3	3	0.05	5.45
1998	61	0	0	0.00	0.00
1999	61	7	6	0.11	9.84
2000	55	3	2	0.05	3.64
2001	57	4	4	0.07	7.02
2002	54	3	3	0.06	5.56

**Table E3 – Hagfish abundance in the NEFSC summer shrimp survey, 1983-2002**

*Source: Northeast Fisheries Science Center*

*\* only weight recorded in database*

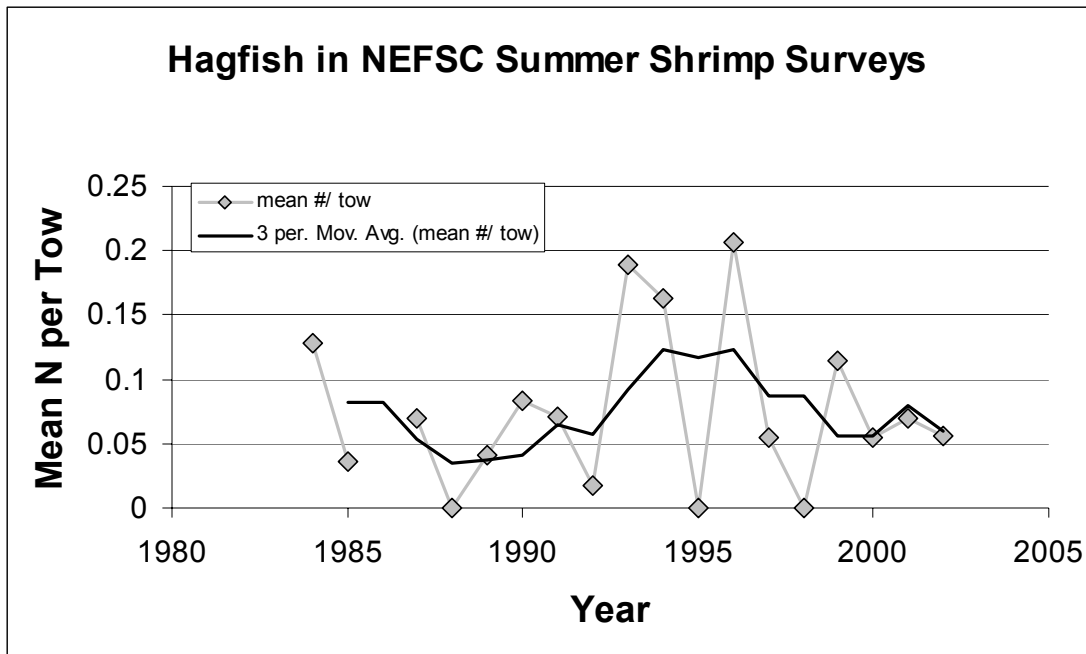


Figure E13 – Mean number of hagfish per tow in Gulf of Maine shrimp survey areas, summer (1983-2002)

Source: Northeast Fisheries Science Center

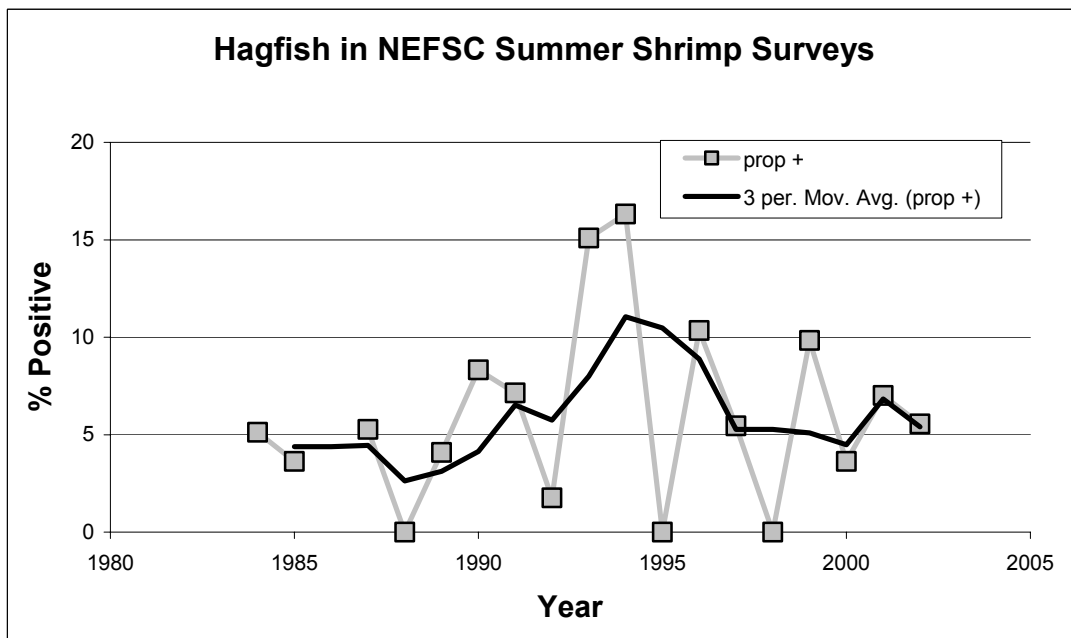


Figure E14 – Proportion of positive hagfish tows in Gulf of Maine shrimp survey areas, summer (1983-2002)

Source: Northeast Fisheries Science Center

## **Summary**

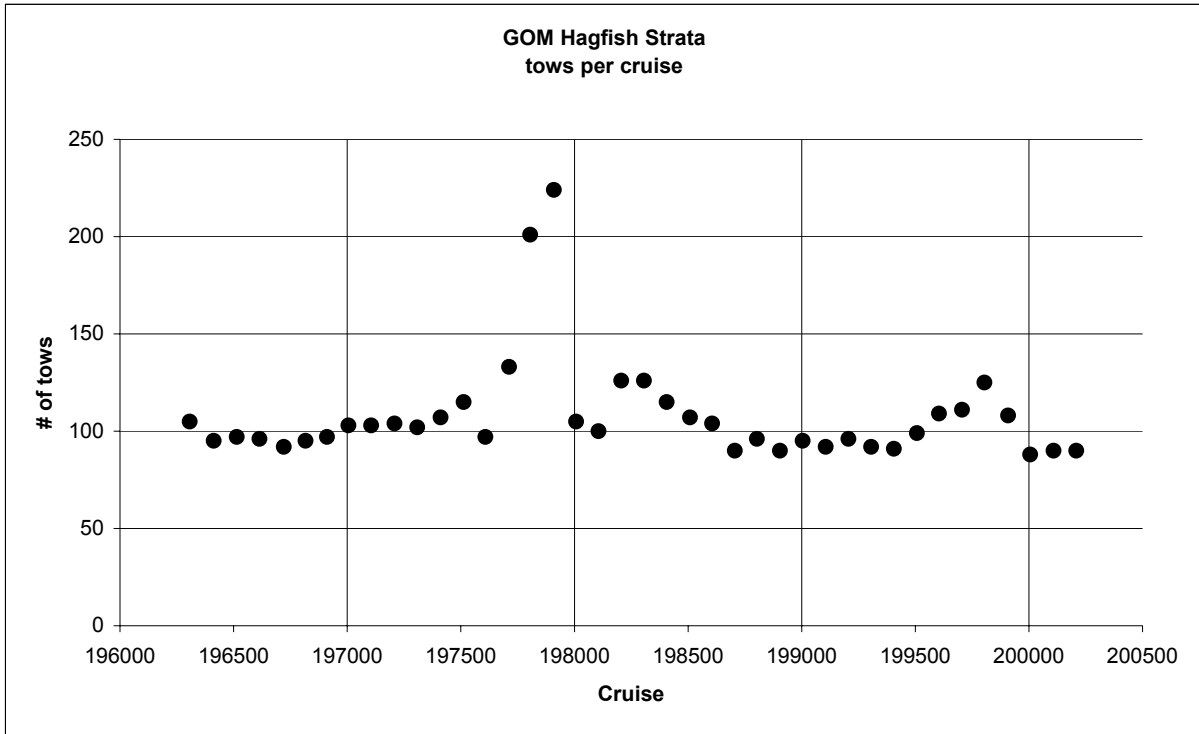
In general, hagfish are rare in both groundfish bottom trawl and shrimp surveys and it is not known to what degree trends in abundance are confounded by noise resulting from small sample sizes. Data from groundfish bottom trawl surveys cover a larger area, are based on more tows, and may be more reliable.

## **4.2 Hagfish Length Frequencies**

### **4.2.1 Data Sources and Caveats**

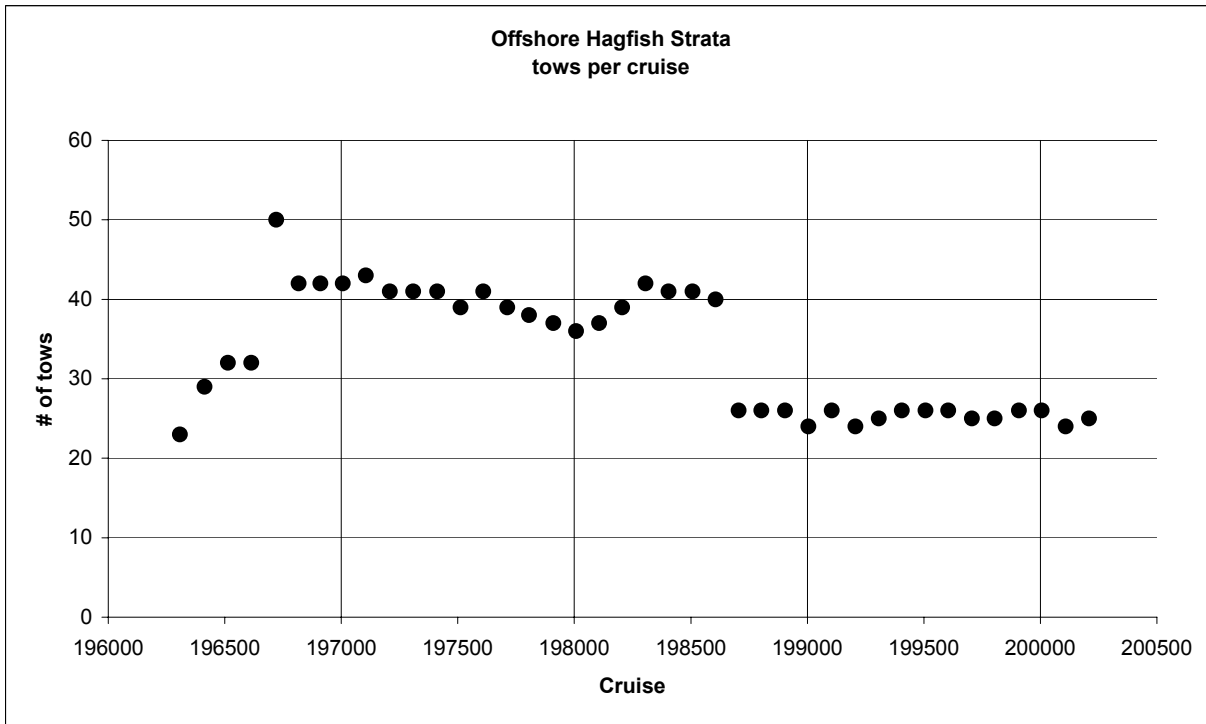
- Length frequency data for hagfish in these analyses were taken from NEFSC spring (1968-2002) and fall (1963-2002) bottom trawl surveys for groundfish, and from NEFSC summer shrimp surveys from 1982 to 2002.
  - Length data for hagfish were total length from snout to tip of tail in centimeters.
  - Length composition data were numbers per 1 cm size group for all hagfish measured in successful random survey tows (database SHG codes  $\leq 136$ ). Since tows are allocated to strata randomly and all fish are identified and measured, simple counts are adequate for characterizing length frequency of survey catches.
- Length data from spring and fall bottom trawl surveys were aggregated by two geographic areas [Gulf of Maine (GOM) and Offshore (OFF), see Figure E1 and Figure E2] for analysis. Length and survey catch data from the Gulf of Maine shrimp survey were for a third area, which largely overlapped the Gulf of Maine trawl survey area (Figure E3).
- Survey coverage –  
The number of tows in OFF declined over time but all strata were sampled in most years (Figure E15, Figure E16, Figure E17, and Figure E18).
- For some length frequency analyses, fall survey data were aggregated by decade to examine trends over time. Spring groundfish trawl and shrimp survey data were too sparse for this type of analysis.





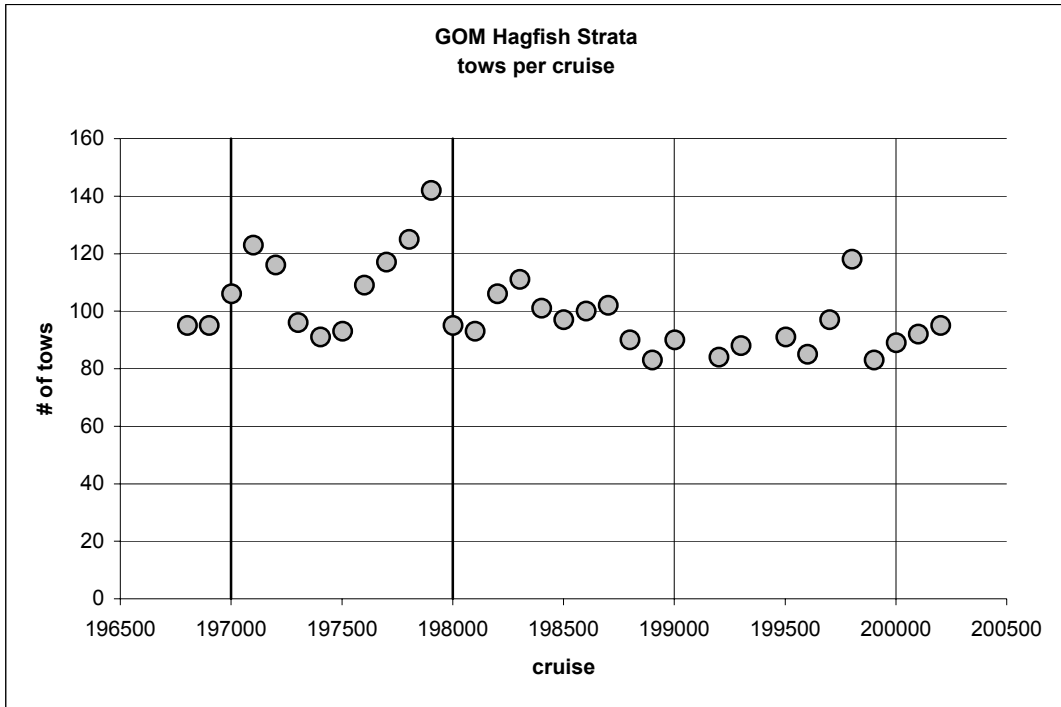
**Figure E15 - Tows per cruise in the GOM fall survey area**

*Source: Northeast Fisheries Science Center*



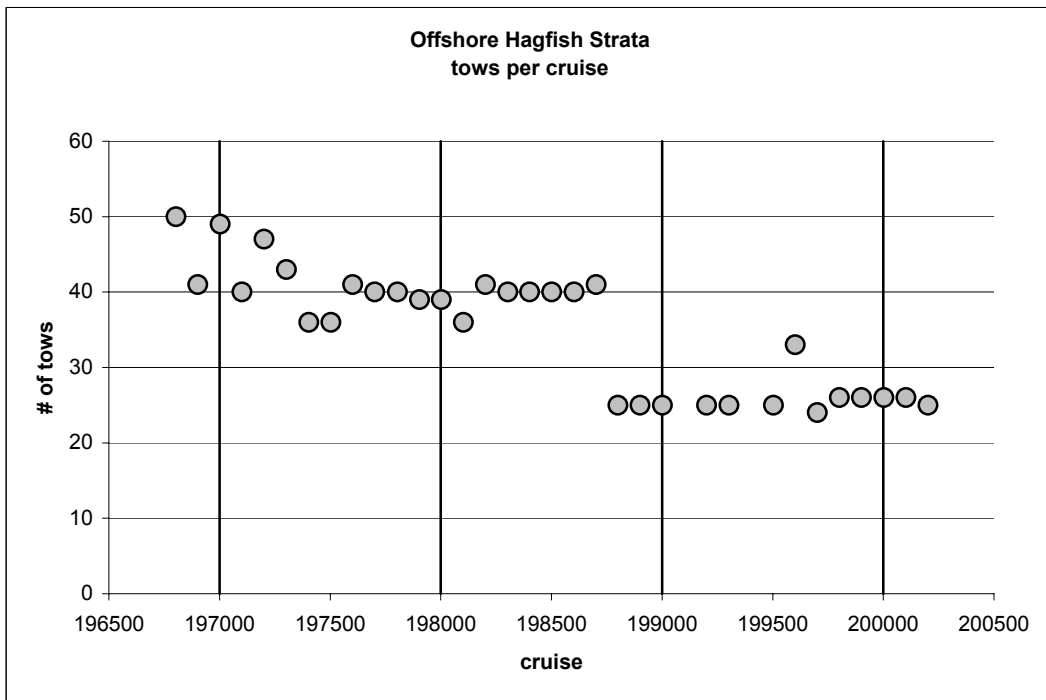
**Figure E16 - Tows per cruise in the Offshore fall survey area**

*Source: Northeast Fisheries Science Center*



**Figure E17 – Tows per cruise in the GOM spring survey area**

*Source: Northeast Fisheries Science Center*



**Figure E18 – Tows per cruise in the Offshore spring survey area**

*Source: Northeast Fisheries Science Center*

#### 4.2.2 Groundfish Bottom Trawl and Shrimp Surveys

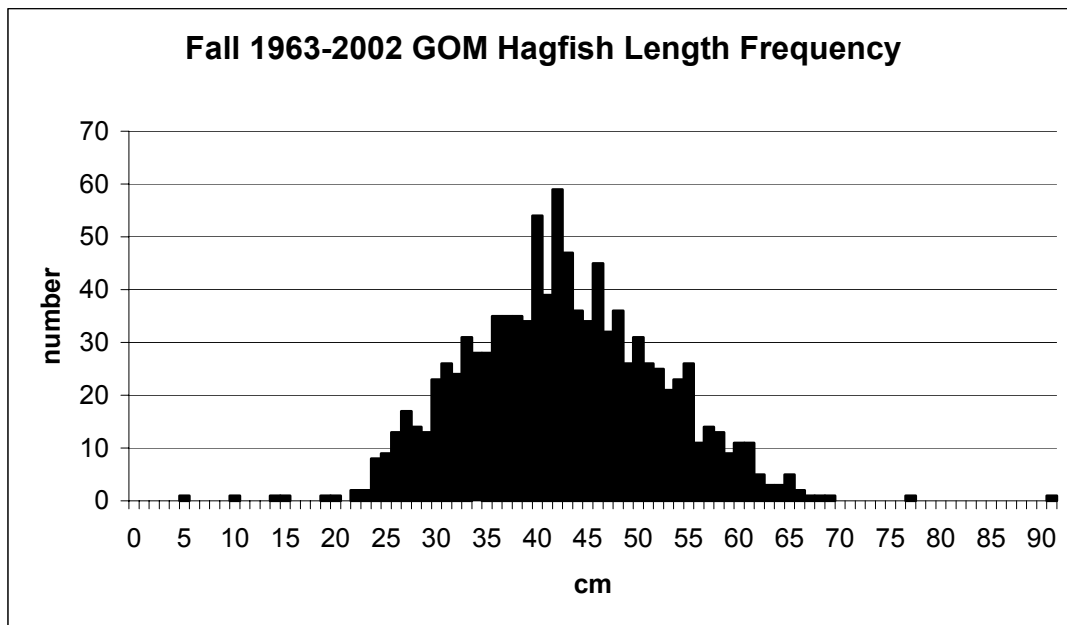
Hagfish caught during spring and fall surveys in the GOM were larger than animals captured in the Offshore area. Hagfish caught in the shrimp surveys had the highest mean length (Table E4).

Area	Grand Mean Catch Per Tow (N/Tow)	Proportion Positive Tows (%)	Modal Length (cm)	Mean Length (cm)	Minimum Length (cm)	Maximum Length (cm)	N Measured
GOM spring	0.164	7	43	40.5	10	70	589
GOM fall	0.253	11	42	42.6	5	91	1035
OFF spring	0.126	7	36	34.7	19	48	269
OFF fall	0.106	5	37	34.6	15	50	294
Shrimp summer survey	0.08	6	60	55.5	18	66	65

**Table E4 – Catch and length data for hagfish in the groundfish and shrimp surveys**

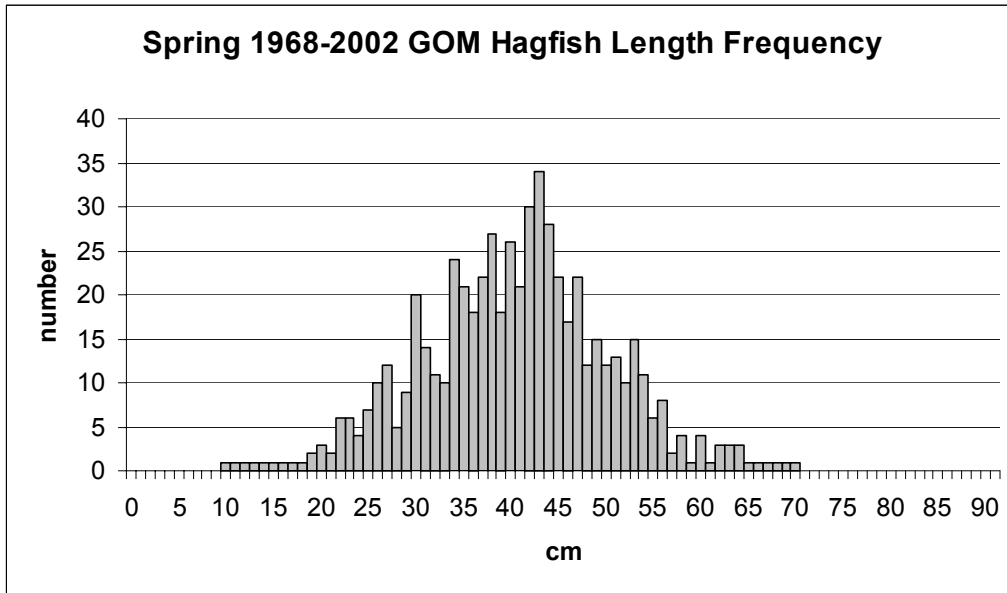
*Source: Northeast Fisheries Science Center*

Length frequency curves were similar for hagfish caught during the spring and fall in both the Gulf of Maine and Offshore areas. In the Gulf of Maine, hagfish length averaged 40.5 cm in the spring and 42.6 cm in the fall. In the Offshore survey area, mean length in the spring was 34.7 cm and 34.6 in the fall. (Figure E19, Figure E20, Figure E21, and Figure E22).



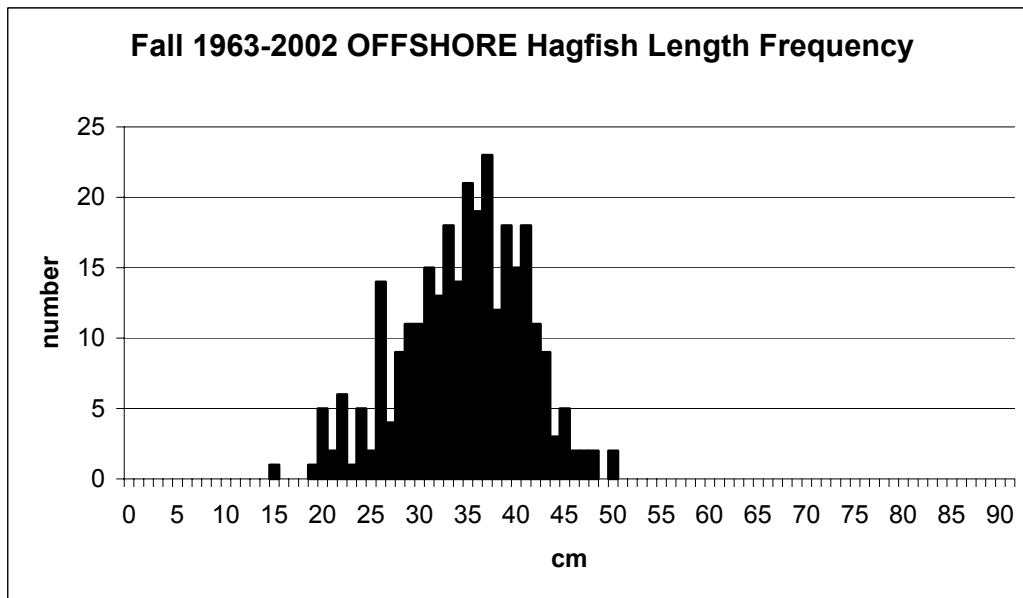
**Figure E19 – GOM hagfish length frequency in the fall groundfish survey**

*Source: Northeast Fisheries Science Center*



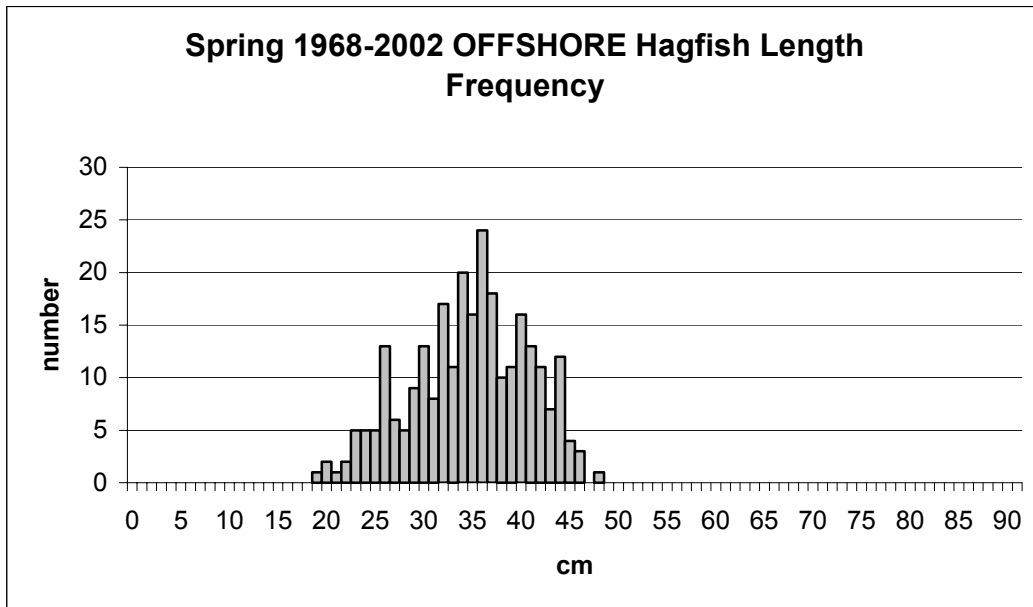
**Figure E20 - GOM hagfish length frequency in the spring groundfish survey**

*Source: Northeast Fisheries Science Center*



**Figure E21 - Offshore hagfish length frequency in the fall groundfish survey**

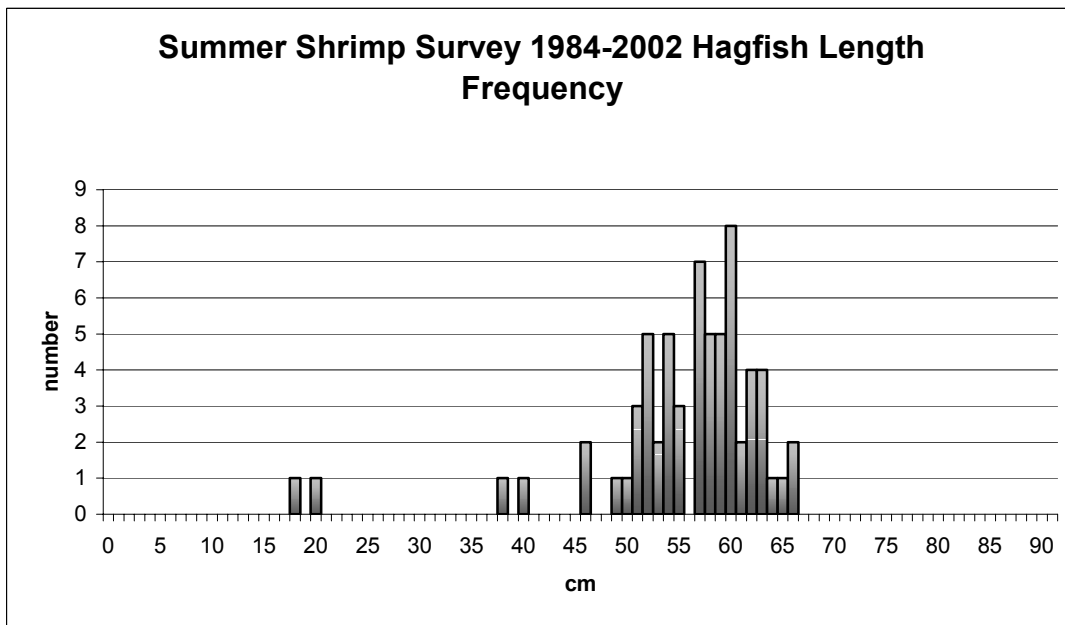
*Source: Northeast Fisheries Science Center*



**Figure E22 - Offshore hagfish length frequency in the spring groundfish survey**

*Source: Northeast Fisheries Science Center*

Length frequencies for hagfish caught during the summer shrimp survey have a higher mean and mode than the other surveys but a much smaller sample size, with only 65 individuals measured and a mean of 0.08 individuals per tow (Table E4 and Figure E23).



**Figure E23 - GOM hagfish length frequency in the summer shrimp survey**

*Source: Northeast Fisheries Science Center*

Based on visual analyses, it appears that modal length declined in the Gulf of Maine from the 1980s to 2002 (Figure E24, Figure E25, Figure E26, and Figure E27). Too much noise exists in data from spring surveys to detect changes in modal size. Mean length for hagfish in the GOM declined after the 1970s (Table E5). Mean values for the 1960s and 2000s are uncertain because of low sample size and fewer years of data.

<b>Survey/Region</b>	<b>1963/8-69</b>	<b>1970-79</b>	<b>1980-89</b>	<b>1990-99</b>	<b>2000-02</b>
Spring GOM	40.0 (29)	41.3 (365)	43.4 (55)	38.5 (70)	35.5 (56)
Fall GOM	39.0 (97)	44.8 (424)	44.2 (187)	40.3 (220)	38.4 (107)
Spring OFF	34.0 (9)	34.8 (187)	34.8 (65)	32.5 (6)	37.5 (2)
Fall OFF	33.4 (143)	35.4 (141)	35.4 (14)	32.9 (8)	36.8 (9)

**Table E5 - Mean length (cm) and sample size (number hagfish) in NEFSC surveys**

*Source: Northeast Fisheries Science Center*

*Note - First value in each column is mean length and second is sample size.*

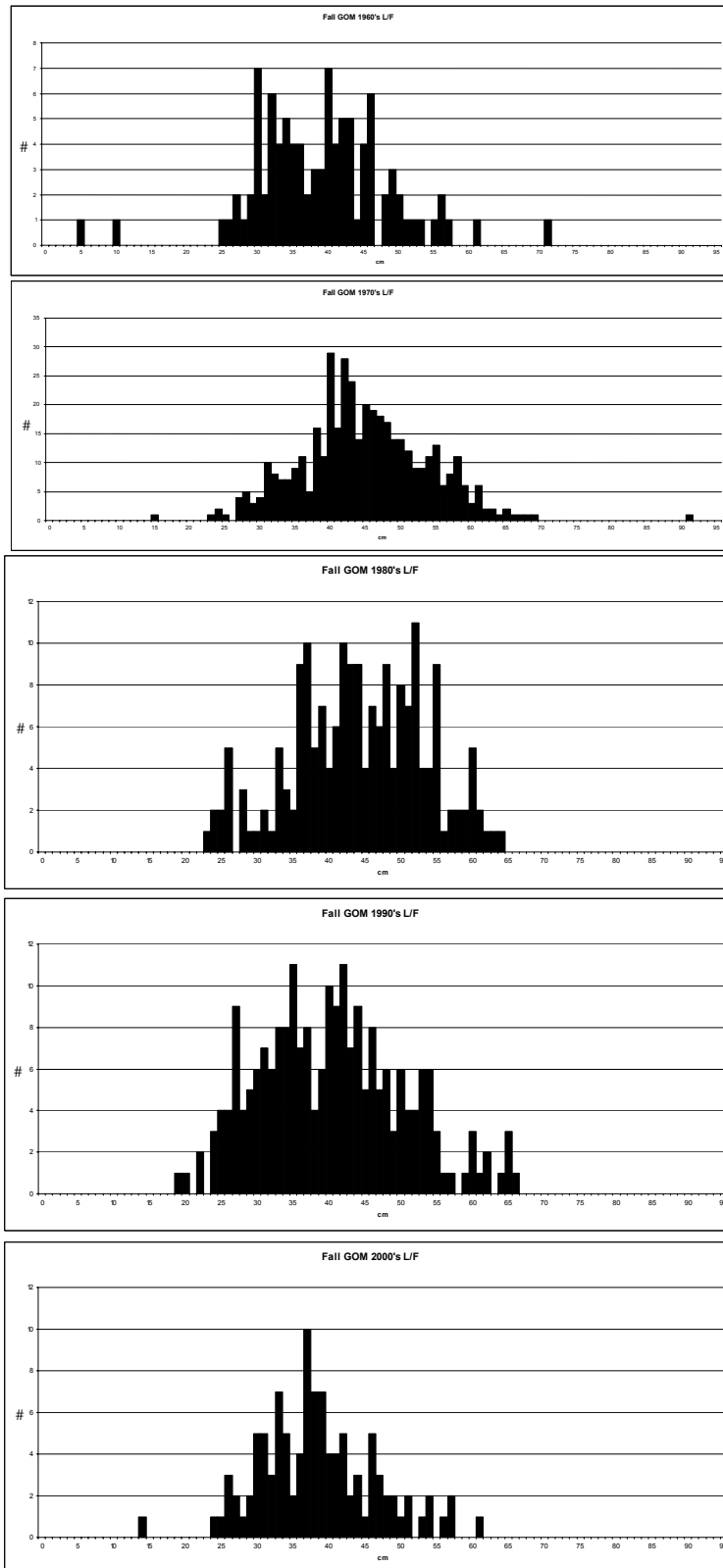


Figure E24 - Hagfish length frequencies in the Fall GOM bottom trawl survey

*Note: Y-axes are variable*

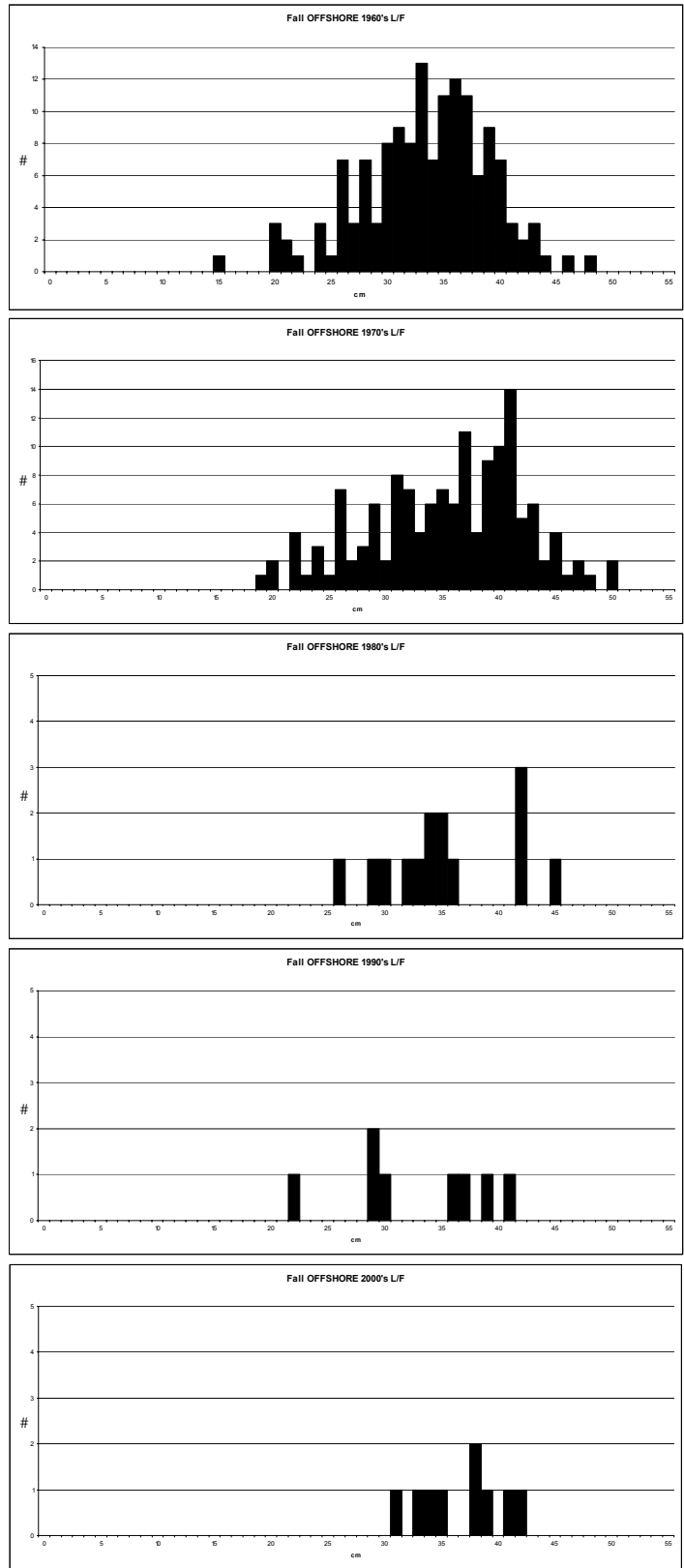
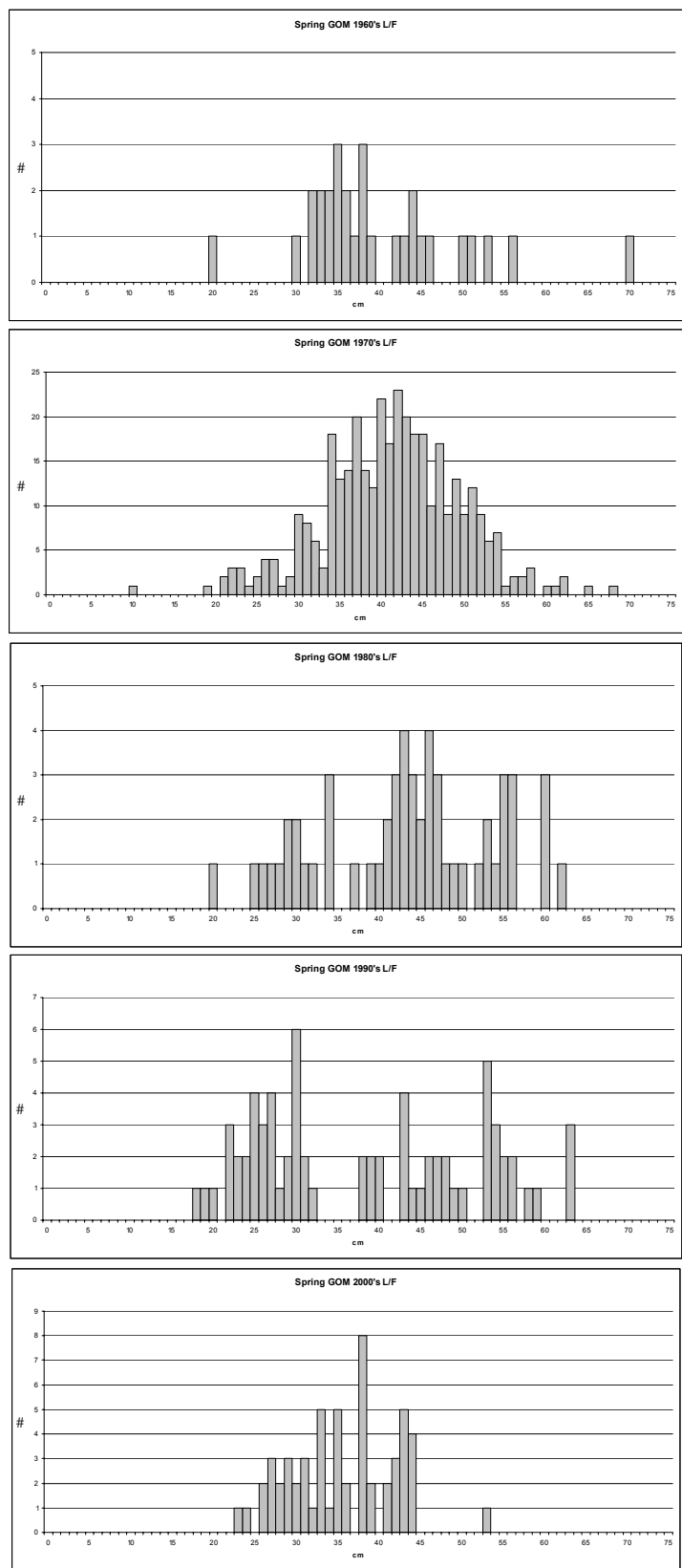


Figure E25 - Hagfish length frequencies in the Fall Offshore bottom trawl survey

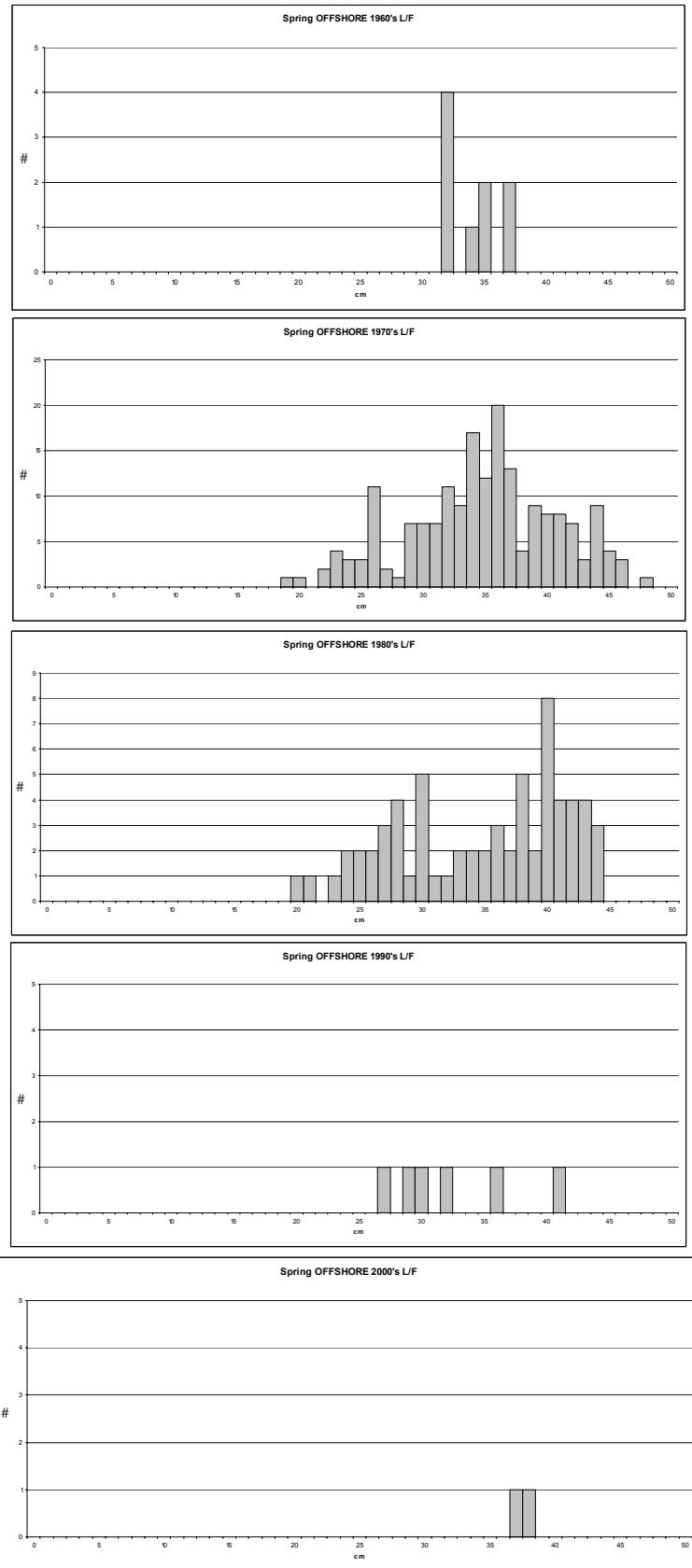
*Note: Y-axes are variable*





**Figure E26 - Hagfish length frequencies in the Spring GOM bottom trawl survey**

*Note: Y-axes are variable*



**Figure E27 - Hagfish length frequencies in the Spring Offshore bottom trawl survey**

*Note: Y-axes are variable*

### 4.2.3 Length-Weight Relationship

A preliminary length-weight relationship was estimated based on all available length and weight data for individual hagfish in NEFSC surveys (Figure E28). Sample size was low (n=49) with specimens taken from GOM in 2002.

Linear ( $W=0.0028L-0.0616$ ) and power ( $W=0.0004L^{2.5571}$ ) models were fit by linear regression to individual length and body weight data for hagfish. Both models fit the bulk of the data for hagfish 20-50 centimeters well, however, there is uncertainty about the nature of the relationship for larger hagfish due to a lack of data for specimens larger than 50 cm. Length-weight data for larger specimens would be useful for improving estimates of the length-weight relationships for hagfish.

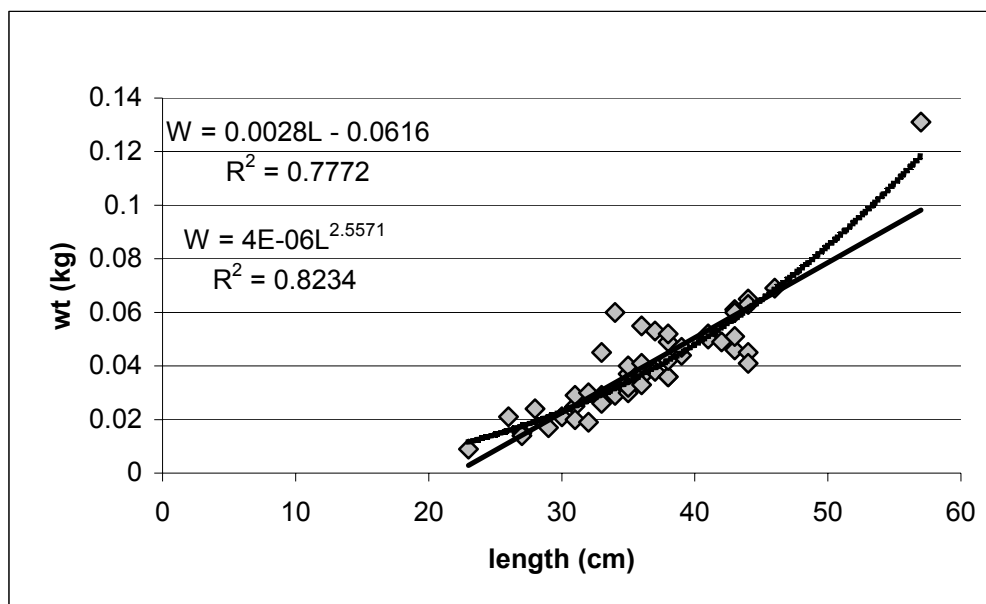
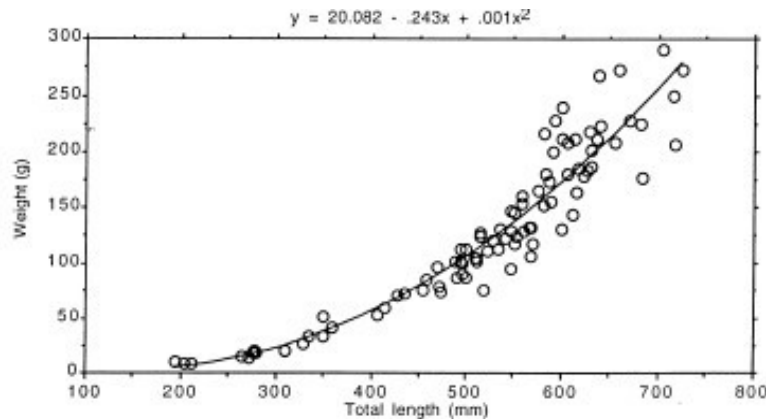


Figure E28 - Hagfish length-weight relationship from 2002 NEFSC survey data (n=49)

*Source: NEFSC 2002 Gulf of Maine surveys  
Length in centimeters; weight in kilograms*

Martini et al. (1997a) collected samples of Atlantic hagfish from the Bigelow Bight in the Gulf of Maine, approximately 25 km west of Jeffrey’s Ledge and 50 km east of the New Hampshire coast between June 1989 and August 1992. A length-weight curve was constructed based on a random sample of 83 individuals (Figure E29). These data include a large number of specimens greater than 50 cm, which were primarily absent from NEFSC samples. Martini et al. present a very similar length-weight relationship for hagfish as that derived from the NEFSC survey data.



**Figure E29 – Hagfish length-weight relationship from Martini et al. 1997 (n=80)**

*Source: Martini et al. 1997a*  
*Length in millimeters; weight in grams*  
 $W = 20.082 - 0.243L + 0.001L^2$

## 5.0 HISTORY OF THE FISHERY

### 5.1 Western Pacific Hagfish Fishery (Asia)

An active hagfish fishery originated in Japan and Korea, where hagfish were an historically important source of food for human consumption (Leask & Beamish 1999). After World War II, the skins of hagfishes (*Paramyxine atami* & *Eptatretus burgeri*) also became valued in Asia for their use as a soft, strong leather. During the late 1980s, South Korea annually exported “eelskin” (hagfish skin) leather products worth \$80 million. By 1986-1987 the Korean fleet had grown to about 1,000 vessels which sold their catch to approximately 100 shore-side processing plants (Martini & Flescher in Collette & Klein-MacPhee 2002). By 1995, Koreans consumed nearly 5 million pounds of hagfish meat each year. Because of depletion of the stock, exports had dropped to about \$20 million by 1992 and a new source of high quality skins was sought in the western Atlantic. Overfishing in Korea had caused the collapse of the hagfish fishery there and created an opportunity for such a fishery to be developed in the United States (Maine/New Hampshire Sea Grant Press Center 1995).

### 5.2 Eastern Pacific Hagfish Fishery (North America)

A North American hagfish fishery began in 1987, when Korean buyers began purchasing Pacific hagfish (*Eptatretus stoutii*) from the Monterey area of California (Martini & Flescher in Collette & Klein-MacPhee 2002). By 1989 an active west coast fishery was established in the United States and Canada. Korean traps – 24” long and 5” in diameter with one entrance funnel on one end – were used in west coast fisheries with one exception in 1992 when 5-gallon plastic traps were used experimentally in British Columbia (Benson et al. 2001, Leask & Beamish 1999).

### 5.2.1 Canadian Fishery

An experimental fishery for hagfish existed in British Columbia from 1988-1992. In addition to basic management measures for this fishery, participating vessels were required to collect biological information in specific areas (Leask & Beamish 1999). (See Section 7.1 for more information on the experimental fishery.) In Canada, patterns of CPUE suggest there may be biological factors such as seasonal movements or spawning periods that affect catch rates (McCrae 2002).

### 5.2.2 U.S. Fishery

The Oregon fishery began in 1988 and peaked in 1992 with 16 vessels landing over 750,000 lb (Table E6). Catch-per-unit-effort (CPUE) for Oregon vessels using small Korean traps ranged from 0.8 - 1.4 kg per trap (McCrae 2002).

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Landings	0	0	0	0	25.8	344.2	167.5	274.5	751.2	332.8
Number of vessels	0	0	0	0	2	7	12	12	16	5

**Table E6 – Annual harvest of Pacific hagfish in Oregon, 1984-1993**

*Landings in thousands of pounds*

*Source: McCrae 2002*

In the late 1980s, California, Oregon and Washington initiated a permit requirement for the hagfish fishery in state waters. The states also established regulations on the fishery, including limited entry, trap limits, and specific gear requirements. These measures are discussed in greater detail in Section 7.2. The Pacific U.S. and Canadian fisheries had effectively ended in the early 1990s due to Korean market limitations (including a ban on hagfish imports), overproduction, and product quality issues (McCrae 2002).

## 5.3 Western Atlantic Hagfish Fishery (North America)

### 5.3.1 Canadian Fishery

A small Atlantic hagfish fishery was developed in Nova Scotia, Canada during the mid-1990s. Hagfish landings in the Scotian fishery, as reported by the Nova Scotia Department of Agriculture and Fisheries, diminished from a high of 1.1 million pounds in 1995 to 33,000 pounds in 1997, and increased again to about 858,000 pounds in 1999. Since 2000, no hagfish landings have been reported to the Nova Scotia Department of Agriculture and Fisheries. It has been suggested that activity has diminished in this region due to the absence of shore-side infrastructure for processing and exporting hagfish (Cho pers. comm. 2003). The Department of Fisheries and Oceans in Atlantic Canada does not conduct a formal stock assessment for hagfish. The fishery is managed through a Joint Project Agreement (JPA) which requires industry participants to collect length and weight data on hagfish, similar to the experimental fishery for hagfish in British Columbia (Stobo pers. comm. 2003).

### 5.3.2 U.S. Fishery

A Saltonstall-Kennedy Fishery Development Grant stimulated development of the Atlantic hagfish fishery in Georges Bank and the Gulf of Maine in the early 1990s (Allen 2001). A 1996 report by the New England Fisheries Development Association on the result of this effort indicated that while Atlantic hagfish leather has been successful in both the domestic and export markets, it had been difficult to create a domestic market for hagfish meat because of the difficulty in preparing it for consumption and the aversion of American consumers to the texture of the flesh (Hultin et al. 1996). Revenues from the hagfish fishery in New England more than doubled in the second year of its development. However, this rapid increase in exploitation led R.B. Allen (2001) to write:

The experience of the hagfish fishing fleet in the Gulf of Maine tends to corroborate experience with other hagfish resources. As early as 1996, fishermen were already seeing classic signs of resource stress. In just two years, fishermen noted a diminishing marketable catch level per trap. One fisherman reported that two summers of fishing one area revealed an impact on the eels' average size (Hall-Arber 1996). Since 1995 hagfish vessels have experienced fairly rapid local depletions with a corresponding need to continually shift fishing grounds to maintain catch rates (Nippert personal communication).

Today, the primary market for hagfish is the meat for human consumption. Small slime eels, which were previously unmarketable because of the small size of their skins, are now accepted by buyers because of their suitability for consumption.

## **6.0 CHARACTERIZING THE NEW ENGLAND COMMERCIAL HAGFISH FISHERY**

### **6.1 Data Sources and Caveats**

*Data Sources:*

- NMFS Commercial Fisheries Databases (WODETS/CFDETS)
  - NMFS Dealer Database
  - NMFS Vessel Trip Report (VTR) Database
- Industry phone interviews (March 2003)

The number of active hagfish vessels was determined by counting the number of distinct vessels, identified by hull number, with documented landings of hagfish in the NMFS Dealer database for each year. Aggregate records representing activity by multiple vessels provided no information on number of individual vessels. The total number of active vessels may be higher than the numbers reported. Where "UNK" is indicated in Table E9, *all* hagfish landings for that year were reported as aggregate records. The number of individual vessels landing these fish, however, is unknown.

Hagfish landings are underreported. Because there are no requirements for reporting landings of hagfish, documentation of landings and revenues generated in this fishery has not been consistent or complete. Due to a normal lag in data processing, 2002 data are especially incomplete.

### **6.2 Gear**

The directed hagfish fishery in New England uses specialized traps for capturing hagfish which are different in size and structure from Korean traps (described in Section 5.2). While hagfish have been caught incidentally in lobster pots, eel traps, otter trawls, gill nets, and sea urchin dredges, in New England they are caught predominantly using specialized hagfish gear. Fifty-five gallon plastic barrels with 3-6 entrance funnels and several rows of approximately 3/8" escape holes are used to trap hagfish. The traps are attached to 1/2" Polysteel groundline and set 25-35 fathoms apart, with 1/2" polypropylene/polydacron anchor and buoy lines at either end (Nippert pers. comm. 2002).

### **6.3 Fishing Practices**

For both large and small vessels, the soak time for the gear is from 6-24 hours. Small boats fish 20-40 traps in a string, hauling several times per trip. Larger vessels fish 80-200 traps in a string, hauling 1-2 times per day (Nippert pers. comm. 2002, Boulay pers. comm. 2003). One Gloucester captain of an 85 foot hagfish boat reported that he sets and hauls 1,000 traps (5 sets of 200 traps) on each 5 day trip (Boulay pers. comm. 2003). Gear is deployed to depths of 50-155 fathoms (in 1993, some vessels successfully fished in 18-22 fathoms outside Boston harbor) (Nippert pers. comm. 2002). Bait used is herring, tuna racks and occasionally mackerel (Nippert & Boulay pers. comm. 2002). Incidental catch of other species in hagfish traps is extremely low. One fisherman reported that in seven years of slime eeling, he has seen a single juvenile cod individual, around a half dozen juvenile hake and several dozen

shrimp in the hagfish traps. Bycatch only occurs when an entrance funnel is damaged (Nippert pers. comm. 2002).

One hundred percent of the hagfish landed in New England are frozen whole and shipped to Korea. The current price per pound for hagfish is 36 cents. Processors get \$1.60 per kilo, or about 75 cents per pound from Korean buyers (Cho pers. comm.).

#### **6.4 Dealer Data – Landings and Revenues**

The Atlantic hagfish fishery was developed in the early 1990s, with the first landings reported at just over 1 million pounds in 1993 (Table E7). Landings increased dramatically from 1.1 million pounds in 1993 to 4.3 million pounds in 1996, with an average annual increase of 66% during that period (Figure E30). Landings declined about 26% from 1996-1998, and doubled from 1998 to 2000. About 6.8 million pounds were landed in 2000, more than a six-fold increase since 1993. According to the NMFS Dealer database, landings declined dramatically in 2001, to around 1.5 million pounds, increasing only slightly in 2002 to 2.9 million pounds.

There is considerable uncertainty regarding the actual level of hagfish landings. According to a hagfish dealer/processor in Gloucester who contributes 70-75% of the total landings to the market each year, his personal records show that total landings for 2001 and 2002 were much higher. He estimates his 2001 landings to be between 2.3-2.4 million pounds, nearly 1 million pounds more than the *total* reported in the NMFS Dealer Database for that year. The dealer, who reports all landings to NMFS at least 2-3 times per month, provided a detailed record of 2002 trip reports by vessel to NEFMC staff in March, 2003. Total landings by vessels that sold the product to this dealer were 4.4 million pounds, 1.5 million pounds more than total landings reported by NMFS. Using the information provided by the dealer (March 2003), total landings for 2001 and 2002 are estimated to be 3.2 million pounds and 6.0 million pounds, respectively. The following formula was used to calculate these estimates:

Calculated total landings = (Dealer's landings) / (Dealer's expected percent contribution to total landings)

Dealer's expected percent contribution to total landings: 73% (between 70 and 75 percent)

Estimated landings in 2001 (according to dealer): 2.35 million pounds

Calculated total landings: 3.2 million pounds

Dealer's expected percent contribution to total landings: 73%

Exact landings in 2002 (Dealer's records): 4.4 million pounds

Calculated total landings: 6.0 million pounds

Approaching this calculation from a slightly different angle leads to a similar estimate. According to the dealer, 145 containers of landed hagfish were filled (105 by this dealer, 40 by other processors) in 2002. With about 42,500 pounds per container, the total landings were around 6.2 million pounds.

This new estimate of 2001 landings was half the level of the reported landings in 2000. From 2001 to 2002, landings (newly estimated) nearly doubled, reaching around 6 million pounds (Figure E31).

A NMFS port agent suggested that landings currently absent from the database were likely unreported to the National Marine Fisheries Service (Mason pers. comm. 2003). The database is currently being corrected for these errors. Because these data are incomplete, whether they are accurate enough to provide a basis for management is an issue. Landings data will only improve through the implementation of a permitting system requiring vessels and dealers in the hagfish fishery to report landings.

Revenues exhibited a similar trend to landings from 1993 to 2002 (Table E8, Figure E30). The ex-vessel price for hagfish remained relatively stable throughout the 1990s at 28 cents per pound, and recently increased to 36 cents per pound. Total revenues in 2000 were 1.9 million dollars.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
<b>ME</b>	182,510	64,537	0	904,075	922,259	1,929,874	2,907,644	1,199,474	0	0
<b>MA</b>	869,386	2,372,037	3,133,716	3,415,107	2,745,943	1,261,403	2,344,004	5,602,082	1,514,277	2,886,773
<b>NH</b>	0	0	0	0	8,196	0	0	0	0	0
<b>CT</b>	0	0	0	0	0	0	0	0	70	0
<b>RI</b>	0	0	0	0	0	0	0	0	0	3,280
<b>TOTAL</b>	<b>1,051,896</b>	<b>2,436,574</b>	<b>3,133,716</b>	<b>4,319,182</b>	<b>3,676,398</b>	<b>3,191,277</b>	<b>5,251,648</b>	<b>6,801,556</b>	<b>1,514,347</b>	<b>2,890,053</b>

**Table E7 - Total hagfish landings by state of landing, 1993-2002**

*Landings in pounds.*

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
<b>ME</b>	\$88,272	\$19,941	\$0	\$267,179	\$234,778	\$586,028	\$755,988	\$408,275	\$0	\$0
<b>MA</b>	\$252,186	\$716,769	\$906,384	\$955,942	\$758,578	\$328,650	\$667,811	\$1,449,016	\$384,198	\$982,201
<b>NH</b>	\$0	\$0	\$0	\$0	\$2,141	\$0	\$0	\$0	\$0	\$0
<b>CT</b>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10	\$0
<b>RI</b>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$479
<b>TOTAL</b>	<b>\$340,457</b>	<b>\$736,710</b>	<b>\$906,384</b>	<b>\$1,223,121</b>	<b>\$995,496</b>	<b>\$914,678</b>	<b>\$1,423,799</b>	<b>\$1,857,290</b>	<b>\$384,207</b>	<b>\$982,680</b>

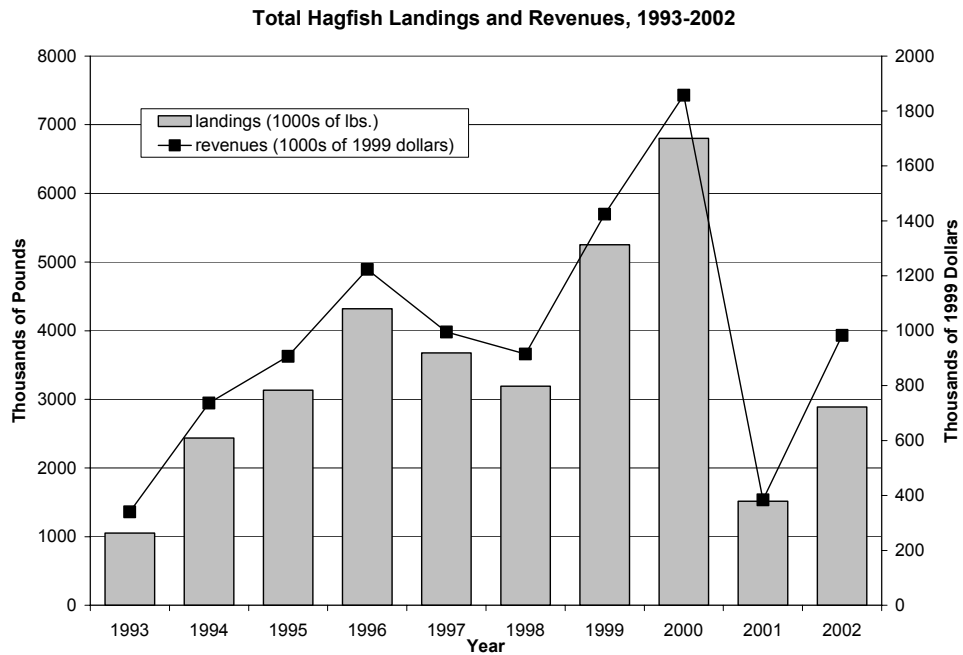
**Table E8 - Total hagfish ex-vessel revenues by state of landing, 1993-2002**

*Revenues expressed in 1999 dollars.*

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

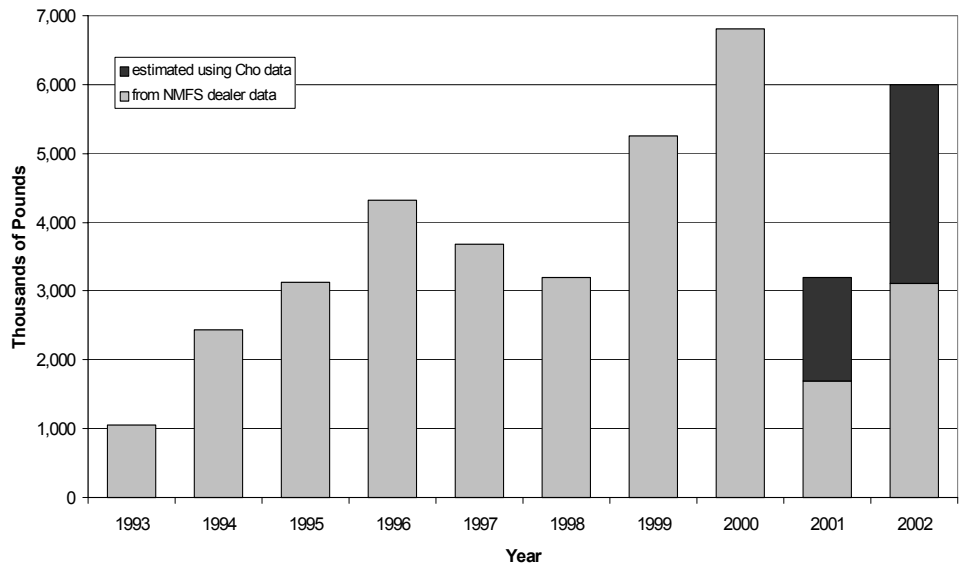




**Figure E30 - Total hagfish landings and revenues, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*



**Figure E31 - Total hagfish landings and revenues adjusted in 2001 and 2002 based on individual dealer records, 1993-2002**

*Data Sources: NMFS Dealer Database (WODETS/CFDETS); Yang Cho, personal communication*

#### **6.4.1 Reporting of Landings**

Dealers with federal fishery permits are required to report landings of all species to the National Marine Fisheries Service. In recent years, hagfish dealers have made efforts to report all landings to NMFS, although the database may be incomplete due to unreported or unrecorded landings. The total live or frozen weight of the catch landed by fishermen is discounted by 10% to account for the slime and water associated with the catch and is reported at this discounted rate in dealer and vessel trip reports (Boulay, Cho, Chu, Nippert pers. comm. 2003). This reported weight is also the paid weight, or the weight for which fishermen receive payment from the dealer. The weight of the catch that may be lost in this calculation is referred to as “shrinkage,” and the extent to which this practice may be misrepresenting the actual level of landings is unknown. The formula is an industry standard used by dealers both for vessels that freeze their catch at sea and those which land a live catch in RSW tanks or barrels. Simple tests comparing live weight and frozen weight of a sample of hagfish may illuminate potential disparities in the reporting of live hagfish and hagfish frozen at sea.

#### **6.4.2 Discards**

There are two major sources of discards in the hagfish fishery: at-sea culling of small slime eels and landed catch that is rejected by dealers due to quality concerns. The portion of the catch that is rejected at port is returned to sea by the fishermen who landed the catch or by a boat hired to dispose of the discarded hagfish.

The discard rate is unknown and is likely to vary widely among individual vessels. Producing a marketable catch in the hagfish fishery requires a great deal of skill and experience because of the challenges of maintaining freshness, locating large aggregations of hagfish and handling the live slime eels. Vessels with more experienced captains and crew tend to generate fewer discards than new entrants.

We have no current estimate of discards – total landings reported may be much lower than total removals from the hagfish stock. Estimating the volume of hagfish discarded at sea is difficult because sorting occurs continuously and at a rapid rate as traps are returned to the deck. The proportion of the catch that is rejected by the dealer and later discarded at sea is not measured. Most fishermen report only the landed catch accepted by the dealer on their vessel trip reports (VTRs).

#### **6.4.3 Number of Active Vessels in the Fishery**

It is difficult to establish a definitive count of vessels in the hagfish fishery because of the absence of permits and reporting requirements. However, the known number of active vessels (vessels reporting landings of at least one pound of hagfish in a given year) was derived from the NMFS Dealer Database and may be used to estimate total number of active vessels and observe trends in participation since 1993 (Table E9). The number of participants in the hagfish fishery has fluctuated since the early 1990s (Figure E32). In part, this is a result of the unique challenges to success in this fishery. Hagfishing (slime eeling) requires very specialized gear (see description in Section 6.2) and is technically difficult because of the nature of the fish. Many who enter the fishery in the hopes that it will provide a good alternative to other fisheries find the copious amounts of slime produced by the hagfish to be repulsive and difficult to handle. In addition, there is little movement in and out of other fisheries by those committed to slime eeling since it is difficult to convert vessels designed for trawling and dredging to boats capable of slime eeling and vice versa. The number of participants generally increased from 1993 to 1997, achieving a maximum of 31 vessels. This number dropped in 1998 to around 6 vessels and is currently about 16 boats.

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
ME	UNK	1	0	8	16	3	4	UNK	0	0
MA	7	14	7	11	13	3	10	6	4	13
NH	0	0	0	0	2	0	0	0	0	0
RI	0	0	0	0	0	0	0	0	0	3
CT	0	0	0	0	0	0	0	0	1	0
<b>TOTAL</b>	<b>7</b>	<b>15</b>	<b>7</b>	<b>19</b>	<b>31</b>	<b>6</b>	<b>14</b>	<b>6</b>	<b>5</b>	<b>16</b>

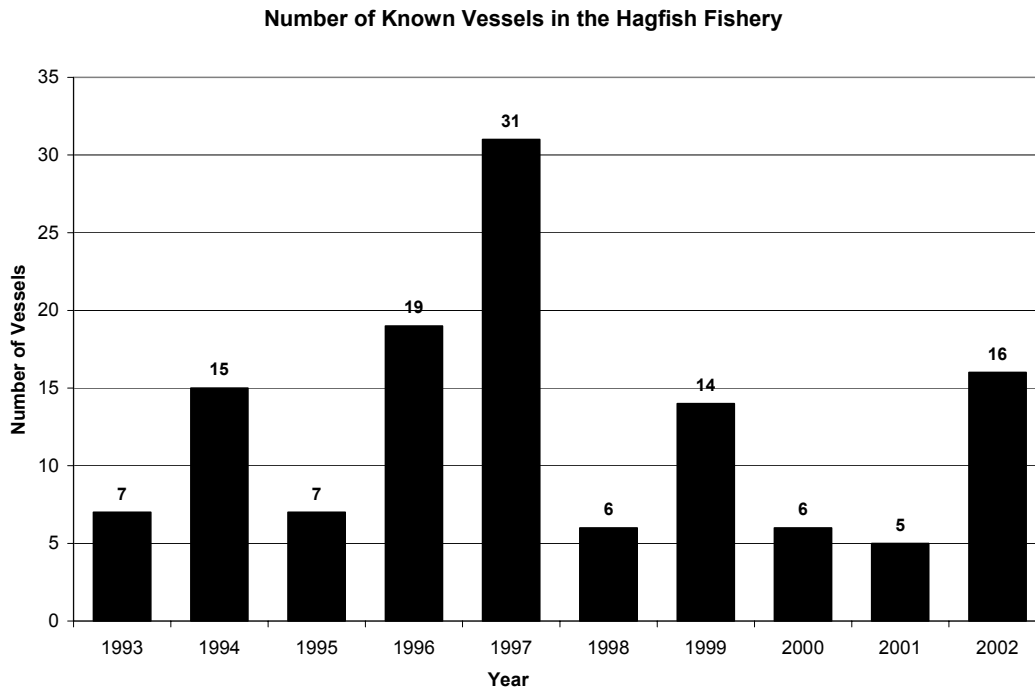
**Table E9 - Total number of known active hagfish vessels, 1993-2002**

*UNK = unknown greater than zero*

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

*Number of vessels is an approximation, probably lower than actual number. [see Data Caveats discussion]*



**Figure E32 – Active hagfish vessels reported by dealer records, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

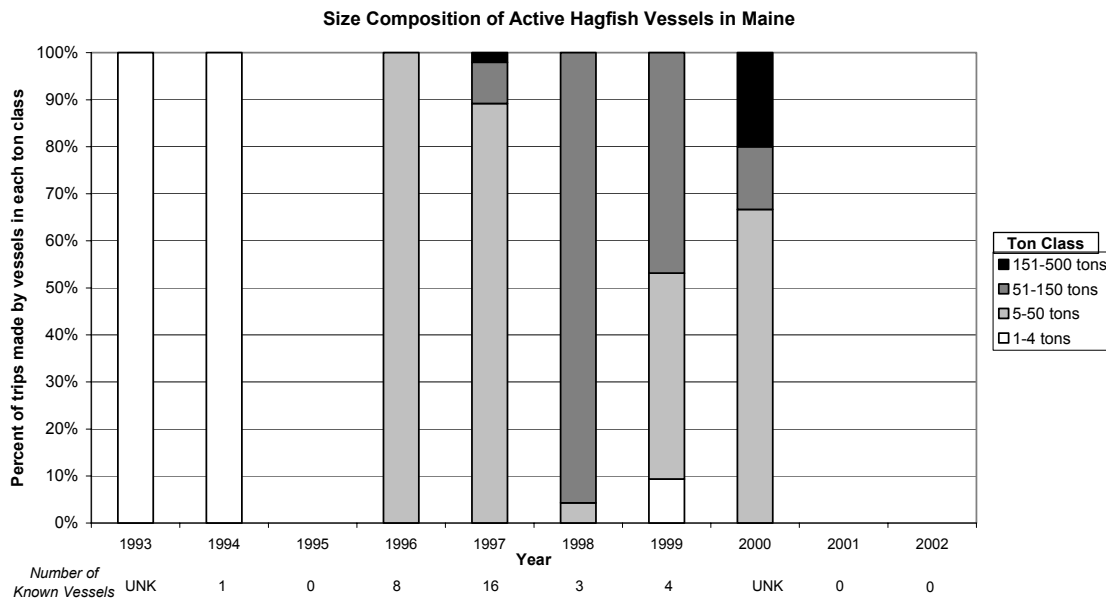
*Note: 2002 data may be incomplete*

#### 6.4.4 Size Composition of Active Vessels

For vessels for which tonnage was reported in the NMFS Dealer Database, the size composition of active vessels was examined. Tonnage is reported by ton class in the database. Four ton classes were represented by hagfish vessels:

- Ton Class 1 – 1-4 tons
- Ton Class 2 – 5-50 tons
- Ton Class 3 – 51-150 tons
- Ton Class 4 – 151-500 tons

Figure E33 and Figure E34 show the percentage of trips made by vessels in each ton class out of the total number of trips taken in each fishing year from 1993 to 2002. In general, the size of vessels has increased throughout this period. Vessels in the 1-4 ton range were absent from the fishery after 1994 in Massachusetts and Maine (with the exception of 1999). In Maine, the smallest vessels accounted for 100% of the trips in 1993 and 1994. In Massachusetts, trips by vessels 5-50 tons made up at least 50% of the total from 1993 to 1997. From 1997 to 2001, about 60-95% of trips by Massachusetts vessels were made by those in the 51-150 ton range. In 2002, 40% of the trips by Massachusetts vessels were made by large vessels in the 151-500 ton range. There is no direct correlation between vessel tonnage and vessel length. However, vessels in Ton Class 4 (largest) generally correspond to those with lengths in the 80-120 foot range, while those in Ton Class 2 (small-mid sized) generally range from 30-60 feet. As a point of reference, the majority of currently active permitted groundfish vessels are 30-50 feet in length. Because larger vessels tend to take fewer, longer trips, these data would more accurately represent distribution of effort by vessel size if the number of trips was weighted by the average length of a trip for each ton class before determining the percent composition of total trips. However, the following visual analyses provide a rough estimate of size composition of the fleet and demonstrate a general trend towards larger vessels, consistent with information recently provided by current industry participants.

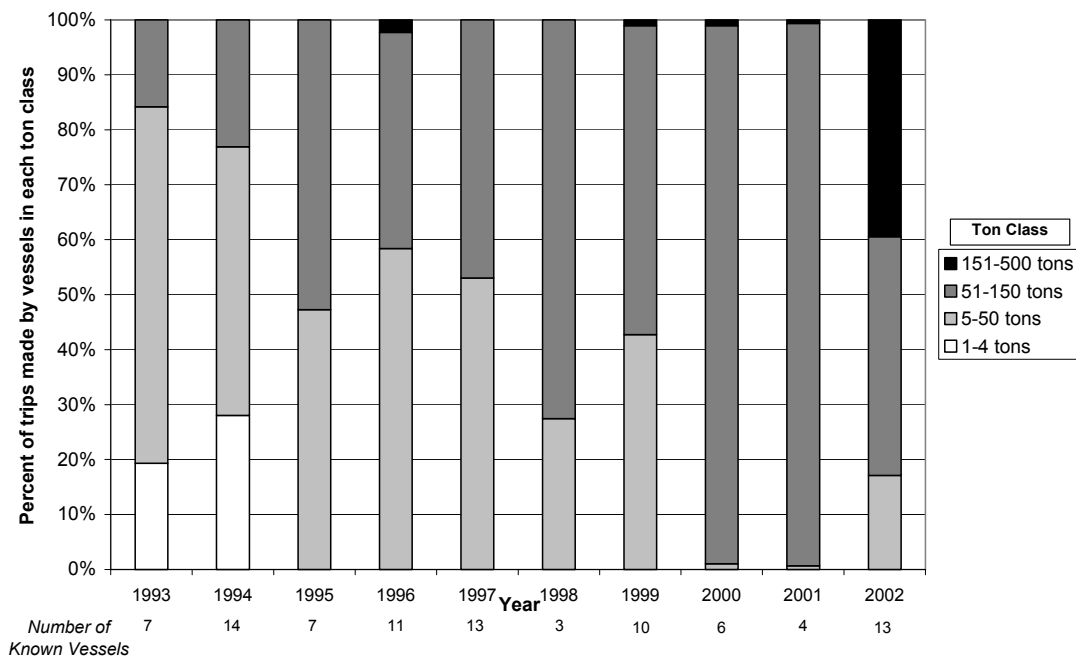


**Figure E33 - Size composition of active hagfish vessels in Maine, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

### Size Composition of Active Hagfish Vessels in Massachusetts



**Figure E34 - Size composition of active hagfish vessels in Massachusetts, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

Based on the Cho 2002 data, six of eleven active hagfish vessels fell into Ton Class 4, the large vessel category. Between one and two vessels were in Ton Class 2 and 2-3 in Ton Class 3. In just one year, hagfish vessels have extended their capabilities to allow for longer trip duration and more effective handling of the product at sea. Less than one year ago, a Gloucester hagfish fisherman noted that the larger vessels in the fishery ranged from 65-90 feet and made trips of 4-5 days in length (Boulay pers. comm. 2002). Now, in March 2003, he considers his 85 foot vessel (which takes 5-6 day trips) to be on the “small side” (Boulay pers. comm. 2003). Since the winter of 2002, at least four vessels between 145 and 165 feet entered the fishery. Two of these, each 165 feet, remain active participants while two 145-foot boats left hagfish to pursue other fisheries (P. Chu pers. comm. 2003). Currently, two new vessels around 160 feet are making preparations to begin slime eeling in April 2003 (Y. Cho pers. comm. 2003).

There are several categories of hagfish vessels which differ in their means of at-sea processing and storage of the product and, to some extent, size. Up until the winter of 2002, the two major types of hagfish vessels were:

- “barrel” vessels – 36-65 feet, carrying 10-20 traps per trip
- “tank” vessels – 65-90 feet, carrying 80 traps per trip; there are a limited number of these vessels over 150 feet

The larger, “tank” vessels have refrigerated sea water (RSW) systems on board which allow for increased freshness of the product. Some also have processing and sorting capabilities which may aid fishermen in discarding small juvenile hagfish at sea. The smaller “barrel” vessels do not hold RSW tanks and transport the hagfish back to port in barrels on deck (Boulay and Cho pers. comm. 2002).

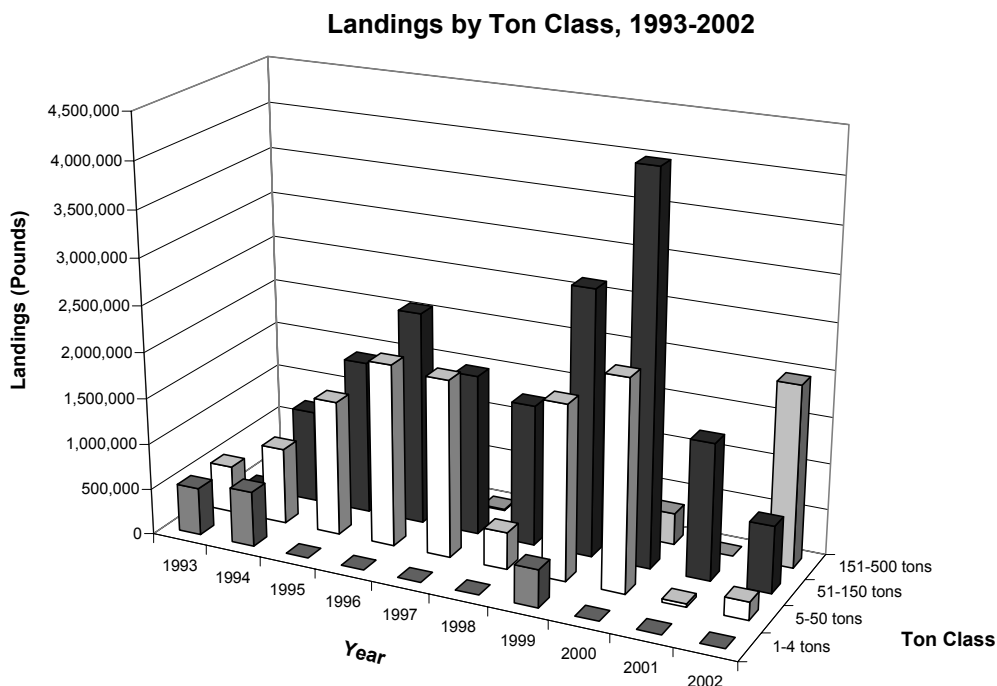
Traditionally, all vessels were “barrel” boats which transported hagfish back to port in barrels on deck (Cho pers. comm. 2002). Now, many larger vessels use alternative storage facilities on board in order to ensure greater freshness of the product. Freshness is a major concern in this fishery, particularly during

hot summer months when hagfish stored in barrels on deck can literally boil in their own slime, diminishing the quality of the skins and meat. The nature of the fishery has changed dramatically over the past few years. Even since last spring (2002) vessels' fishing capabilities have expanded and vessel size increased. Today, vessels under 80 feet are considered "small" and many more boats over 150 feet have entered into the fishery. "Tank" vessels now use a variety of means of processing and storing the fish on board. While most tank boats use RSW, some of the largest vessels have freezing capabilities on board. At least one utilizes a blast cooling system. To a large extent, sorting and discarding of small slime eels occurs at sea on tank boats equipped with sorting tables on deck. Limited deck space on barrel boats inhibits the crew's ability to sort at sea.

On average, small to mid-sized (less than 80 feet) vessels bring in about 3,000 – 20,000 pounds per trip for 1-4 day trips while larger vessels land 40,000 – 75,000 pounds per trip for 5-6 day trips (Cho landings data, 2003).

### 6.4.5 Landings by Vessel Ton Class

The highest total landings across the time series are attributed to fishing activity by vessels in Ton Classes 2 and 3 (5-50 tons and 51-150 tons, respectively) (Figure E35). Vessels in Ton Class 3 had slightly higher landings than those in Ton Class 2. Both vessel classes exhibited local maxima for landings in 1996 and 2000. Data for the years 2001 and 2002 should be regarded as incomplete, for the reasons previously discussed (Section 6.4). Assuming that the omissions in data for these latter years discriminate equally against all size classes, it is possible to examine relative landings for hagfish vessels, even if the absolute levels are unknown. In 2001, landings for Ton Class 3 vessels were substantially higher than those for other ton classes. In 2002, landings by Ton Class 4 vessels (151-500 tons) exceeded landings by smaller vessels.

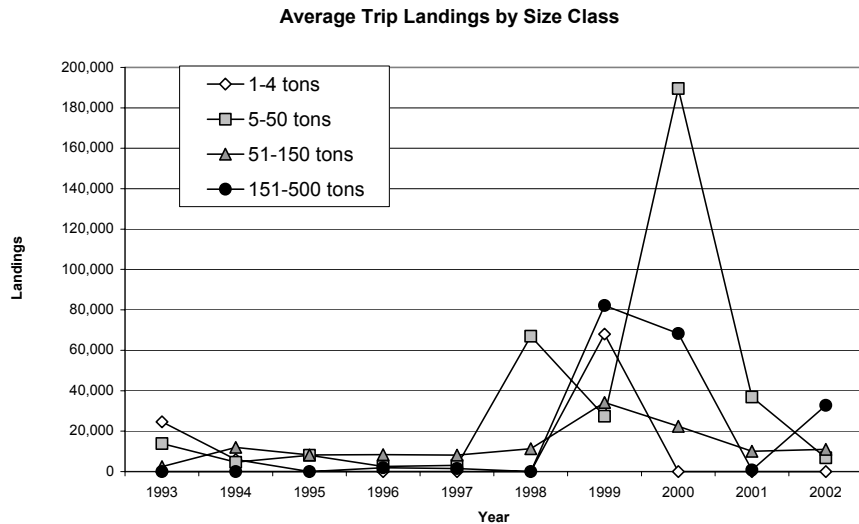


**Figure E35 – Total hagfish landings by ton class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

The average landings per trip were examined for the four ton classes (Figure E36). Trip duration is not accounted for in determining averages. The highest landings per trip for all size classes occurred between 1998 and 2001. In 2000, 5-50 ton boats exhibited the highest average landings per trip over the time period from 1993 to 2002. With this exception, trips on 151-500 ton boats consistently landed the highest average landings per trip in 1999 and 2000, the years of highest *reported* landings overall. Boats between 51-150 tons demonstrate the most consistency in landings per trip from year to year. Consistency in average trip landings may be related to increased operator skill.

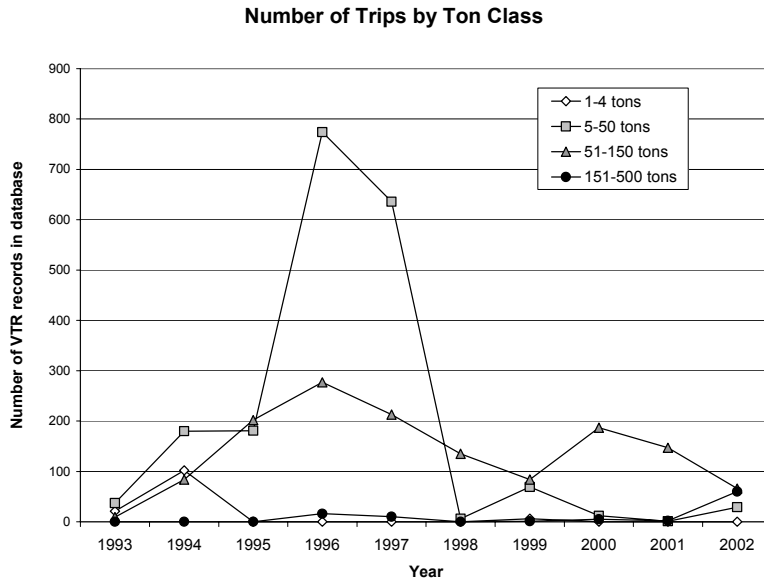


**Figure E36 – Average landings per trip by size class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

The highest number of trips occurred in 1996 and 1997, with the majority of these trips made by 5-50 ton vessels (774 trips in 1996 and 636 trips in 1997). 51-150 ton boat landings followed, exhibiting two local maxima, at 277 trips in 1996 and 187 trips in 2000. Figure E37 shows the number of VTR records in the NMFS Dealer Database from 1993 to 2002. Across all years in the time series there was a relatively low number of trips for the smallest (1-4 ton) and largest (151-500 ton) vessels. This is likely due to low numbers of vessels in the smallest ton class in all years and in the largest ton class during the early years of the time series. In later years when the number of very large vessels increased, a low number of trips for these vessels relative to the smaller size classes is likely due to longer trip duration.



**Figure E37 – Number of trips by ton class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

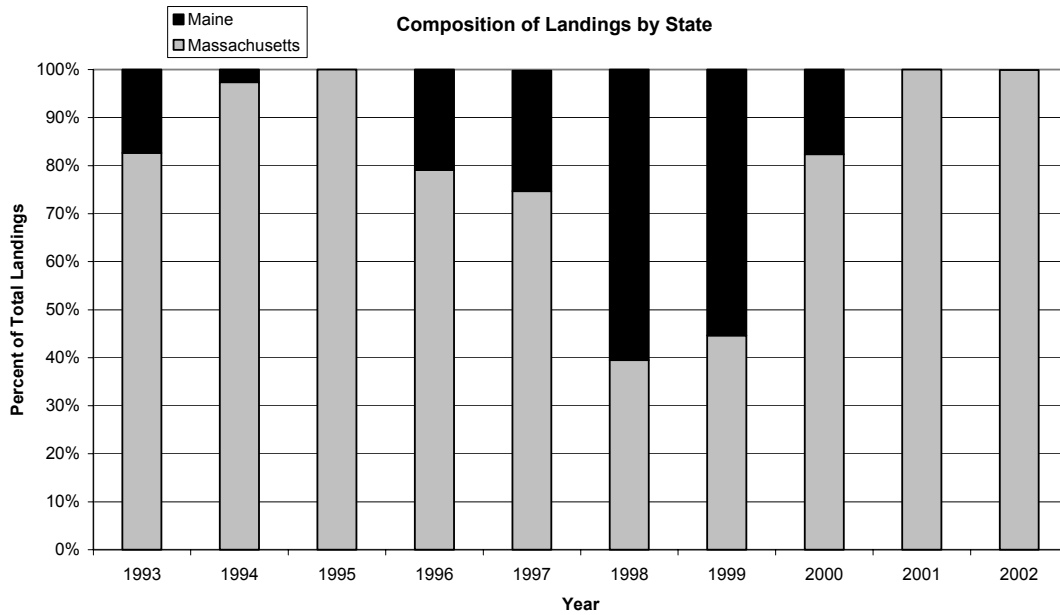
*Note: 2002 data may be incomplete*

#### 6.4.6 Ports and Shoreside Processing Facilities

From 1993 to 1997, between about 75% and 100% of the total hagfish landings in New England were brought in by vessels landing their catch in Massachusetts (Table E7 and Table E8). In 1998 and 1999, 40-45% of the total was landed in Massachusetts, while 55-60% of the total was landed in Maine (Figure E38 and Figure E39). Landings in Massachusetts increased in 2000 to 82% of total landings. In 2001 and 2002, 100% of the total hagfish landings were landed in Massachusetts. Less than 0.1% of the total hagfish landings in each year were reported in other states. Between 1993 and 2002, very low landings were reported in New Hampshire (8,196 pounds in 1997), Connecticut (70 pounds in 2001), and Rhode Island (3,280 pounds in 2002).

In 1995 the Maine/New Hampshire Sea Grant Press Office reported that the hagfish fishery is centered around the ports of Gloucester, MA, Portsmouth, NH and Stonington, ME which were “equipped with the freezing and packing facilities required to send the frozen product to Korea, where most of the skinning, tanning and meat processing is still being done” (ME/NH Sea Grant Press Office 1995). From 1993 to 2000, landings were reported in Gloucester (MA), Chatham (MA), Portsmouth (NH), Portland (ME), Camp Ellis (ME), South Bristol (ME), Cundys Harbor (ME), Stonington (ME), and Lincoln County (ME). The primary ports in which hagfish were landed during this period were Gloucester and Portland, with very low landings in other ports. In 2000, 92.7% of the total hagfish landings in New England were landed in Gloucester, MA, with 7.3% of the total in Portland, ME. Since 2000, however, a directed fishery for hagfish has ceased to exist in Maine. Currently, 100% of the catch is landed in Gloucester, Massachusetts. There are two major buyers in New England, all with processing facilities located in Gloucester.



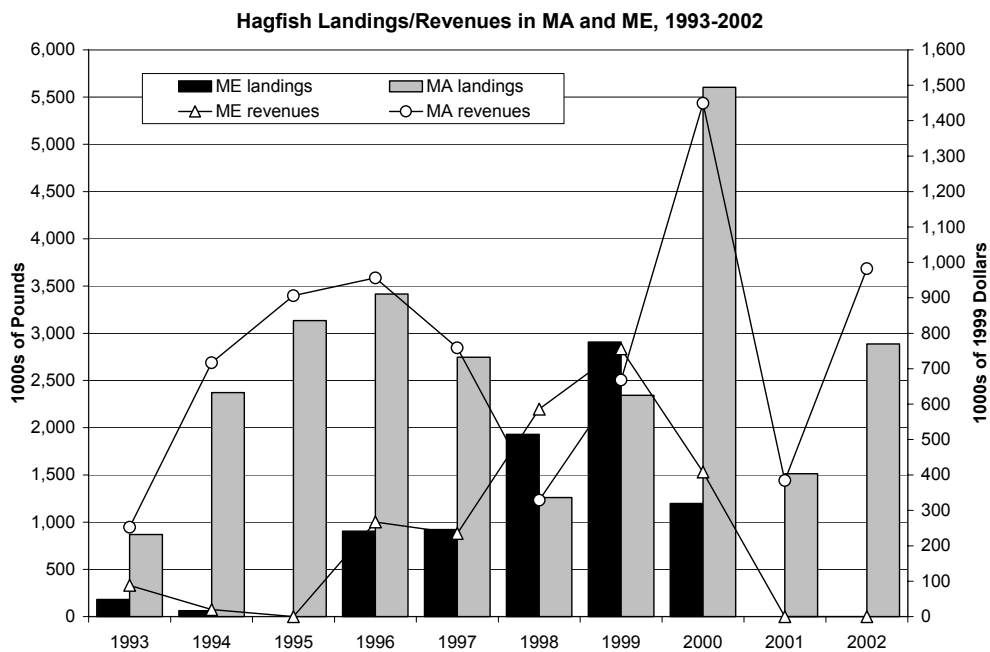


**Figure E38 - Composition of hagfish landings by state**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

*States with less than 0.1% of total landings are not included.*



**Figure E39 - Hagfish landings and revenues in Massachusetts and Maine, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

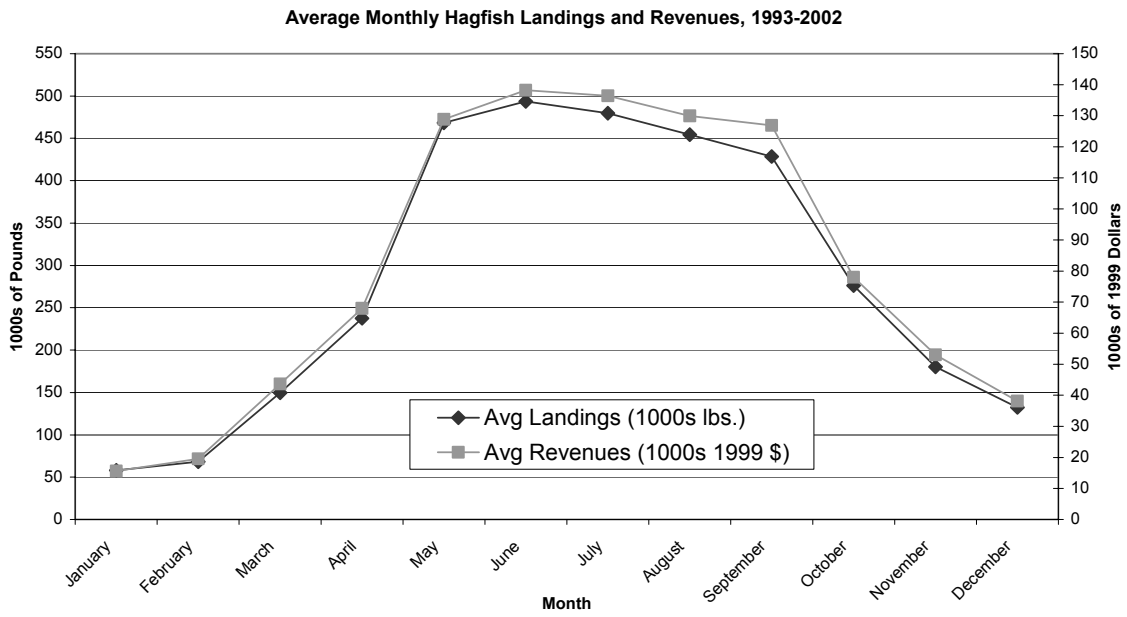
*Note: 2002 data may be incomplete*

#### 6.4.7 Spatial and Seasonal Fishing Effort

Vessels fish for hagfish within a 40-130 mile radius of Gloucester throughout the Gulf of Maine and out to the Hague line as weather permits. In 1993-1994, these vessels fished within a 63 mile radius of Gloucester (6-7 hours of steaming time plus 8 hours hauling). With a diminishing marketable catch (smaller slime eels), these vessels moved their operations to a 63 mile radius out of Portland (Nippert pers. comm. 2002). In 1996, these vessels targeted hagfish in the Western Gulf of Maine groundfish closed area, an area with open access for certain non-groundfish fisheries. At that time, 3-4 larger boats fished the eastern boundaries of the closed area and smaller inshore boats fished the western boundaries. In March, 2002, one of the smaller vessels was fishing about 10 hours off Cape Cod and another in Closed Area 1 (Nippert pers. comm. 2002). Fishermen have noted that hagfish have diminished in size since the early 1990s and that it has become increasingly difficult to find large abundances of the fish in the inshore Gulf of Maine (Boulay, Hill, Nippert, Palumbo, pers. comm. 2003).

Over time, trips have grown longer and vessels have moved further offshore in search of marketable catches. One fisherman gave a detailed report of how hagfish fishing grounds have shifted over the past few years (Boulay pers. comm. 2003). In 2000 and 2001, he made all of his trips to Wilkinson Basin, Franklin Swell, Franklin Basin and Mayo Swell (50-125 nautical miles off Gloucester). During 2001, a few trips were also made to Jordan Basin (150-200 nautical miles off Gloucester). By 2002, it had become necessary to fish almost exclusively in Jordan Basin, out to the Hague line. During the winter of 2003, a particularly difficult season due to harsh weather and sea conditions, he fished from Eastport, ME to Cape Cod, MA in search of large aggregations of hagfish and met with limited success. A few trips off New York and Virginia yielded a low number of hagfish but the individuals captured were very large (up to 4 feet).

Average landings of hagfish exhibit a seasonal trend, with the highest landings occurring from May to September (Table E10 and Figure E40). Fishermen have indicated that they land the greatest abundance and largest sized hagfish from late spring through November, when waters are warmer (Nippert pers. comm. 2002). Hagfish tend to “herd” or aggregate when water is warmer. Dense aggregations of active feeding hagfish are captured in summer months, resulting in “choker” barrels packed full of slime eels. When the waters cool in late fall and winter, hagfish seem to scatter and become dormant, becoming more difficult to capture (Boulay pers. comm. 3/17/03).



**Figure E40 - Average monthly hagfish landings and revenues, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

	January	February	March	April	May	June	July	August	September	October	November	December
Average Monthly Landings (Pounds)	58,080	68,131	149,659	237,473	468,223	493,544	479,565	454,434	428,497	276,323	180,420	132,317
Average Adjusted Monthly Revenues (1999 Dollars)	\$15,603	\$19,569	\$43,688	\$67,995	\$128,879	\$138,237	\$136,423	\$129,981	\$126,919	\$77,989	\$53,034	\$38,103

**Table E10 - Average monthly hagfish landings and revenues, 1993-2002**

*Landings in pounds. Revenues expressed in 1999 dollars.*

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*

*Note: 2002 data may be incomplete*

## **6.5 Vessel Trip Report (VTR) Data – Landings and effort trends**

### **6.5.1 Objectives**

From the working group meeting on March 28, two topics related to analysis of commercial landings data were assigned for further investigation.

- 1) Couple VTR data with dealer data to look at spatial distribution of hagfish trips and calculate LPUE if possible.
- 2) Couple VTR data with spatial component of surveys to look at localized depletion/relative abundances of hagfish from one area to the next over time, also incorporating bottom temperatures, if possible.

Feedback from commercial fisherman at the working group meeting indicated that, while hagfish landings from vessels without groundfish permits were not required to be reported through the VTR program, a substantial number of trips are reported either on a voluntary (the vessel has no other federal permits requiring logbook reporting) or mandatory basis (Nippert pers. comm., Boulay pers. comm. 2003). Furthermore, this feedback indicated that due to the nature of the hagfish fishery, the landed weight reported per VTR trip is likely to match closely if not exactly with the same trip's landings reported through the dealer database system. For this reason, it was not instructive to couple VTR and dealer data for analysis consistent with the first objective, described above.

Due to tight time constraints, survey data was also not coupled with VTR data in meeting the second objective. Bottom temperatures were not available from VTR data and therefore are not included as a variable for the purposes of this portion of the investigation.

These two caveats did not prevent a thorough analysis of available VTR data, however. Spatial distribution of the hagfish fishery, regional and temporal LPUE estimates, and the potential of localized depletion are investigated below. These data are often noisy, and the relatively short time series does not often reveal meaningful trends, but a few broad conclusions may be reached. Spatial analysis of VTR data indicates that, on average, vessels are moving farther off shore for their hagfish trips (+27 statute miles per trip from 1995 to 2002). Consequently, days absent reported via VTR are increasing, from 1.1 days absent in 1994 to 1.7 days absent in 2002 per average trip reported. The fishery is becoming more geographically diffuse; the number of ten minute squares attributed annually to VTR landings is increasing, while the average landed weight of hagfish from a ten minute square is decreasing.

In general terms, nominal LPUE estimates fluctuate in an almost cyclical pattern both seasonally and annually; no trends emerge. When standardized for vessel size (gross tonnage), LPUE estimates fluctuated, with a slightly declining trend.

### **6.5.2 Commercial Trip Data**

Logbook (vessel trip report, or VTR) data is used for this analysis. Hagfish logbook data are available from 1993 – November 2002 but due to changes in data structure between 1993 and 1994, 1994–2002 data are used here. Trips not landing hagfish were filtered. Logbook data were merged with vessel permitting data, yielding one dataset with variables describing vessel landings, trip locations and vessel characteristics. Table E11 contains the variable names that were used to form the hagfish trip dataset. Table E12 summarizes data from the hagfish VTR dataset.

1994-2002 VTR Dataset	
year	Calendar Year
tripid	Individual trip ID
ves_name	Vessel name
permit	Vessel permit number
gearqty	Number of traps
nemarea	Statistical area fished
lat_degree	Latitude - degrees
lat_minute	- minutes
lon_degree	Longitude - degrees
lon_minute	- minutes
nhaul	Number of hauls
depth	Water depth
tenmsq	Ten minute square ID
haglb	Lbs of hagfish landed
hagdisc	Lbs of hagfish discarded
month	Month landed
day	Day landed
da	Days absent
crew	Number of crew
port	Port landed
hport	Vessel home port
len	Vessel length
gtons	Vessel gross tonnage
vhp	Vessel horsepower

**Table E11 – Variable names for Hagfish VTR dataset.**

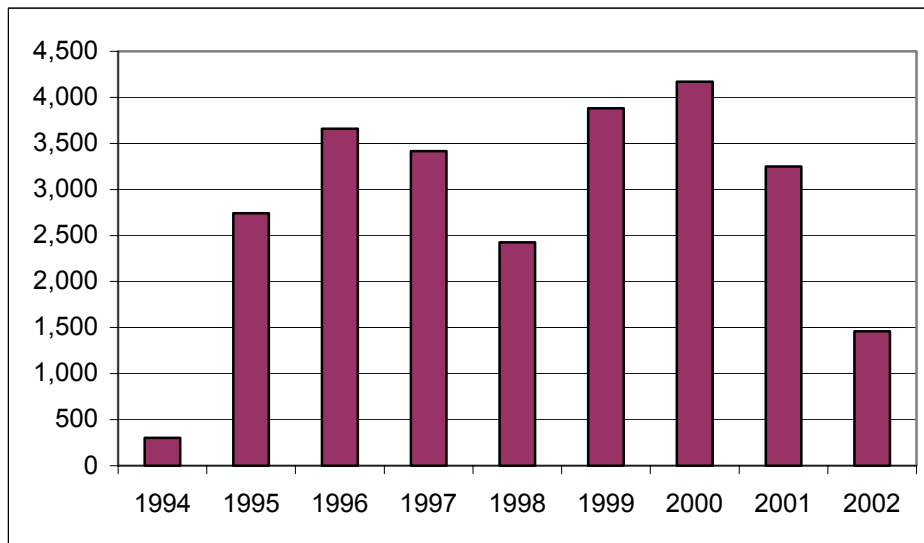
Variable	Sum	Mean	Std Dev	Minimum	Maximum
Pounds landed	25,302,836	5,456.73	5,163.71	85	122,295
Number of traps	363,185	78.32	49.35	0	500
Number of hauls		9.65	17.67	0	312
Days absent	5,603	1.21	0.88	1	20
Water depth		72.66	30.16	0	514
Number of crew		2.56	0.68	0	11
Vessel length		51.37	12.17	28	96
Vessel gross tonnage		39.63	28.36	4	258
Vessel horsepower		336.34	77.10	120	1,200

**Table E12 – Statistics for all trips landing hagfish (n=4,637).**

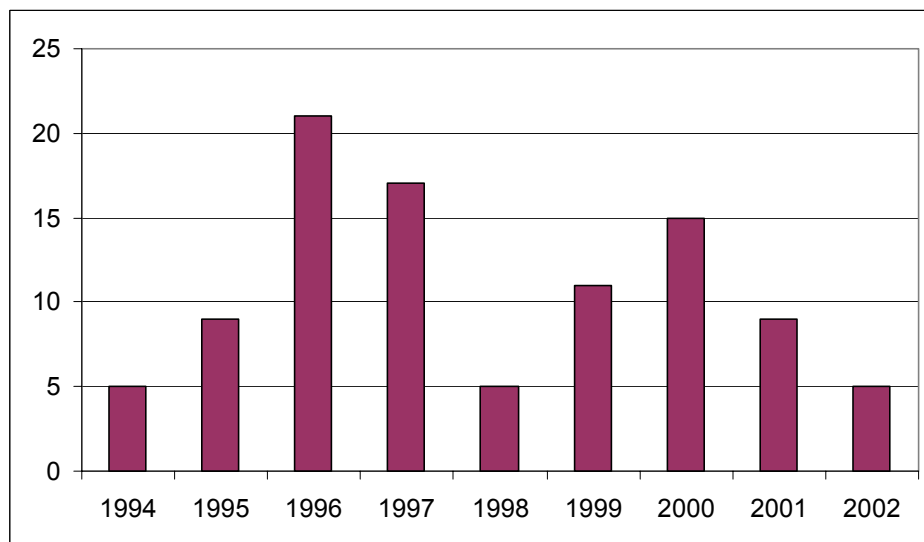
### 6.5.3 Landings and vessels

As evident in both the dealer and VTR data, the hagfish fishery expanded greatly between 1993 and 1996 as landings and the number of participating vessels both increased (Figure E30, Figure E32, Figure E41 and Figure E42). Vessels reported historically high landings during the period from 1999 to 2001 after a brief dip in VTR landings in 1998, while numbers of reporting vessels declined from 1999-2002. General trends in landings and number of active vessels from the VTR data were similar to trends seen in the

dealer data (Section 6.4). However, there were some discrepancies between the two data sets. Reported landings from the VTR data were lower than dealer-reported landings in all years except 2001, when VTR landings exceeded dealer landings by over 100%. It is expected that the total VTR-reported landings would be lower than dealer-reported landings, as only vessels with federal permits in other fisheries are required to report via VTR and many, if not most, hagfish vessels do not possess permits for other federal fisheries. Therefore, much of the VTR reporting is voluntary. The anomalously low dealer records in 2001 yield the need for further investigation into the reporting process for hagfish. Total numbers of active vessels also differed between dealer reports and VTRs. Numbers of vessels reporting via VTR would, in some years, be lower than dealer-reported vessels due to individual vessels opting to not report. In other years, though, the number of active vessels reporting by VTR may be higher due to the reporting of aggregate records by dealers, in which a single trip record is not associated with a particular vessel and may represent landings by several vessels. There is no discernable pattern in the differences between numbers of active vessels reported in dealer and VTR databases.



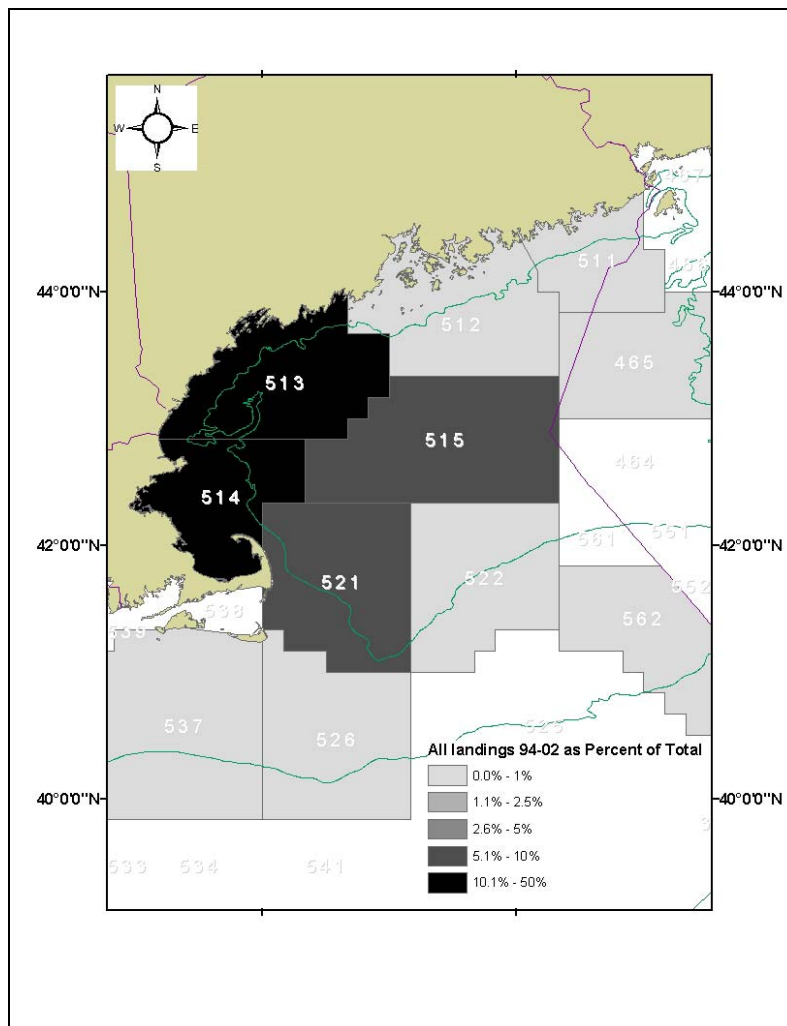
**Figure E41 – Hagfish landings (1,000 lbs.) by year reported via VTR.**



**Figure E42 – Number of vessels reporting via VTR, 94-02 (total # vessels = 48).**

#### 6.5.4 Spatial distribution of the hagfish fishery

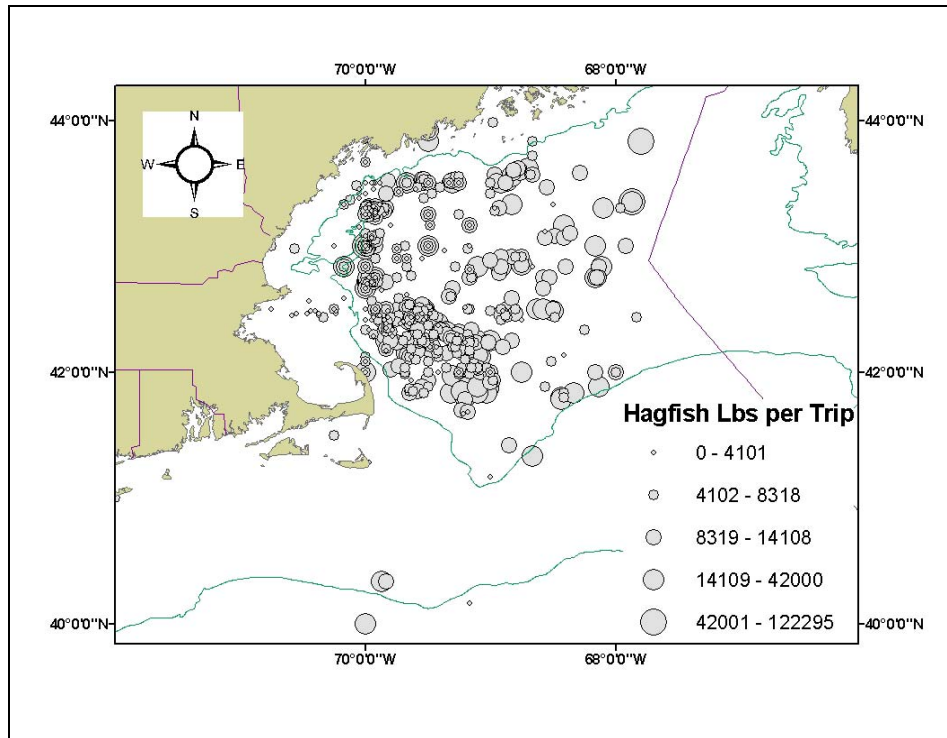
The hagfish fishery is generally prosecuted from Atlantis Canyon (70nm south of Nantucket) to the south, the eastern seaboard from Cape Cod to Downeast Maine to the west and north, and the Hague line to the east. Figure E43 shows that the majority of landings came from statistical areas 513 and 514, with 515 and 521 also contributing significantly.



**Figure E43 – Hagfish landings per statistical area, as a percent of total (1994-2002 VTR data, n=4,637).**

The vast majority of trips occur in the deeper water (greater than 40 fathoms) in the Gulf of Maine, within a 60nm radius of Gloucester, MA. Figure E44 provides some detail for the spatial distribution of landings and their magnitude. Figure E45 shows the differences in landings in greater detail, revealing that the majority landings from hagfish trips reporting their positions (latitude and longitude) were prosecuted in the Wilkinson Basin area. Two large trips in the Jordan Basin (northeast corner of the fisheries' range) are the exception to this rule.





**Figure E44 – Point estimates for hagfish landings based on reported trip lat/lon (1994-2002 VTR data, n=1,571).**

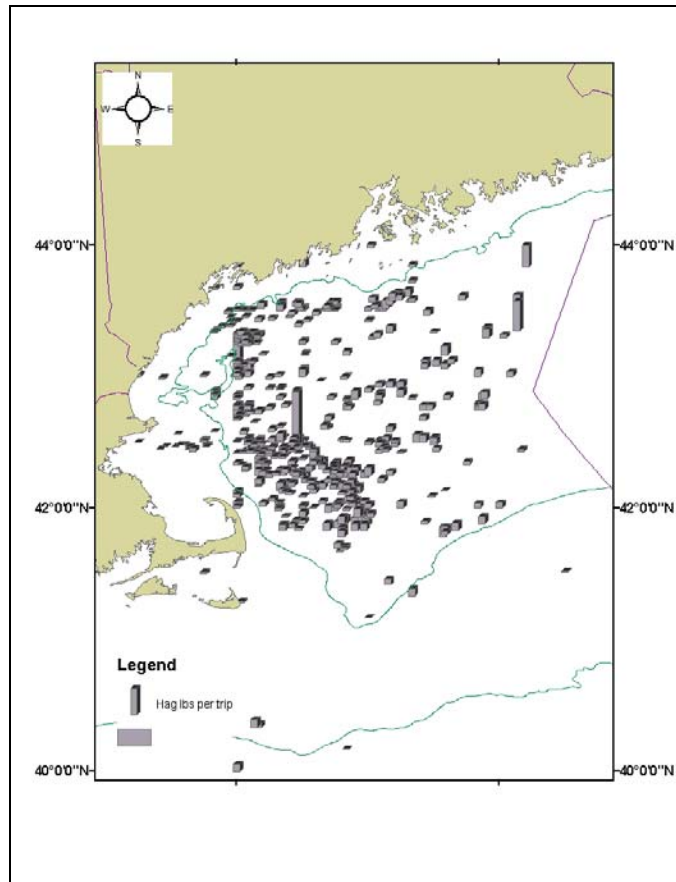


Figure E45 – Bar chart of point estimate hagfish landings (1994-2002 VTR data, n=1,571).

NEMAREA	Sum	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	n
	haglb	haglb	GEARQTY	NHAUL	da	DEPTH	CREW	LEN	GTONS	VHP	
0	13,110	3,278	21.3	2.0	1.3	5.0	2.5	44.5	18.5	275.8	4
513	12,556,379	6,195	91.6	7.8	1.1	74.8	2.8	56.1	48.6	345.6	2,027
514	7,629,682	3,885	62.8	11.3	1.1	62.9	2.3	43.9	23.8	319.2	1,964
515	2,419,937	8,897	100.2	8.5	1.7	94.0	2.6	59.2	57.3	365.2	272
521	2,446,929	7,529	75.5	11.4	1.7	102.0	3.0	59.2	58.1	335.1	325
522	42,538	3,545	45.2	22.8	5.7	98.0	4.1	72.5	124.3	543.3	12
526	980	245	40.0	34.5	6.8	106.5	4.5	58.5	70.0	397.5	4
612	844	211	1.0	3.0	1.0	26.3	2.0	60.0	77.0	365.0	4
All other areas	192,437	8,337	72.6	10.4	2.5	71.5	3.6	58.4	75.3	485.3	25

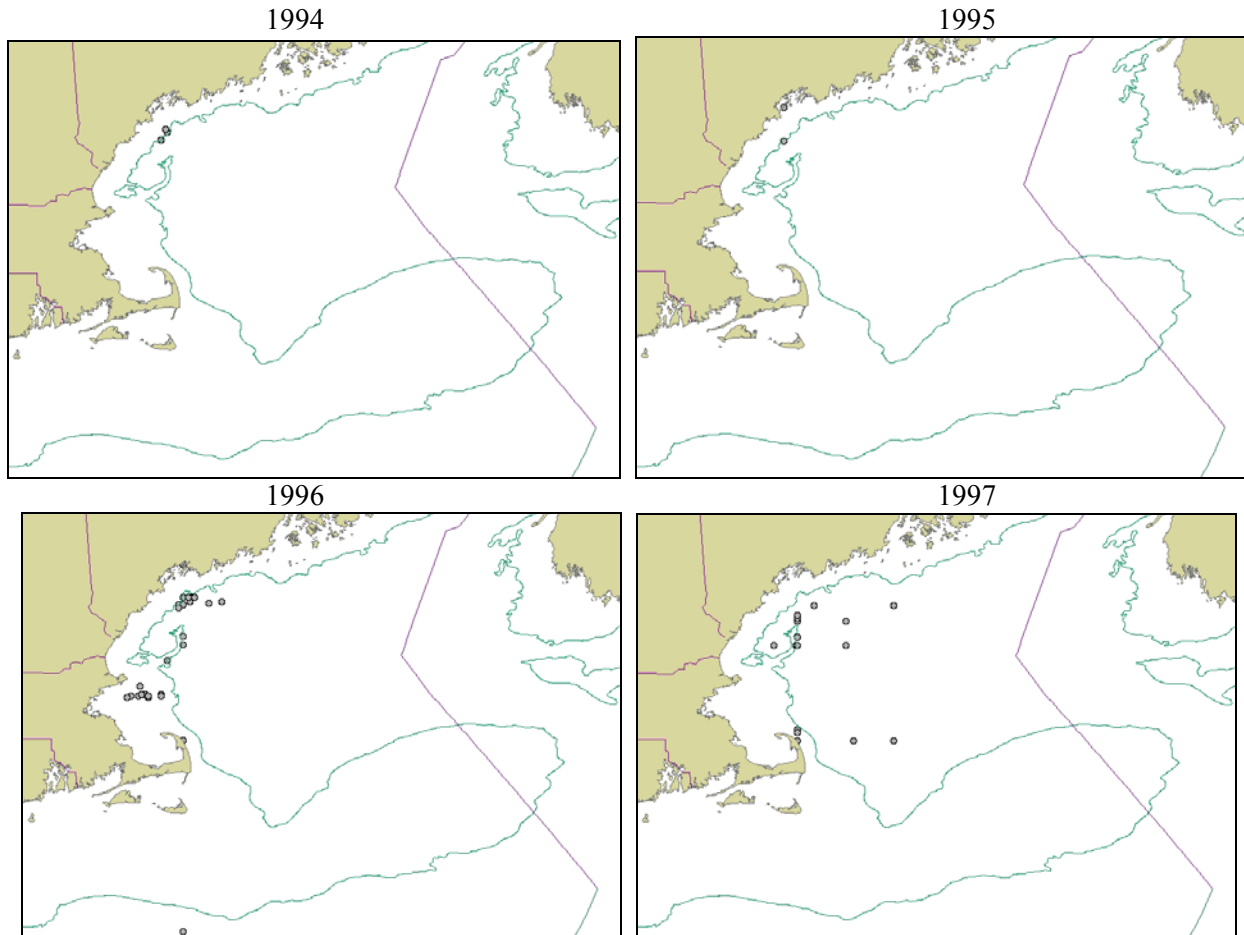
Table E13 – Statistics for all trips landing hagfish, by statistical area (1994-2002 VTR data, n=4637).

Clearly the bulk of landings stem from areas 513, 514, 515 and 521. These areas tend to see shorter trips by, on average, smaller vessels. Larger vessels making longer trips have landed hagfish (eg. in Areas 522 and 526) but this mode of fishing has not, to this point, become overly popular.

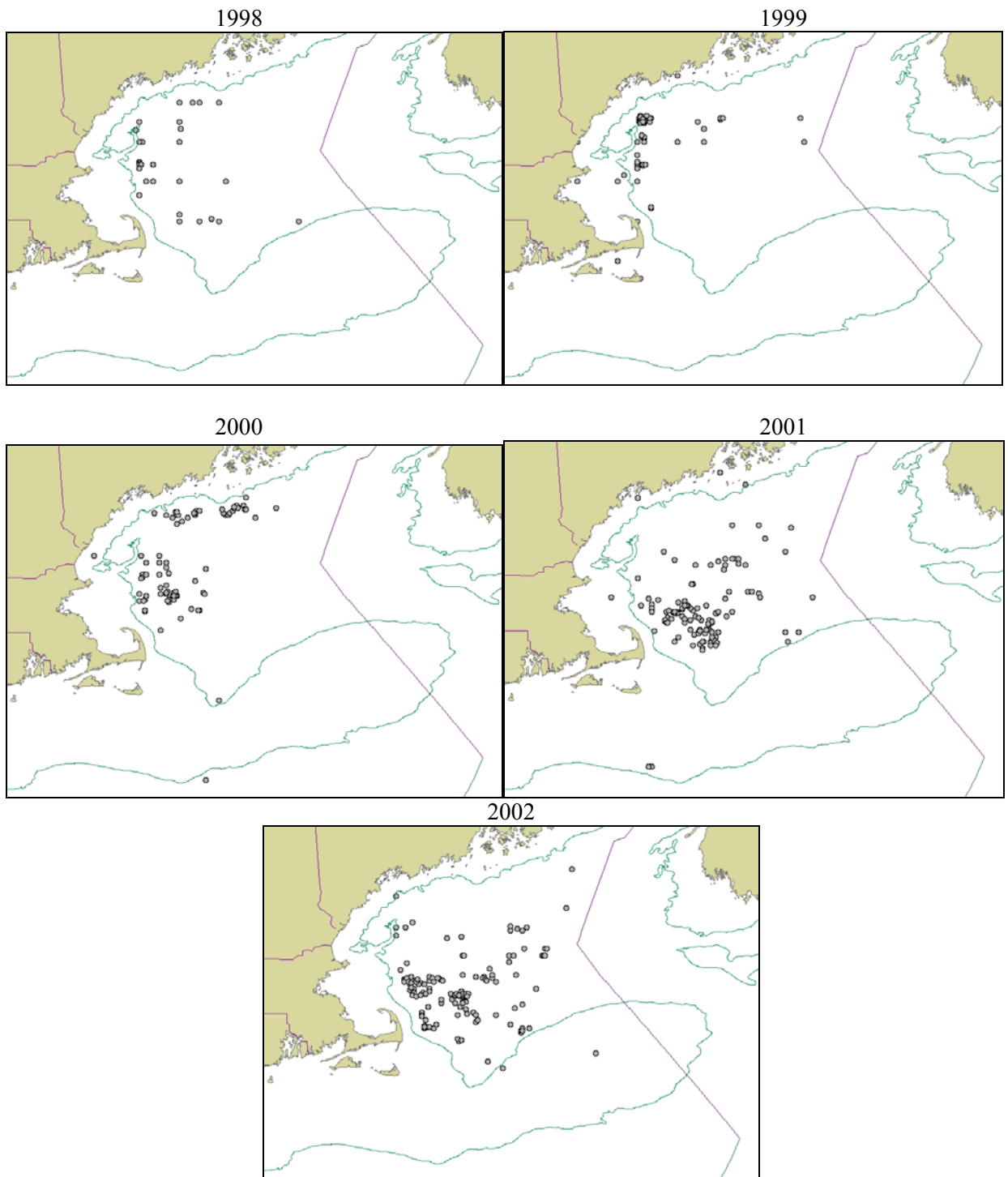
## 6.5.5 Spatial and temporal trends within the hagfish fishery

### 6.5.5.1 Spatial distribution

Map E1 shows the reported position of trips on an annual basis. These figures show that vessels reporting trips have tended to move further and further offshore. These trips have also trended southward, with a cluster of trips in the coastal Maine area occurring in 1998-2000, while the bulk of the fishing trips shifted southward off of Cape Cod along the southern reaches of Wilkenson Basin in 2001-2002. This brings to light the possibility that vessels are moving farther from their traditional fishing grounds in search of better fishing. The concept of localized depletion will be investigated in a subsequent section of this document.



**Map E1 - All trips reporting via VTR, 1994 - 2002.**



**Map E1 - All trips reporting via VTR, 1994 – 2002.**

(continued)

### 6.5.5.1.1 Spatial distribution measures

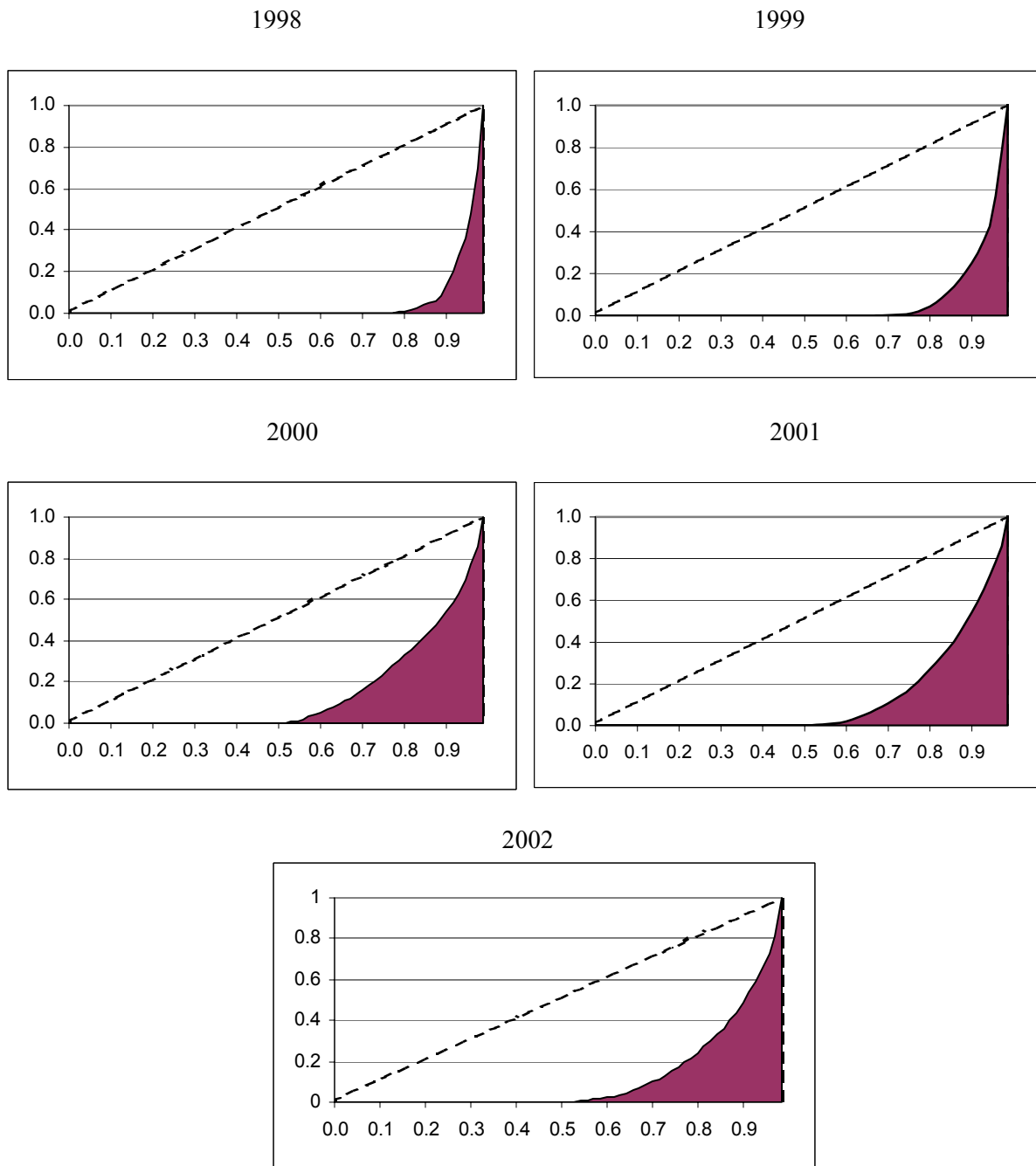
In addition to the eastward and southward expansion of the hagfish fishery's range, it is also becoming more geographically diffuse. A Lorenz curve, plotting cumulative landings ( $X$ ) versus cumulative area ( $Y$ ), is applied to the VTR data for trips where the "ten minute square" variable is available ( $n=2,646$ ). Area is defined by the number of ten minute squares found within the demonstrated range of the fishery; landings are summed for each ten minute square and a cumulative distribution is computed. If the density of landings was the same across all ten minute squares, i.e. both effort and abundance were uniformly distributed, the Lorenz curve would be a straight line from the origin to (1, 1). Figure E46 shows the Lorenz curves for the hagfish fishery from 1994 through 2002.

The Gini coefficient is a measure typically used to quantify dispersion of wealth. Here it is used to demonstrate the spatial diffusion of the hagfish fishery. It is essentially the sum of the differences between the Lorenz curve and the identity function (equal distribution of landings). Figure E47 shows that reported hagfish fishery landings are becoming more spatially diffuse over time.

Another measure of spatial distribution is mean geographical distance. A simple algorithm (SAS macro) is used to compute the distance from landed port for each trip reporting a position (latitude and longitude). Figure E48 shows that the mean distance from landed port for reporting trips is increasing.

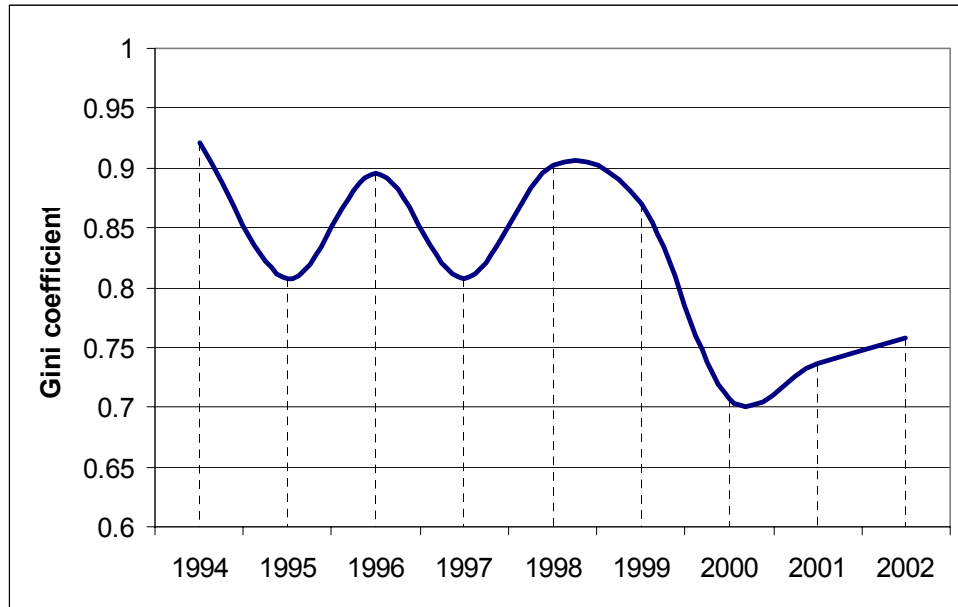


**Figure E46 - Lorenz curves for reported hagfish landings (94-02 VTR, number of trips = 1,571).** Cumulative % landings is on the X axis and cumulative % area is on the Y axis. Greater curvature indicates a greater spatial concentration of landings. The dashed line represents what would be expected if landings were equally distributed across the range of the fishery.

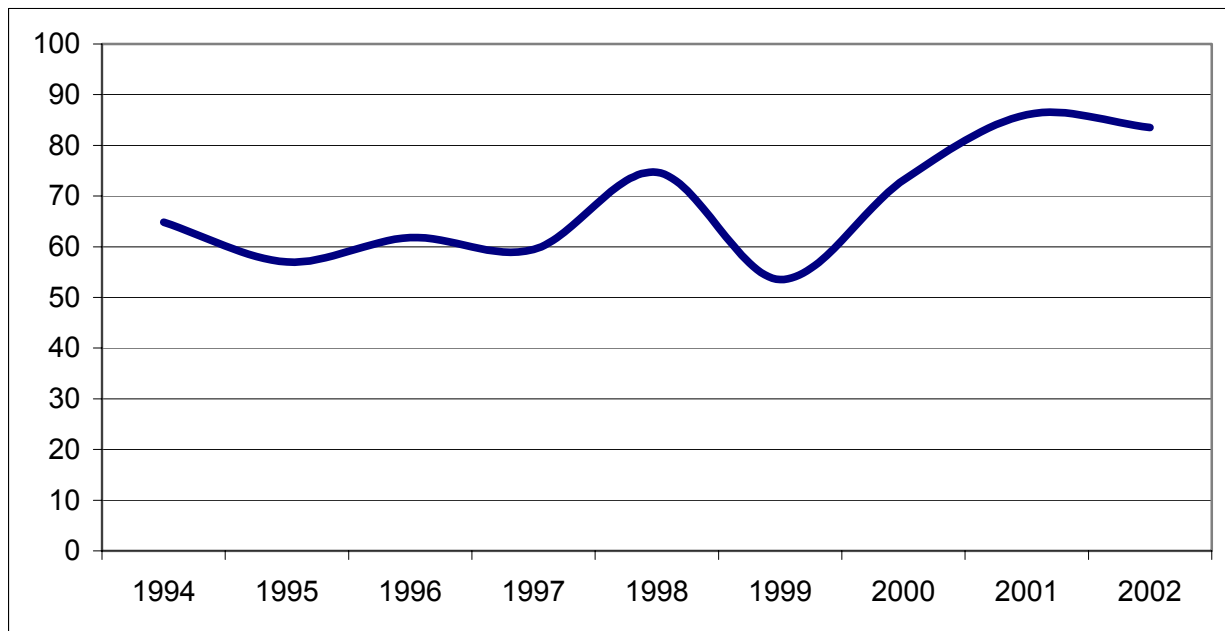


**Figure E46 – Lorenz curves for reported hagfish landings (94-02 VTR, number of trips = 1,571).**

*Cumulative % landings is on the X axis and cumulative % area is on the Y axis. Greater curvature indicates a greater spatial concentration of landings. The dashed line represents what would be expected if landings were equally distributed across the range of the fishery.*



**Figure E47 – Gini coefficients for the hagfish fishery (all VTR trips reporting lat/lon, n = 1,571).**  
*A coefficient of zero would represent equal distribution of landings across the range of the fishery.*



**Figure E48 – Mean distance (statute miles) from landed port per trip, VTR 94-02 (n=1,571).**

### 6.5.5.2 Changes in fishing practices

In addition to the geographic changes noted above, changes in fishing practices over time have been observed. As the mean distance from landed port has increased with time, so too has the mean number of days absent and the number of traps used per trip (Figure E49).

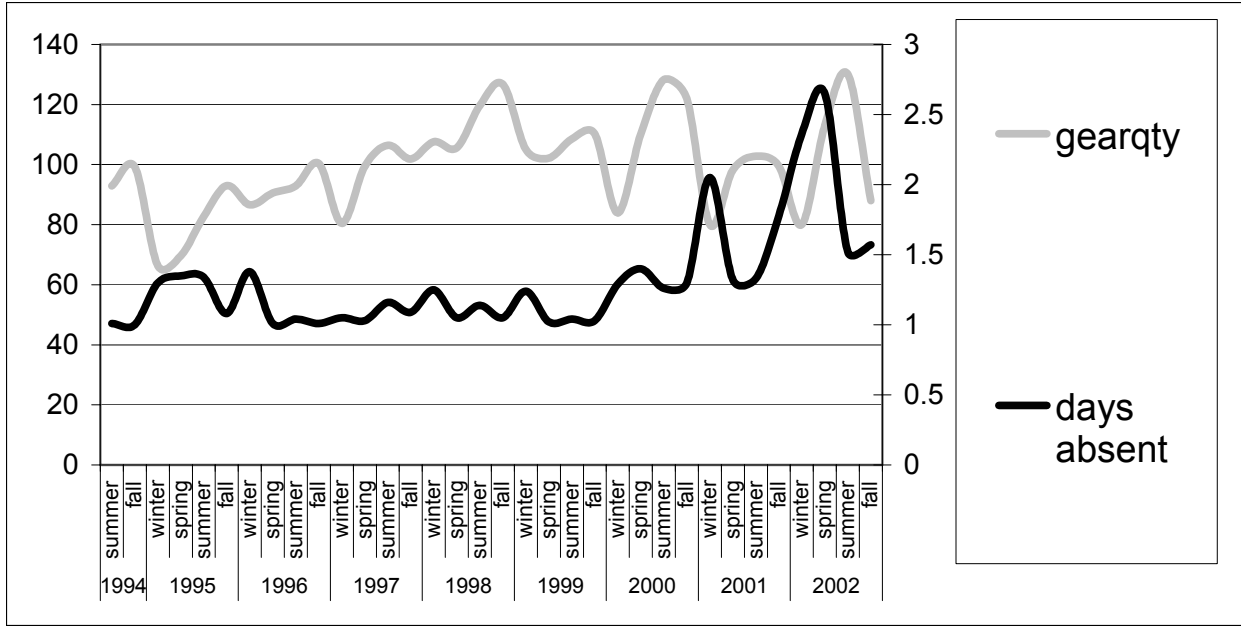


Figure E49 – Mean number of traps employed and days absent per trip (n=3,410).

6.5.5.3 Seasonal trends

Landings tend to be significantly higher in the spring and fall months, peaking in summer (Figure E50). This trend is very similar to that which emerged from monthly dealer landings data (Figure E40). Reported trips tended to occur in the northern areas of the fisheries’ range in the summer and fall months, and in the southern areas in the winter and spring.

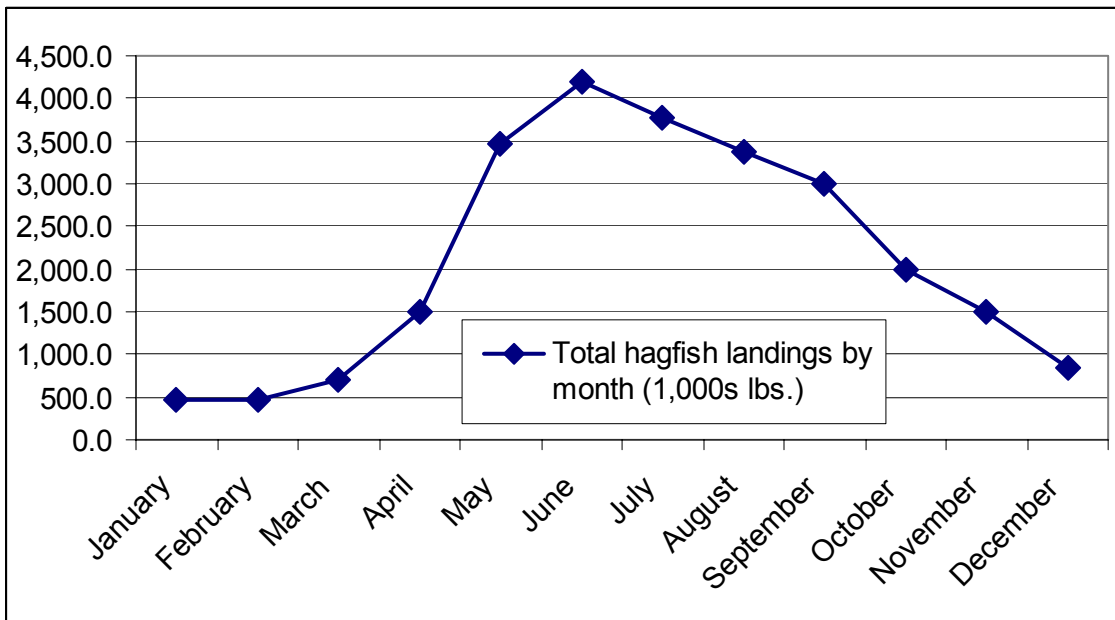
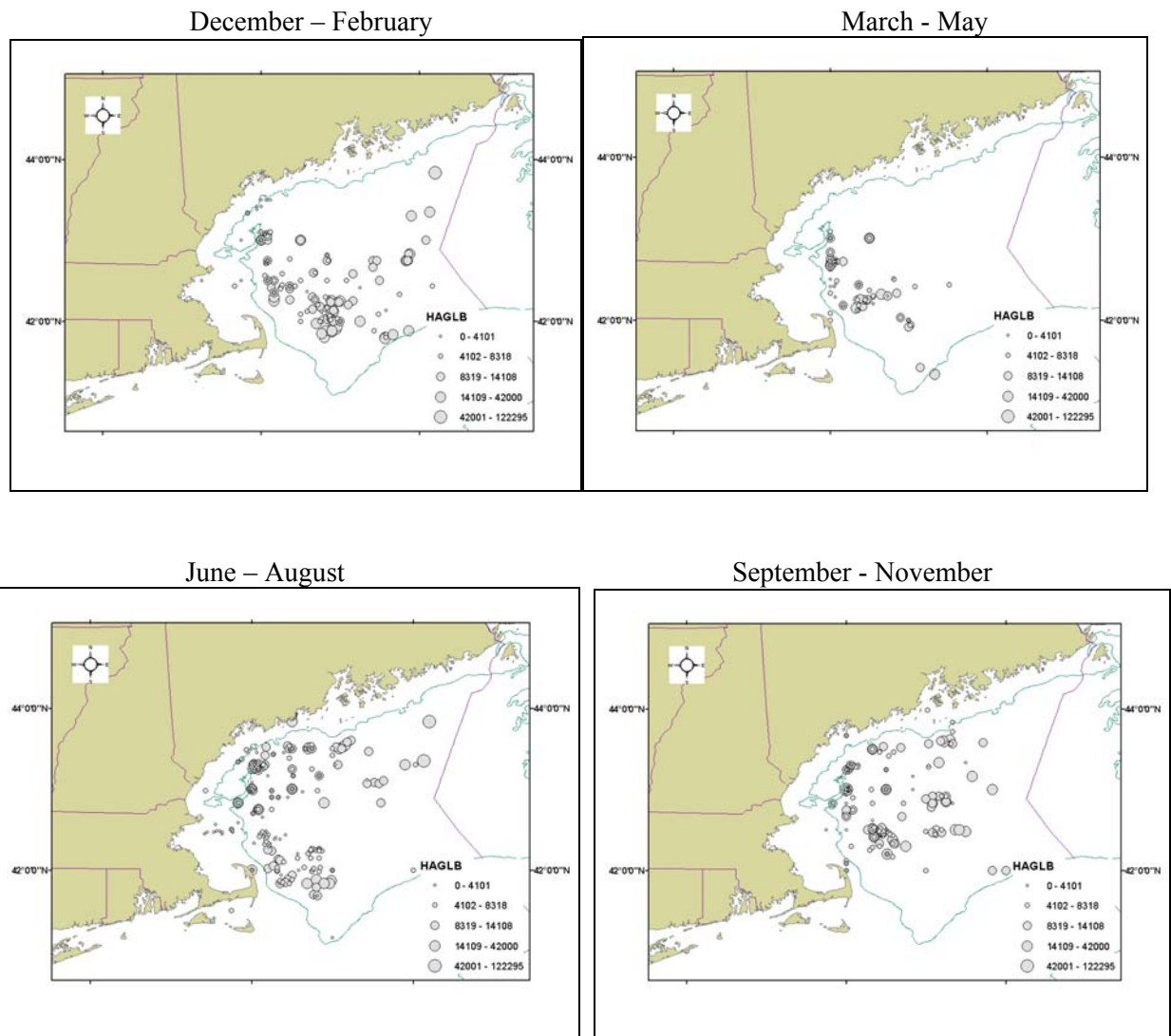


Figure E50 – Season total landings as reported via VTR.





**Map E2 – Seasonal distribution of trips reported via VTR, 1994-2002 (n=1,571).**

### 6.5.6 Landings per unit Effort

Fishing effort refers to the ability of fishing vessels to translate inputs (vessel, gear and crew) into outputs (pounds of fish, dollars). In trap fisheries, number of traps or number of trap-hauls often function as a proxy for effort inputs (Briand 2001, DFO 2002, Benson 2001, DFO 2002). As trap fisheries tend to focus on a small array of species, pounds of fish is the most common output. These conventions are used here.

In these analyses, landings per unit of effort (LPUE) were examined. Because the weight of the catch reported by VTR is, in nearly all cases, identical to the landed (paid) weight reported by the dealer, it is not possible to accurately estimate catch per unit of effort (CPUE). Measures of LPUE underestimate true effort because they do not include discards and other possible reductions in true landed weight (e.g. “shrinkage”).

To further focus the data, exclusion rules were employed as follows:

- days absent less than 1 were assigned a value of 1, with subsequent days absent employing partial days
- trips reporting more than 30 days absent were deleted
- trips reporting more than 60 hauls were deleted
- trips landing less than 75 lbs of hagfish were deleted
- trips reporting less than 15 traps were deleted

This reduced the size of the dataset from 4,637 trips to 3,410 trips. Days absent refer to days absent from port.

#### **6.5.6.1 Nominal LPUE**

Nominal landings per unit effort is measured here as pounds of hagfish per trap per reported day absent. Number of hauls was investigated as an input variable but found to be less reliable due to inconsistencies in the way data were recorded—some captains listed 1 haul per day, while others listed as many as 100 hauls per day. Due to this inconsistency, number of hauls was not used in estimating LPUE.

Figure E51, below, shows nominal LPUE for the hagfish fishery. The days absent variable is also listed as an indicator of total fishing effort. As LPUE has declined, total days absent have declined as well. An obvious seasonal trend emerged as well, and Figure E52 shows nominal LPUE per season.

LPUE tended to hold steady throughout much of the late 1990s, but began to decline after the spring of 2001. All season-specific LPUE estimates have trended down since 2001, and all are currently between 30 and 50 percent of their historic highs (Figure E52).

At smaller spatial scales, nominal LPUE varied cyclically with a generally declining trend across years in all areas except 514. Effort, measured in days absent, has recently increased in Area 514, with historically high LPUEs for much of 2000 and 2001 (Figure E54).

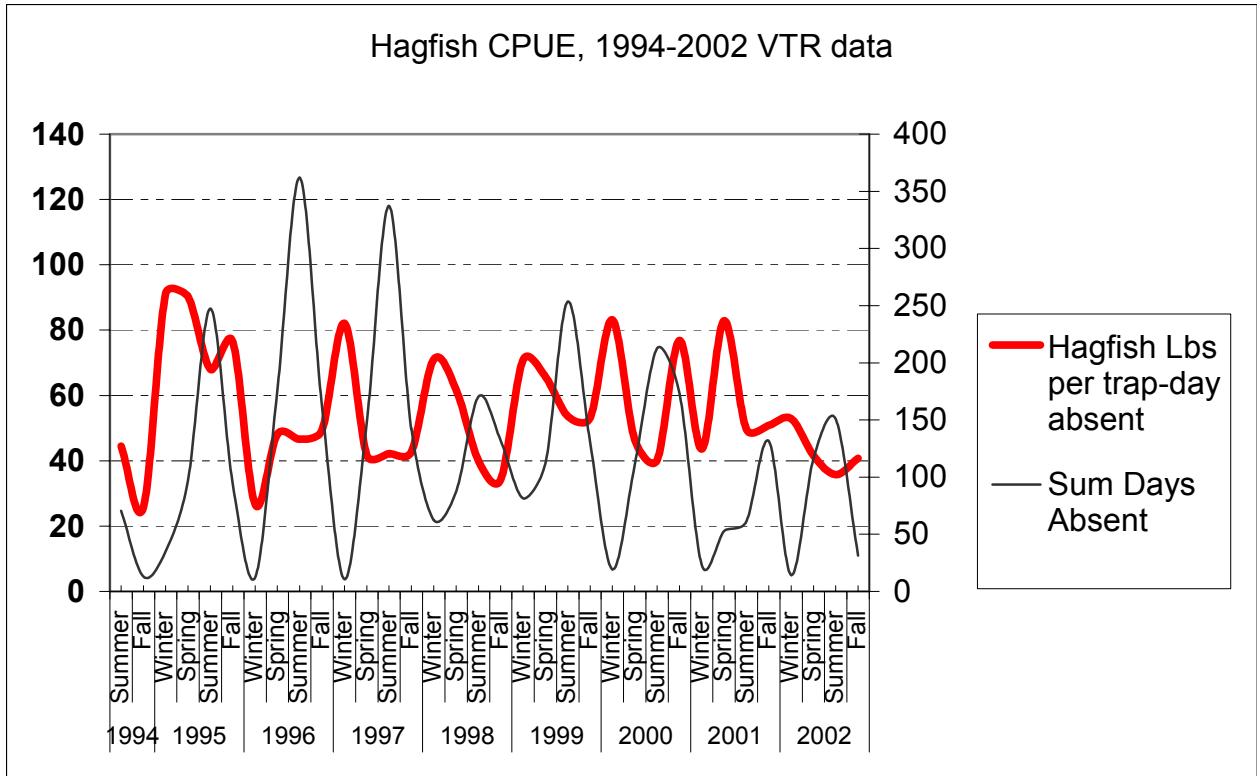


Figure E51 – Nominal LPUE for trips reported via VTR, 94-02 (n=3,410).

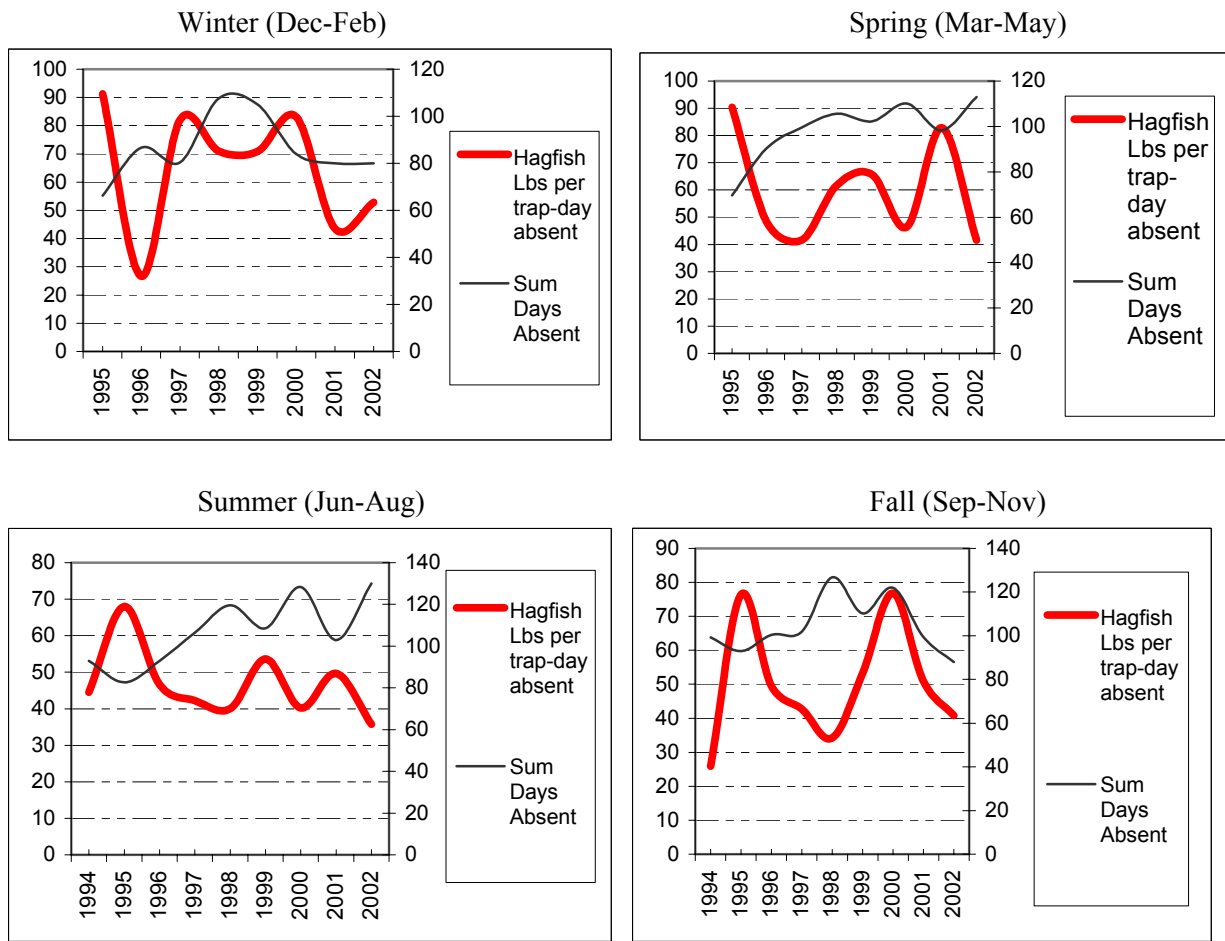


Figure E52 – Seasonal trends in nominal LPUE (VTR data, n = 3,410).

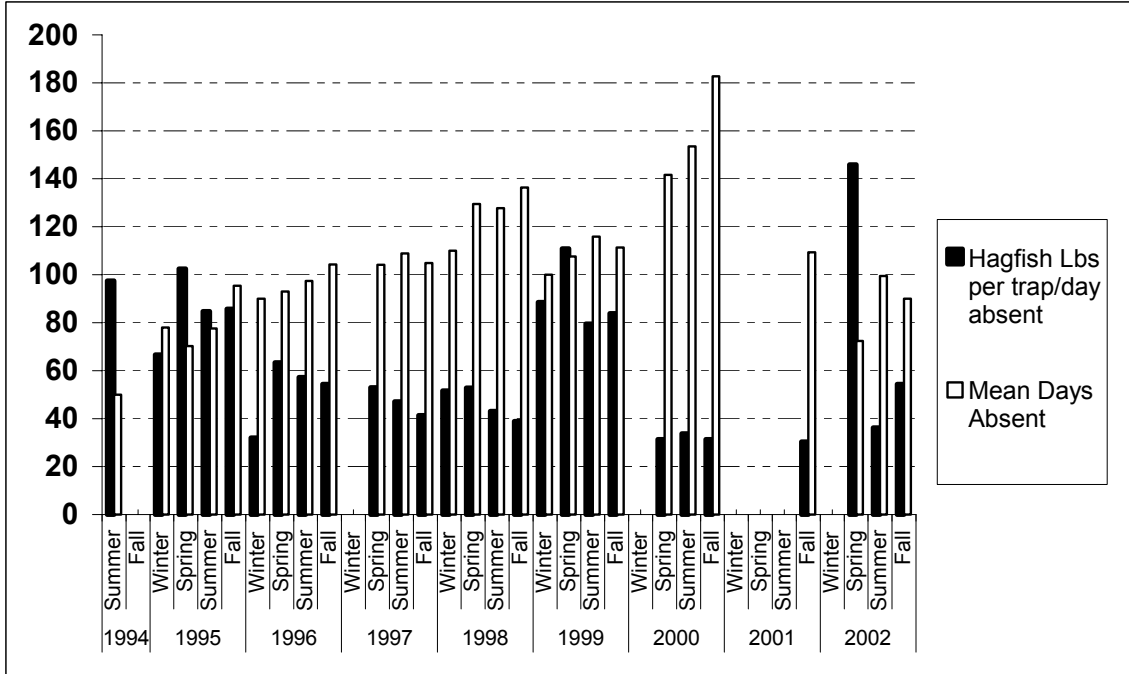


Figure E53 - Nominal LPUE for Area 513 (1994-2002 VTR data, n=1,687).

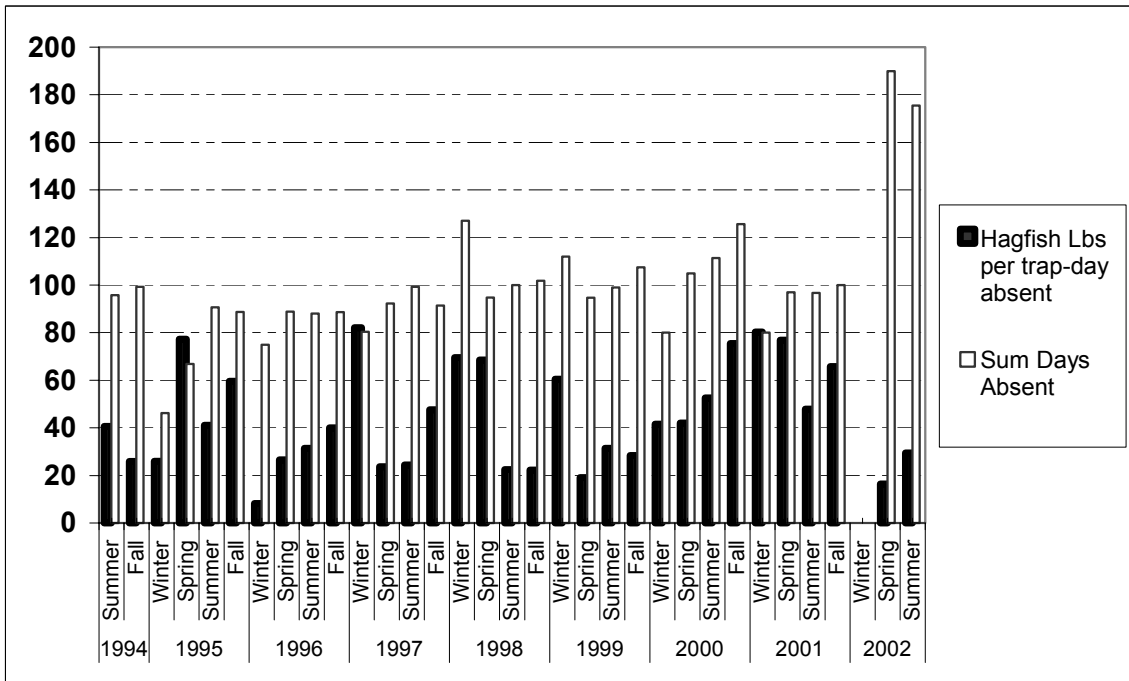


Figure E54 - Nominal LPUE for Area 514 (1994-2002 VTR data, n=1,190).

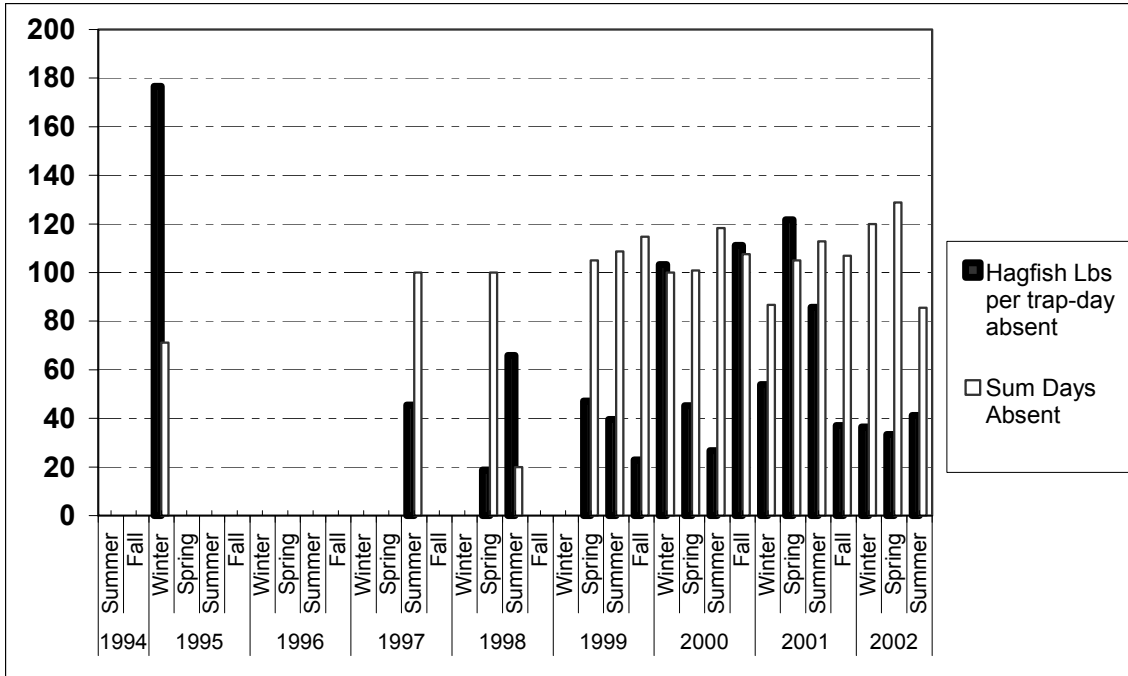


Figure E55 - Nominal LPUE for Area 515 (1994-2002 VTR data, n=254).

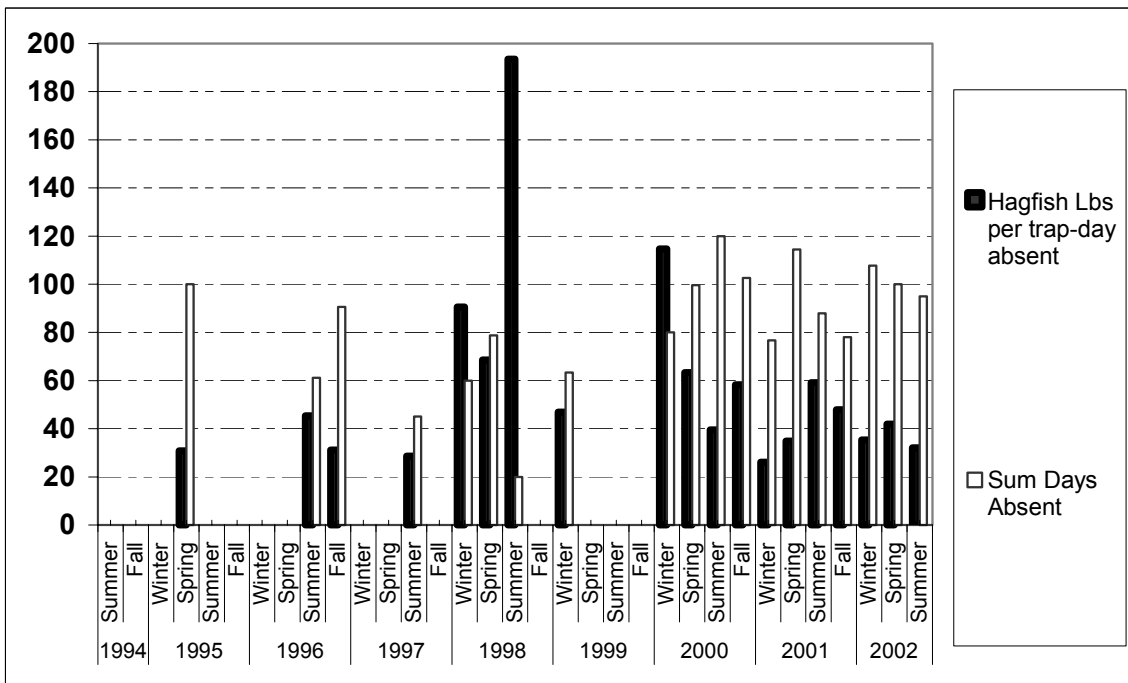


Figure E56 - Nominal LPUE for Area 521 (94-02 VTR, n=256).

### 6.5.6.2 Standardized LPUE

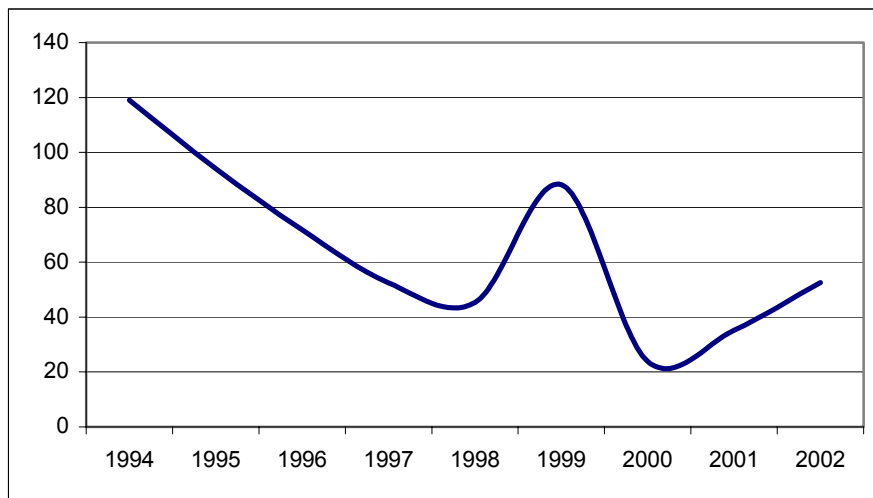
Nominal LPUE inputs were not found to be comprehensive predictors of actual landings. LPUE was modeled using a generalized linear approach to test for vessel-specific variables that may contribute toward actual fishing effort. Specifically the crew, length, gross tonnage and horsepower variables were modeled (Table E14).

Variable	Parameter Est	St Error	t Value	Pr >  t
Intercept	18.15641	8.63073	2.1	0.0355
Number of crew	2.75166	1.45549	1.89	0.0588
Vessel length	0.54475	0.16135	3.38	0.0007
Vessel gross tonnage	0.38779	0.08465	4.58	<.0001
Vessel horsepower	-0.05878	0.0115	-5.11	<.0001

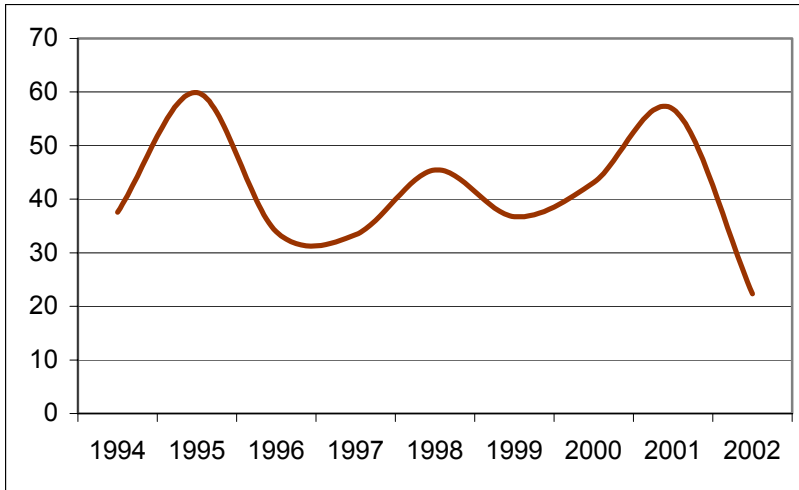
**Table E14 – Regression statistics with nominal LPUE as the dependent variable (LPUE mean = 52.18, df = 3,409).**

The crew variable was not significant at the  $P > 0.05$  level (though just barely), and multicollinearity was observed between the gross tonnage, length and horsepower variables. A modified ad-hoc step-up procedure was used to fit the best models, and the number of crew, horsepower, and length variables were eliminated. LPUE was then standardized for vessel gross tonnage using a generalized linear model.

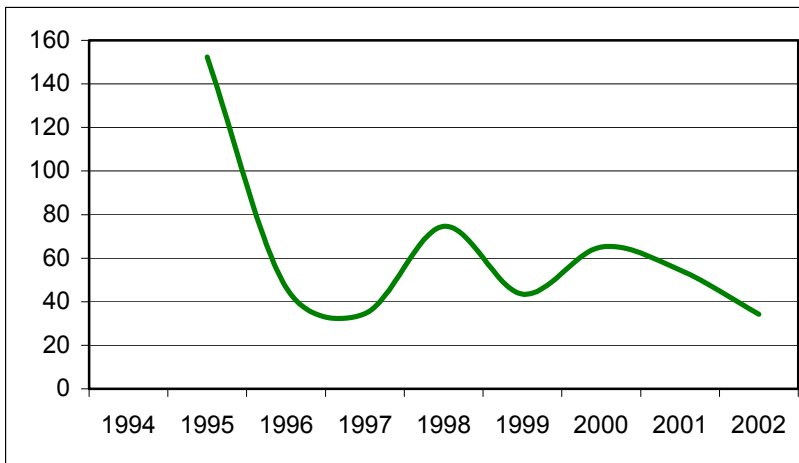
Standardized LPUE trended down in all areas, with declines on the order of 50% from historical highs (generally in the 1994-1996 time frame) being common.



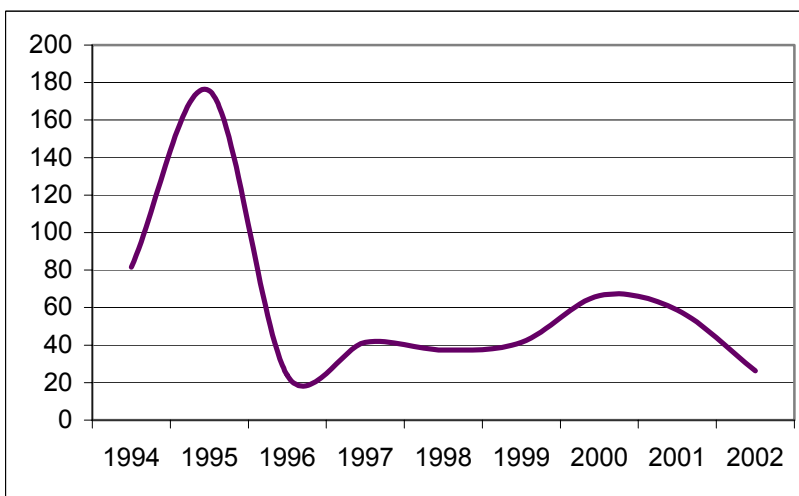
**Figure E57 - Standardized LPUE for area 513 (VTR 94-02, n=1,670).**



**Figure E58 - Standardized LPUE for area 514 (VTR 94-02, n=1,190).**



**Figure E59 - Standardized LPUE for areas 515 and 521 (VTR 94-02, n=510).**



**Figure E60 - Standardized LPUE for all other areas (VTR 94-02, n=277).**



### 6.5.6.3 Vessel-specific LPUE

A relatively large number of vessels have entered and exited the hagfish fishery, targeting hagfish for only a short time. To eliminate the influence of short-time operators on LPUE, standardized LPUE was computed for the top five hagfish landing vessels, each of which remained in the fishery for more than 2 years. After an initial “fishing up” period in 94-95, and another again in 97-98 as new long-term (greater than 2 years) operators entered the fishery, LPUE estimates declined as they have on nearly every spatial and temporal scale investigated (Figure E61).

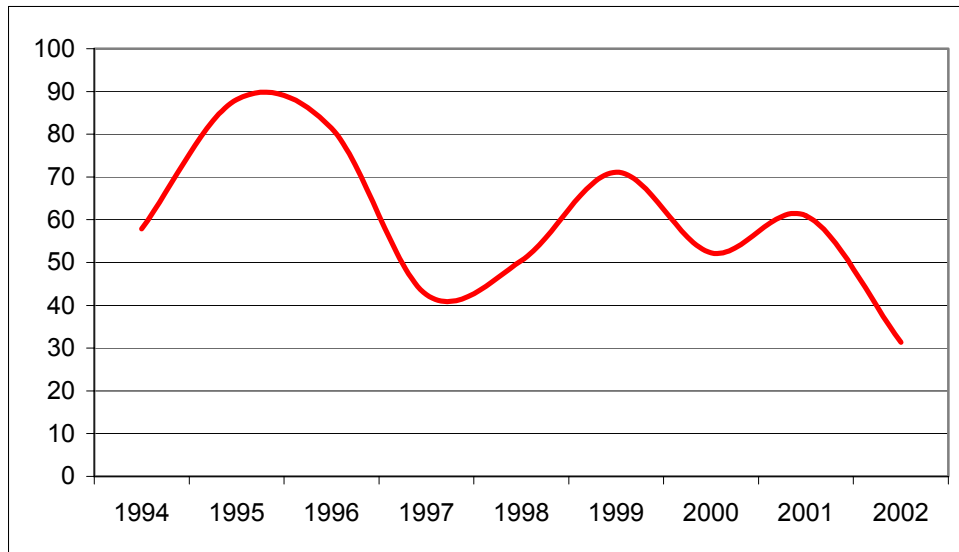


Figure E61 - Standardized LPUE for the top 5 landing vessels (VTR 94-02, n=2,176).

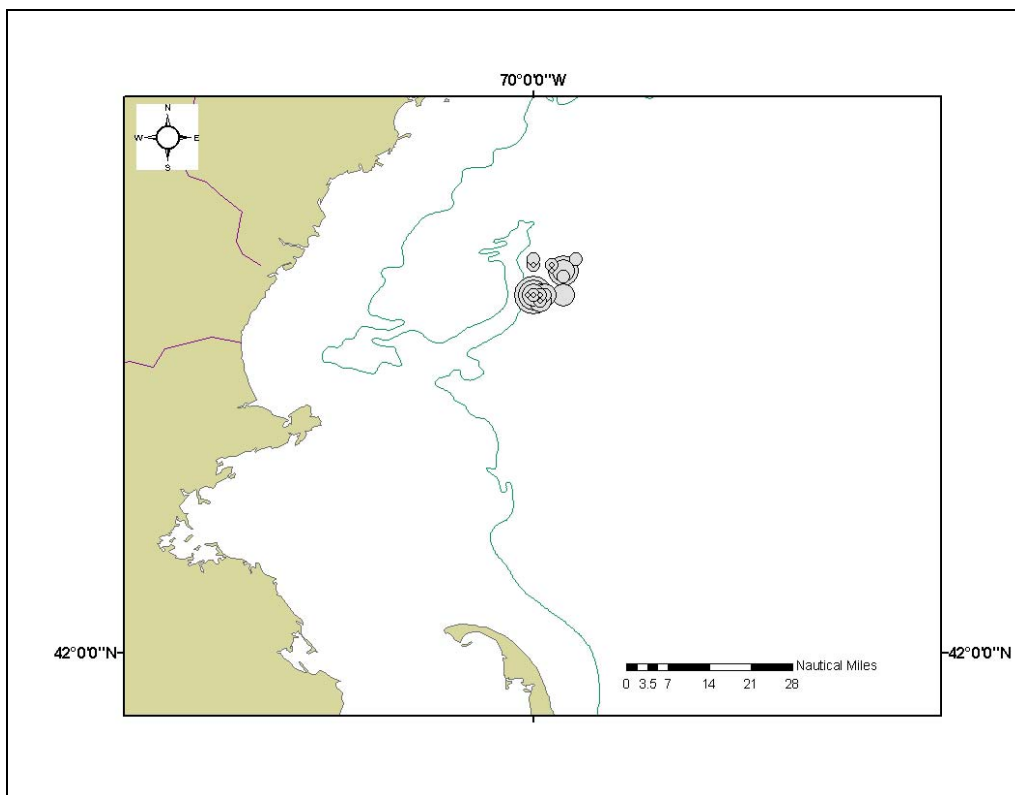
### 6.5.7 Localized Depletion

The trends noted above, specifically the increasing diffusion of fishing effort and increasing mean distance from landed port, call to mind the potential that hagfish may be targeted intensely on a small spatial scale, potentially leading to localized depletion. To investigate this, small spatial areas with numerous trips reported were sought. Three such areas were identified through geo-statistical analysis using ArcGIS. The first two clusters were comprised of trips by only one or two vessels and analysis results cannot be shown due to data confidentiality. The third cluster, described in Table E15 and shown in Map E3, contains 411 trips by more than three vessels. Table E16 shows the regression statistics for modeling standardized LPUE for this cluster. Note that all trips in this cluster were made between 1996 and 2000.

Analysis shows two periods of sharply declining LPUE. These declines are somewhat consistent with those observed in statistical area 513 (in which this cluster resides). Further investigation is required to differentiate the localized declines in LPUE from those of the region. The important fact here is that localized concentrations of fishing effort are available in these data and, while the time series is too short to reach any conclusions, the potential for further investigation using more savvy statistical tests exists.

Variable	N	Mean	sd	Minimum	Maximum
HAGLB	411	8459.1	5416.62	300	82522
LPUE	408	82.3	87.43	3	1363.25
GEARQTY	411	110.6	22.28	0	180
NHAUL	411	11.5	5.57	0	100
DA	411	1.0	0.16	0	2
DEPTH	411	72.7	27.29	0	144
CREW	411	3.0	0.21	0	3
GTONS	411	57.4	9.20	17	63

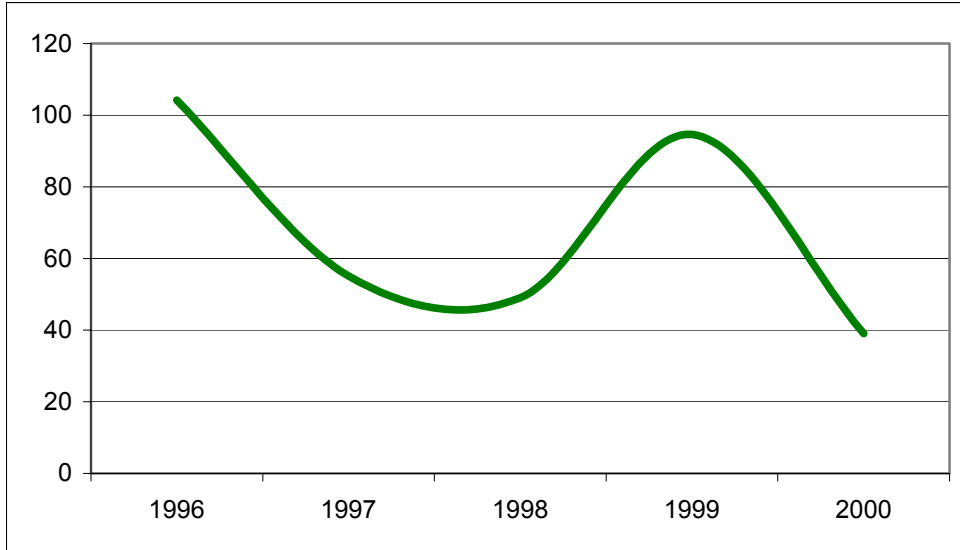
**Table E15 - Descriptive statistics for identified cluster**



**Map E3 - Location of identified cluster (symbols proportional to pounds landed per trip, VTR 94-02, n=411).**

Intercept	1	-75.8379	36.44146	-2.08	0.0381
GTONS	1	1.99975	0.48068	4.16	<.0001
1996	1	65.20874	21.50996	3.03	0.0026
1997	1	16.13869	23.01507	0.7	0.4836
1998	1	10.05016	22.37558	0.45	0.6536
1999	1	55.59023	23.07742	2.41	0.0165

**Table E16 - Modeled regression statistics for identified cluster (cluster mean gross tonnage = 57.43, df = 410).**



**Figure E62 - Standardized LPUE for identified cluster (VTR 94-02, n=411).**

## 7.0 MANAGEMENT HISTORY

### 7.1 British Columbia, Canada

In British Columbia, the commercial fishery for Pacific hagfish (*E. stoutii*) and Black hagfish (*E. deani*) was classified as experimental from 1988 to 1992 (Leask & Beamish 1999). During this time, the fishery was managed by limiting participation in the fishery and establishing differential trap limits based on area fished, of either 2000 Korean traps or 3500 Korean traps per vessel (Benson et al. 2001). There was no minimum size established but a market limit of 30 cm was in place for the duration of the fishery. The most critical element of the management program was the requirement for active vessels to participate in a biological sampling program, recording length, weight, sex, and presence/absence of eggs of a random sample of 1,000 landed hagfish each month. Catch and effort were also recorded for each set (Benson et al. 2001). Gear fished was required to have biodegradable fastenings for entrance funnels to prevent ghost fishing of lost gear (Leask & Beamish 1999).

### 7.2 Western U.S.

In the Pacific U.S. hagfish are managed in state waters only. In Oregon, hagfish were harvested using traps with a required biodegradable escape panel and no incidental catch was allowed. Before the traps were approved for the hagfish fishery, experimental gear permits were issued for their use. By fall 1990, 52 permits had been issued (McCrae 2002).

California also required a biodegradable panel in each trap. Gear studies in California demonstrated that larger fish could be selected for using traps with larger escapement holes (0.48 inches) and allowing for longer soak times (12 hours) (McCrae 2002). The most efficient trap design had more than one entrance funnel, escapement holes only in the area around the funnel, and shorter funnels made of solid material (McCrae 2002). California set a trap limit of 1,200 Korean traps or 300 plastic bucket traps (5 gallons or less in capacity). In addition, any vessel with hagfish gear on board is prohibited from possession of species other than hagfish. As in all California trap fisheries, a trap permit is required for hagfish (CA Regs. FGC §§9000-9024).

### 7.3 New England

There is currently no management plan for Atlantic hagfish and the fishery has not been managed by federal or state agencies since its inception in 1993. The following is a timeline describing the development of management for Atlantic hagfish in New England.

- **November 2001:** The New England Fishery Management Council (“Council”) received a letter and petition signed by 13 members of the Gulf of Maine hagfish industry requesting that the Council take action to conserve the Atlantic hagfish resource and prevent overcapitalization of the fishery. The petitioners sought expedient implementation of a control date and the development of a Fishery Management Plan (FMP) for hagfish.
- **January 2002:** The Council tabled a motion to establish a control date for the hagfish fishery and moved to ask state directors to develop regulations for managing the fishery and report back to the Council within a six-month period. (The states have not provided this requested information to the Council). While there was disagreement about the merits of establishing a control date for hagfish, there was overwhelming consensus among Council members and industry representatives alike that more information on the biology and ecology of hagfish and the character of the fishery is essential to making sound management decisions.
- **April 5, 2002:** A Federal Register notice announced a petition to the Secretary of Commerce requesting emergency rulemaking for the Atlantic hagfish fishery.

- **April 2002:** The Northeast Region Coordinating Council tentatively placed the review of a hagfish assessment on the agenda for the 37<sup>th</sup> Stock Assessment Review Committee (SARC) workshop in June, 2003.
- **August 28, 2002:** *Control Date Published*— In response to public comment on the proposed emergency rulemaking, NMFS Northeast Regional Office established a control date for the Atlantic hagfish fishery and urged the Council to begin development of a Hagfish FMP.
- **November 2002:** The New England Fishery Management Council considered development of an Atlantic hagfish FMP in their discussion of priorities for 2003. They decided to wait for the results of the June SARC and completion of a Stock Assessment and Fishery Evaluation (SAFE) report before beginning development of a plan. The Council formed a hagfish committee which has not yet met.
- **March 28, 2003:** A working group met to (a) evaluate and discuss existing fishery and biological data and to highlight remaining data needs, and to (b) discuss and consider survey and assessment methods for hagfish. This report is the result of the group's efforts to address informational needs of the SARC.

## 8.0 FUTURE RESEARCH

### 8.1 Informational Needs

The working group identified specific data and information needs for management of the hagfish fishery and resource. The following is a list of the most essential research foci.

- estimate abundance based on existing data and new studies
- determine the level of discards in the hagfish fishery
- determine survivability of discarded hagfish
- collect more detailed information on spatial distribution of fishing effort and changes in effort over time
- develop studies to collect information on reproduction, growth and development, including age at maturity; growth rates; lifespan; and timing, condition and location of reproduction and egg deposition
- highlight differences between hagfish in the Gulf of Maine and those south of New England as well as differences between the inshore and offshore populations
- describe the range of hagfish and determine the extent of movement and migratory behavior
- develop a more detailed habitat profile for hagfish in the Gulf of Maine

The group also discussed means of collecting these data, including biological sampling, surveying and tagging studies, described in further detail in the following sections.

### 8.2 Biological Sampling

#### 8.2.1 At-Sea Observer Program

In accordance with the NMFS federal observer program, placing observers on vessels fishing for hagfish is possible. There are three possibilities for funding and administration of such a program:

1. Vessels participating in the fishery could hire NMFS-certified observers on a per day/per trip basis and compensate the observer contractor directly. Costs could range from \$700-\$1000 per day depending on the timing, duration and extent of coverage.

This option may be useful at the present time in identifying data that should and can be collected, issues associated with processing samples, variability in observations, and so forth. It is not clear whether industry is willing to incur such costs.

2. There is a limited pool of observer sea days which were earmarked for supporting cooperative research projects. To date, projects which have tapped into those days have involved joint design and execution by teams of NMFS scientists, industry and other participants.

Typically, projects to date which have tapped into the cooperative research observer sea day pool have involved about as much lead time in terms of planning and review as a typical cooperative research proposal. Only a part of the non-marine mammal observer days are associated with cooperative research. Most of these days are reserved for observer coverage in the New England groundfish fishery, as mandated by a federal court order.

3. A specific cooperative research proposal could be funded which would explicitly provide an appropriate level of coverage to the hagfish fishery.

In all cases, the data that should be collected, the precision necessary to draw inferences from the data and the variability in observations of those data must be determined prior to the specification of a sampling regime. A pilot study may be necessary to determine the relationship between precision and sample size.

### **8.2.2 Port Sampling**

Taking length and weight measurements of random samples of landed hagfish at port is also a possible source of fishery data. The potential for implementing such a program is currently being examined by the National Marine Fisheries Service Northeast Regional Office.

### **8.3 Fishery Investigation**

The working group discussed ways in which fishermen could provide more detailed information about spatial distribution of fishing effort. A relatively simple means of acquiring more explicit information on fishing patterns would be to conduct chart surveys with fishermen willing to disclose their personal logbook data. By plotting the positions of trips recorded in their logbooks and the catch levels associated with these specific areas, it may be possible to look at localized changes in harvest rates over time.

The New England Fishery Management Council staff is also working with the Canada Department of Fisheries and Oceans to obtain landings and revenues data for the Canadian Atlantic hagfish fishery and further information about the management of the hagfish fishery in Nova Scotia and New Brunswick. Information sharing between the U.S. and Canada may aid the New England Fishery Management Council in developing management approaches for the hagfish fishery.

### **8.4 Tagging Studies**

Hagfish pose a number of logistical problems for researchers interested in monitoring their movements. Tagging studies could provide measures of spatial range, migration, and estimates of growth rates. However, these studies are complicated because of the burrowing lifestyle of the hagfish and its anatomy. For example, long streamers are likely to be tangled or torn away, and holes in the skin cause potential problems not only with infection but also with disturbances in fluid balance since over most of the animal the skin covers a capacious vascular/lymphatic sinus. The skin is also too thin for freeze-branding to be a

viable option, and peritoneal tags, inserted through the cloaca, are likely to be ejected. An additional concern is whether tagged animals are likely to be returned by fishers, given the challenge of identifying tags during the sorting of a large volume of fish.

The literature contains very few reports of successful tagging attempts. Foss (1963) reported some success with small plastic tags (20 x 4 x 0.2 mm) that were originally designed for tagging juvenile herring. The tags were attached by a short length of monofilament line sewn through the dorsal midline about halfway along its length. Walvig (1967) described the problems associated with both external tags and peritoneal tags, and felt that neither was suitable for large-scale studies. He used two tagging methods successfully; both required anesthetizing the animals in cold seawater. The first method involved the injection of undiluted India ink into the subcutaneous tissue of the ventral fin fold using a small syringe. Black, blue, carmine, and green ink were used, with black felt to be most satisfactory. The marks persisted for at least 4 years. The second method involved making a small incision in the ventral fin fold and introducing a smooth plastic tag into the fin fold.

A combination of these methods would seem to have the greatest potential for tagging animals in the New England fishery. The fin fold does not communicate with the subcutaneous sinus, and the black markings would be apparent to a fisherman sorting on deck. The black mark(s) would indicate a tagged animal that could be set aside with the collection information recorded. The plastic tag, which identifies the individual, could then be removed by the investigators shoreside.

Proper handling is essential if the animals are to survive the tagging process. They will need to be transferred into cold, full-salinity seawater containing the anesthetic in a dark/covered container immediately after arriving on deck. Once the tagging is done, animals will need to go into another darkened tank of cold seawater for recovery. The tagged animals must then be transported in that tank to the bottom and released there. During preliminary studies, Martini et al. built and tested an inexpensive 35-gallon release tank that could be lowered over the side and would “trip” automatically on contact with the bottom (Martini pers. comm. 2003). Given the sensitivity of these animals to exposure to low salinity surface waters, such a device is probably essential if the project is to succeed.

## **8.5 Laboratory Studies and Survey Considerations**

Hagfish are fundamentally difficult organisms to work with and study because of their behavioral and physiological characteristics. Researchers have noted that hagfish tend to behave abnormally in captivity, refusing to eat, exhibiting very little growth and demonstrating no reproductive tendencies (Martini & Powell, WG meeting 2003).

Developing a more specialized survey for hagfish to supplement the traditional trawl survey is possible. The working group recommended that pilot projects be developed to examine the distribution of hagfish on more refined spatial scales than those covered in the NEFSC trawl survey in the Gulf of Maine. Among the techniques which may be used to determine localized abundance estimates of hagfish are trap studies which set baited, standardized traps at specific locations for timed periods to collect hagfish; tagging studies (described in detail in Section 8.4); and remotely operated vehicle (ROV) work, particularly to investigate areas in which it is suspected that there are a large number of very small slime eels. These types of projects are conducive to a collaborative process which would benefit substantially from research partnerships between scientists and fishermen.

## **8.6 Assessment Methodology**

The working group considered the utility of existing survey data on hagfish for assessing the stock. There are at least two approaches to assessing the condition of the hagfish population. The first approach, which uses a generalized linear mixed effects models, is more exploratory and purely statistical, while the

other approach, a modified DeLury model, is comparable to more traditional stock assessment methods. Given preliminary evidence of localized depletion of hagfish in the Gulf of Maine as well as uncertainty in vital rates and stock structure, both approaches may be required to fully comprehend changes in the stock.

### **8.6.1 Generalized Linear Mixed-effect Models**

Data from one geographic location at one point in time are not independent from data from a proximate location at the same time or from the same location at a different point in time. For example, when localized depletion is occurring, abundance in one location might have a declining trend while that in other locations may exhibit no trend. Trends in abundance in locations close to the site of depletion may also decline, while those in distant locations may not. Mixed-effects models allow us to account for spatial and temporal correlations (Pinheiro and Bates 2000). Generalized linear mixed-effect models are used when such correlated data comes from a non-normal exponential family (Breslow and Clayton 1993). These models are similar to regression or generalized linear models (McCullagh and Nelder 1989) but directly account for correlated, repeated measures data.

For hagfish, locations could be defined simply by the NEFSC statistical areas, or they could be based on some combination of these statistical areas, distance contours radiating out from the known major hagfish ports, and depth contours. The primary assumption in defining these locations is to make them as internally homogeneous as possible with respect to the assumed distribution of hagfish. In other words, areas that were heavily fished during one period in time should not be lumped with areas in which little fishing occurred during that same period. Doing so will violate the assumption that the areas are homogenous with respect to hagfish distribution, and cloud whatever pattern may be occurring in that location. These locations are assumed to be repeatedly measured.

Besides accounting for the spatial and temporal correlation, mixed-effect models allow for direct estimates of population-wide trends (e.g., fixed-effects) as well as location-specific trends (e.g., random-effects). As in regression and generalized linear models, the response variable from the surveys for mixed-effect models could be either the amount of hagfish caught per tow or simply the presence or absence of hagfish in a tow. In most cases, a non-normal error (binomial, gamma, negative binomial, or even a delta-gamma) would be assumed and generalized linear mixed effects models used.

To execute the analysis, we could use S-PLUS 2000 (Mathsoft, Seattle, Washington, USA, 2000) and the GLME extension developed by Dr. Pinheiro for the NLME software (Pinheiro and Bates 2000) within S-PLUS 2000. The GLME extension implements the methods in Breslow and Clayton (1993). The significance of each fixed-effect, both main effects and interactions, would be tested in an ANOVA framework using marginal F-tests (Pinheiro and Bates 2000) with an  $\alpha$ -level of 0.05 for main effects and 0.10 for interaction effects (Sokal and Rohlf 1981). Pinheiro and Bates (2000:88) state that likelihood ratio tests for testing the significance of the fixed-effects variables in linear mixed-effects models are often "anticonservative" and thus should not be used for the fixed-effects portion of the model. Because the generalized linear mixed-effects model was fitted through a series of linear mixed-effects model approximations, the same problem with the likelihood ratio tests for the fixed effects is expected to occur. The significance of random effects, within-population serial correlation structures (such as autoregressive with lag one or autoregressive-moving average), and heterogeneous variance structures could be tested using likelihood ratio tests (Pinheiro and Bates 2000).

### **8.6.2 Modified DeLury Model (Chapman 1974)**

When an unfished population is in equilibrium, the annual instantaneous rate of recruitment will be approximately equal to the annual instantaneous rate of natural mortality. Over short time periods, the instantaneous rate of natural mortality could be considered constant. It is assumed that these conditions



hold in the early stages of exploitation for a species that is slow to reproduce. Under these conditions, the average population size during year  $j$  ( $\bar{N}_j$ ) can be written as:

$$\bar{N}_j = N_0 - \sum_{i=1}^{j-1} C_i(1-M)^{j-i} - \frac{1}{2}C_j$$

Where  $N_0$  is the initial abundance,  $C_i$  is the catch in year  $i$ , and  $M$  is the instantaneous natural mortality rate. This population dynamics model can be fitted to an index of abundance  $I_j$  by the following equation using regression techniques:

$$I_j = kN_0 - k\left(\sum_{i=1}^{j-1} C_i(1-M)^{j-i} - \frac{1}{2}C_j\right)$$

Where  $k$  is constant of proportionality and the index of abundance would be derived from the survey data. The catch for a given year would be extrapolated from the various sources of catch data. Sensitivity tests should be performed on  $M$  because that value is relatively unknown. If it is assumed that movement of individuals from one location to another is limited, this modified DeLury method may be combined with the generalized linear mixed-effects model to obtain spatially-explicit estimates of abundance over time.

## 9.0 DISCUSSION

Despite the rapid growth of the Atlantic hagfish fishery over the span of the last decade, there remain substantial gaps in basic information on fishery performance, as well as many fundamental unanswered questions on the biology and life history of the animal. The paucity of crucial data make assessing the hagfish resource extremely problematic.

This paper has discussed what is known about the region's hagfish fishery, the biology of hagfish and described some potentially useful approaches to stock assessment.

This concluding section attempts to focus discussion on data and information gaps by revisiting the working group objectives (Terms of Reference, Section 2.2). The goal then, using this structure, is to identify a set of high priority tasks or research recommendations that would allow for progress in determining the status of the hagfish resource and inform managers as to the need for formal fisheries management intervention.

To do this we review fishery dependent information, biological and ecological information, fishery independent information and stock assessment approaches and research needs. Key research issues are highlighted in the discussion below.

### **Fishery Dependent Information (TOR 1, 2)**

Through discussions with industry participants and examination of NMFS dealer and logbook (VTR) data, the working group was able to describe landings and revenues, spatial distribution of trips over time, seasonal trends in landings, geographic range of the fishery historically and currently, fishery participants, and fishing practices. The working group was concerned about the discrepancies between dealer reports and NMFS dealer data for some years, including 2001 and 2002. Other data issues include underreporting by both dealers and fishermen and the affect of "shrinkage" on the reported catch. Anecdotal evidence suggests that discard levels may be quite high, depending on the vessel and season. The working group discussed this issue at length and recommends a closer examination of discarding in the hagfish fishery through formal programs, such as the at-sea observer program and port sampling, as well as the assistance of dealers and fishermen in reporting their discard levels. Measuring the mortality of hagfish culled at sea is also important in determining total fishing mortality for the hagfish stock.

### **Biological and Ecological Information (TOR 3)**

Despite the ubiquity and recognized ecological importance of hagfish, there is still limited knowledge of the life history of these organisms and their adaptability and role in benthic marine ecosystems. The working paper summarizes what is known about the geographic range, habitat, preferred depth, temperature and salinity, feeding habits, ecological role, and reproduction and development of the Atlantic hagfish based on current research. The working group recommends pilot tagging studies in specific areas that are not heavily fished to attempt to measure growth rates of hagfish. In this discussion, the working group identifies potential issues involved in tagging hagfish. Remotely operated vehicles (ROVs) with accompanying video equipment have served as a useful tool in observing hagfish behavior in their natural environment, as well as estimating abundance in specific locations.

### **Fishery Independent Information (TOR 4)**

The working group described and analyzed data collected in NEFSC groundfish bottom trawl and shrimp surveys. The NEFSC groundfish bottom trawl survey, conducted since 1963, is the most consistent long-term source of abundance data on hagfish. These data also provided length frequency curves for hagfish collected within the spatial range of the survey. The NEFSC surveys and sampling studies by Martini et al. provide sufficient data to estimate length-weight curves for hagfish. In general, hagfish are poorly represented in traditional trawl surveys because of their morphology and burrowing behavior. The sample size of hagfish collected during trawl and shrimp surveys is not large enough to distinguish noise in the survey data from true changes in the population or to determine changes in localized populations over the period of the surveys. The working group recommends development of a specialized hagfish survey using standardized, baited traps deployed in random sampling locations. Additional observations on hagfish aggregations may be made using ROVs and towed video equipment.

### **Stock Assessment Approaches and Research Needs (TOR 5, 6)**

The working group seeks additional guidance from the SARC on assessment approaches that are appropriate for hagfish given the data currently available. Two general modeling approaches were discussed – the use of a generalized linear mixed-effect model to standardize commercial catch rates and survey data, and a modified DeLury model which is used for a number of the invertebrate species in the Northeast. These models are limited by deficiencies in abundance and life history data for hagfish, and may be restricted in their potential for determining population trends. Data and research needs were highlighted repeatedly by the working group throughout their discussions and analyses of current data and have been described in the working paper and this summary. It may be appropriate for the SARC to discuss these issues in terms of recommendations for future research and/or data collection programs.

#### **9.1 SARC Discussion**

- Hagfish fisheries around the world have not been sustained and some have a history of overexploitation followed by fishery collapse. The level of a potentially sustainable fishery on Atlantic hagfish is uncertain.
- The working group has developed a set of data requirements necessary for stock assessment to determine the level of a sustainable fishery.
- Based on the life history information that is currently available, there is a strong argument for a management system that, at a minimum, would cap effort and protect juveniles (smaller than 40-45 cm).

#### **9.2 SARC Research Recommendations**

- Consider appropriate measures of “effective” fishing effort, including but not limited to soak time, number of traps, number of hauls per trip, and fishing power differences between large and small vessels, that are directly related to fishing mortality;

- Look at LPUE in conjunction with survey data and use density measures from the surveys to estimate CPUE;
- Establish biological sampling in ports (length and weight, by sex to the extent possible);
- Collect commercial length frequency data for size composition of catch; Seek additional information on the Nova Scotia hagfish fishery (landings, biological sampling data);
- Seek information on hagfish exports from NMFS trade specialists on the west coast who specialize in Asian exports and examine export data;
- Develop a study fleet with electronic reporting;
- Consider conservation engineering studies to minimize the catch of juveniles and the potential for ghost fishing;
- Conduct a directed population dynamics study, examining food web dynamics (stomach sampling data from survey), age and growth, maturation, fecundity and stock identification;
- Evaluate gillnet sea sampling data for evidence of hagfish eating gilled fish. (There may be spatial and temporal overlaps between discards in gillnet fisheries and hagfish that predate on the discarded fish).

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