Northeast Fisheries Science Center Reference Document 93-06

Report of the 15th Northeast Regional Stock Assessment Workshop (15th SAW)

Stock Assessment Review Committee (SARC)
Consensus Sumary of Assessments

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, MA 02543-1097

February 1993

The 15th Regional Stock Assessment Workshop (15th SAW) is documented in seven separate reports. For copies of these documents, contact the NMFS/NEFSC, Information Services Unit, 166 Water Street, Woods Hole, MA 02543-1096, (508)548-5123.

Reports of the 15th Regional Stock Assessment Workshop (15th SAW)

CRD 93-01 Surfclam populations of the Middle Atlantic, Southern New England, and Georges Bank for 1992
by J. Weinberg

CRD 93-02 Ocean quahog populations of the Middle Atlantic, Southern New England, and Georges Bank, and Gulf of Maine for 1992
by J. Weinberg

CRD 93-03 Historic and recent trends in the population dynamics of the redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine - Georges Bank region
by R. Mayo

CRD 93-04 Assessment of the Gulf of Maine cod stock for 1992
by R. Mayo, L. O'Brien, F. Serchuk

CRD 93-05 Assessment of the Georges Bank cod stock for 1992
by F. Serchuk, R. Mayo, L. O'Brien, and S. Wigley

CRD 93-06 Report of the 15th Northeast Regional Stock Assessment Workshop (15th SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

CRD 93-07 Report of the 15th Northeast Regional Stock Assessment Workshop (15th SAW), Plenary and Advisory

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INTRODUCTION

The Stock Assessment Review Committee (SARC) of the 15th Regional Stock Assessment Workshop (15th SAW) met at the Northeast Fisheries Science Center (NEFSC), Woods Hole, Massachusetts during December 7-11, 1992. The thirteen members of the SARC were from a number of organizations within the region and Canada (Table 1). Nearly 50 individuals participated in the meeting overall (Table 2).

The SARC agenda included five species/stocks and gear research (Table 3). Analytical assessments for surfclam, ocean quahog, Gulf of Maine cod, and Georges Bank cod were reviewed. An update of abundance indices and catch were provided for redfish and a review of old and recent studies on mesh selectivity was discussed.

The SARC technically evaluated the assessments to determine the current status of each resource. Additional analyses were conducted and new working papers were presented in response to technical questions that were raised and to support specific recommendations for improving the existing analyses.

Common problems that plague many of our assessments in the Northeast and which were important at this review of cod assessments were:

- recreational harvest amounts were not known
- discard data were not available
- the analyses of effort data were unable to take changes in technology into account over time.

Both cod stocks are fished recreationally by party and charter boats and the catches are significant. Major problems with recreational catches are

- lack of catch estimates in January and February
- estimates of catch, in general, from long-range trips to Georges Bank
- length frequencies of recreational catches.

The effect of these problems on the assessments is an underestimation of the fishing mortality rate and abundance in general.

The quantity of discards is not specifically available, so the assessment were done on landings rather than on catches. Conducting assessments on landings certainly underestimates the overall fishing mortality on the stock and in particular the fishing mortality on the younger fish and the abundance of recruitment, since these are the ones that are generally discarded. The exploitation pattern as determined from landings data is wrong, which also affects the estimates of potential equilibrium yield per recruit and potential spawning stock biomass per recruit. If discard rates vary little, if they are not large, and if they are addressed consistently in all phases of the assessment, they should not pose a problem in the provision of scientific advice.

It is well known that fishermen during the last decade have increased their efficiencies through the use of new technology such as electronics, higher horsepower-to-vessel size ratios. and other gear efficiencies that increase the mortality rate per day fishing over that of earlier periods. The effect of increased technology has not been determined and is not factored into the assessments. Fishing effort for cod stocks is standardized by vessel class, area, and time in terms of days fishing, but without taking increased technology effects into account. This underestimates the increase in fishing mortality rate for a unit of effort in recent years. Even if fishing effort in terms of number of days fished did not increase, fishing mortality would be expected to increase, and perhaps substantially.

The eight working papers presented by scientists at the beginning of the meeting, as well as those produced during the meeting, will not be available after the SARC. The revised procedure for conducting assessment activities allows a variety of working papers to be presented and discussed at the SARC, but these papers have no status anmd are discarded after the meeting. Selected papers wil be upgraded to NEFSC Reference Documents (Table 4), and will be available for distribution shortly after the SARC.

As a step toward the stock assessment process, the Stock Assessment Review Committee not only prepared the Consensus Summary of Assessments (CRD 93-06), but also the first draft of the Advisory Report on Stock Status (CRD 93-07). The advisory report was presented to the SAW Steering Committee at the Plenary session of the SAW, January 26-27, 1992.

Table 1. SAW 15 Stock Assessment Review Committee

Frank Almeida	Northeast Fisheries Science Center, NMFS
Vaughn Anthony	Northeast Fisheries Science Center, NMFS
Andrew Applegate	New England Fishery Management Council
Peter Colosi	Northeast Regional Office, NMFS
Ray Conser	Northeast Fisheries Science Center, NMFS
Wendy Gabriel	Northeast Fisheries Science Center, NMFS
Tom Hoff	Mid-Atlantic Fishery Management Council
Joesph Hunt	Department of Fisheries and Oceans, Canada
Steven Murawski	Northeast Fisheries Science Center, NMFS
William Overholtz	Northeast Fisheries Science Center, NMFS
Ronald Smolowitz	Coonamessett Farm
Mark Tercerio	Northeast Fisheries Science Center, NMFS
Gordon Waring	Northeast Fisheries Science Center, NMFS

Table 2. List of SAW particpants

National Marine Fisheries Service

Northeast Fisheries Science Center

Frank Almeida
Vaughn Anthony
Jon Brodziak
Darryl Christensen
Steve Clark
Ray Conser
Kevin Friedland
Wendy Gabriel
George Grice
Marv Grosslein
Ruth Haas
Dan Hayes
Thomas Helser
Josef Idoine
Blanch Jackson
Ambrose Jearld
John Kocik
Marjorie Lambert
Ralph Mayo
Grace Klein MacPhee
Steven Murawski
Helen Mustafa
Loretta O'Brien
William Overholtz
Paul Rago
Fred Serchuk
Gary Shepherd
Katherine Sosebee
Mark Tercerio
Gordon Waring
James Weinberg
Susan Wigley

Office of Research and Environmental Information

Andrew Rosenberg

Northeast Regional Office

Al Blott
Peter Colosi

New England Fishery Management Council

Andrew Applegate
Philip Haring
Chris Kellog

Mid-Atlantic Fishery Management Council

Tom Hoff

Massachusetts Divison of Marine Fisheries

Arnold Carr
Steven Correa
Arnold Howe

Department of Fisheries and Oceans, Canada

Joesph Hunt

Coonamessett Farm

Ronald Smolowitz

University of Rhode Island

Joesph DeAlteris
Jessica Harris

Conservation Law Foundation

Ellie Dorsey

Woods Hole Oceanographic Institution

Chris Weidman

Table 3. 15th SAW agenda

15th Northeast Regional Stock Assessment Workshop
Stock Assessment Review Committee Meeting

NEFSC Aquarium Conference Room
Woods Hole, Massachusetts
December 7 (9:00 AM) - December 11, 1992

AGENDA

Monday, December 7

OPENING Chairman V. Anthony

SPECIES/STOCK	SOURCE/PRESENTER	RAPPORTEURS
Surfclam	NEFSC/J. Weinberg	T. Hoff
Ocean quahog	NEFSC/J. Weinberg Mid-Atlantic Gulf of Maine	T. Hoff
Redfish	NEFSC/R. Mayo	G. Waring
Tuesday, December 8		
Cod		
Gulf of Maine	NEFSC/R. Mayo	A. Applegate
Georges Bank	NEFSC/F. Serchuk	A. Applegate
Wednesday, December 9		
Gear Research	NEO/P. Colosi, A. Blott URI/J. Harris, J. DeAlteris DFO, Canada/J. Hunt	S. Murawski

Thursday, December 10

Draft Consensus Summary of Assessments - - surfclam, ocean quahog, redfish, cod
Draft Advisory Report on Stock Status

Friday, December 11
Draft Consensus Summary of Assessments - - cod-continued, gear research
Draft Advisory Report on Stock Status
Other Business

Table 4. SARC 15 Northeast Fisheries Science Center Reference Documents

CRD 93-01	Surfclam populations of the Middle Atlantic, Southern New England, and Georges Bank for 1992 by J. Weinberg
CRD 93-02	Ocean quahog populations of the Middle Atlantic, Southern New England, and Georges Bank, and Gulf of Maine for 1992 by J. Weinberg
CRD 93-03	Historic and recent trends in the population dynamics of the redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine - Georges Bank region by R. Mayo
CRD 93-04	Assessment of the Gulf of Maine cod stock for 1992 R. Mayo, L. O'Brien, F. Serchuk
CRD 93-05	Assessment of the Georges Bank cod stock for 1992 by F. Serchuk, R. Mayo, L. O'Brien, and S. Wigley

A. SURFCLAM ASSESSMENT

INTRODUCTION

The status of the surfclam, *Spisula solidissima*, off the Atlantic coast of the United States is updated through 1992. Data analyzed include commercial landings and effort, as well as research vessel surveys conducted by NMFS using a hydraulic dredge. Spatial and temporal trends in resource abundance and size frequency distribution are reported, along with a medium-term prognosis for the resource.

This stock has been assessed throughout the 1970s and 1980s (e.g., Murawski 1986). The recent 1989 assessment (NEFC 1989) stressed the lack of prerecruit sized clams in the population and noted some indication of declining catch rates.

Management of the surfclam resource has changed significantly over time, due to implementation of the FMP in 1977 (Mid-Atlantic Fishery Management Council 1992). Since the inception of the Plan, there has been an overall quota on commercial landings. To limit harvesting and to protect prespawning individuals, a variety of regulations have been in effect for various amounts of time between 1977 and 1990. Regulations have included closures of areas where there were concentrations of small clams (off Atlantic City, N.J., Ocean City, Md., and Chincoteague, Vir.), regional and annual quotas, weekly and quarterly time restrictions, and minimum size limits. Minimum size limits changed from 5.5 in. (14.0 cm) in 1981-1984, to 5.25 in. (13.3 cm) in 1985, to 5 in. (12.7 cm) in 1986-1989. During this period, 1981-1989, discards may have been substantial. In 1990, when the individual transferable quota (ITQ) system was initiated, regulations on harvesting time and legal size were dropped. As a result, discards have represented a negligible fraction of total catch from 1990-1992.

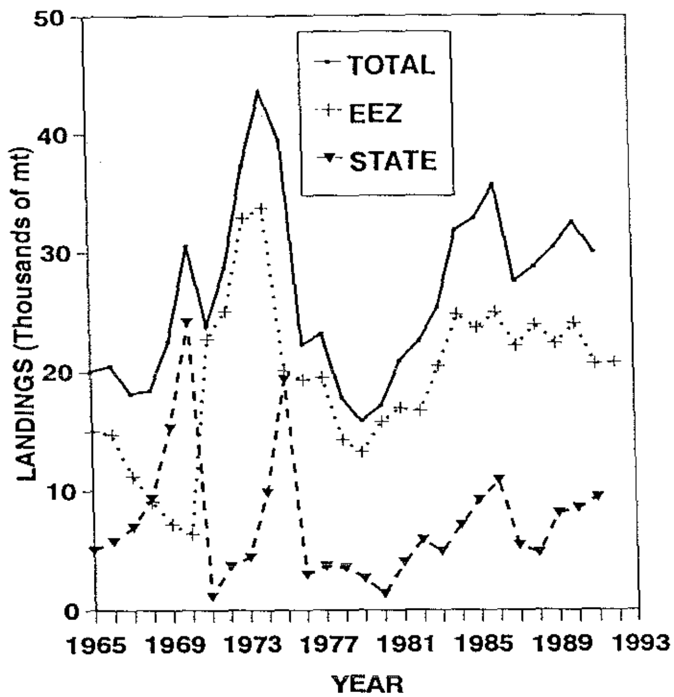


Figure A1. Landings of surfclams (1,000 mt of meats), 1965-1992. EEZ landings for 1992 are a prediction for the entire year based on logbook data availalbe as of October 20, 1992. **Total** is all areas; **EEZ** is the Exclusive Economic Zone, 3 to 200 mi from the coast; **State** is the inshore waters, 0 to 3 mi from coast.

ANALYSIS OF COMMERCIAL DATA

Commercial fishery data from 1980 onward were obtained from vessel logbooks, required of all participants in the surfclam fishery. The logbooks contain information on landings, effort, date and location of catch, and ship weight.

The major obstacle to analyzing commercial landings data has been in determining the locations of catches. This problem was overcome in this assessment. A minor change has been made in the vessel size class categories from those used in previous assessments. All tables and figures in the current report have been updated and converted to the metric system (1 bushel of surfclams = 17 lbs = 7.711 kg).

COMMERCIAL FISHERY

Total surfclam landings in 1991 were 30,000 mt of shucked meats (Table A1; Figure A1), representing a 7.7% decrease from landings in 1990. EEZ landings decreased from 24,000 mt in 1990 to 20,600 mt in 1991 (-14.1%). EEZ landings for 1991 were the lowest since 1983. Surfclam landings from state waters increased from 8,500 mt in 1990 to 9,400 mt (+10.2%) in 1991.

Catch quotas for the Mid-Atlantic region have been in effect since 1984, and EEZ surfclam landings have stabilized between 20,400 and 24,900 mt. This stability is reflected by a reduction in the CV (SD/Mean). The CV for EEZ surfclam landings decreased from 0.51 for the

Table A1. Total U.S. surfclam landings (mt of meats), total landings from the Exclusive Economic Zone (EEZ), landings from state waters, and percent of total from the EEZ

Year	Total Landings	EEZ Landings	State Waters Landings	Percent Landed[1] from EEZ
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
1979	15,836	13,186	2,650	83
1980	17,117	15,748	1,369	92
1981	20,910	16,947	3,964	81
1982	22,552	16,688	5,873	74
1983	25,373	20,485	4,887	81
1984	31,862	24,776	7,086	78
1985	32,894	23,691	9,204	72
1986	35,720	24,923	10,797	70
1987	27,553	22,147	5,406	80
1988	28,823	23,950	4,873	83
1989	30,423	22,334	8,089	73
1990	32,555	24,027	8,528	74
1991	30,036	20,637	9,399	69
1992	-	20,737[2]	-	-

1 Proportions for 1971-1988 based on data presented in "Fisheries of the United States", Current Fishery Statistics Series, NOAA/DOC. Earlier data based in NMFS/BCF dockside interviews.

2 1992 landings reported as of October 20, 1992, and expanded by 1.245 to predict the entire year's landings. Of this total, 20,730 mtons were landed from the Middle Atlantic Bight, and 6 mtons were from Southern New England.

1965-1976 period, to 0.06 for the 1984-1991 period. The CV for state landings for the period 1984-1991 was 0.26. Thus, restrictive management in the EEZ since 1984 has stabilized the annual catch when compared with that in the EEZ before 1984 and compared with catches from state waters since 1984. The previous clam assessment (NEFC 1989) evaluated the surfclam resource as three separate regions: Middle Atlantic, Southern New England and Georges Bank (Mid-Atlantic Fisheries Management Council 1989; Figure A2). To maintain continuity with past assessments, results are presented here for each of the three areas (Table A2). The Middle Atlantic region is further divided into 5 areas for analysis: Long Island, Northern New Jersey, Southern New Jersey, Delmarva, and Southern Virginia-North Carolina. The entire surfclam EEZ resource is now managed under a single quota. The 1992 surfclam quota

Table A2. Total EEZ surf clam landings (mt), by management area, 1983-1992. Data are as reported in mandatory logbooks reported by each vessel. Also given are EEZ totals, as given in the *Fishery Statistics of the United States* series.

Year	Middle Atlantic	Southern New England	Georges Bank	Total	FSUS Total
1983	17,913	679	-	18,591	20,488
1984	19,763	486	2,637	22,886	24,775
1985	19,331	918	2,236	22,478	23,688
1986	21,074	1,596	1,851	24,521	24,922
1987	19,702	1,172	871	21,745	22,146
1988	21,136	1,504	740	23,380	23,950
1989	20,095	1,357	432[1]	21,884	22,331
1990	23,010	1,010	0	24,020	24,027
1991	20,612	0	0	20,612	20,635
1992	20,730[2]	6[2]	0	20,737[2]	-

[1]Fishery closed due to PSP contamination as of late summer, 1989.

[2]1992 landings reported as of October 20, 1992, and expanded by 1.245 to predict the entire year's landings.

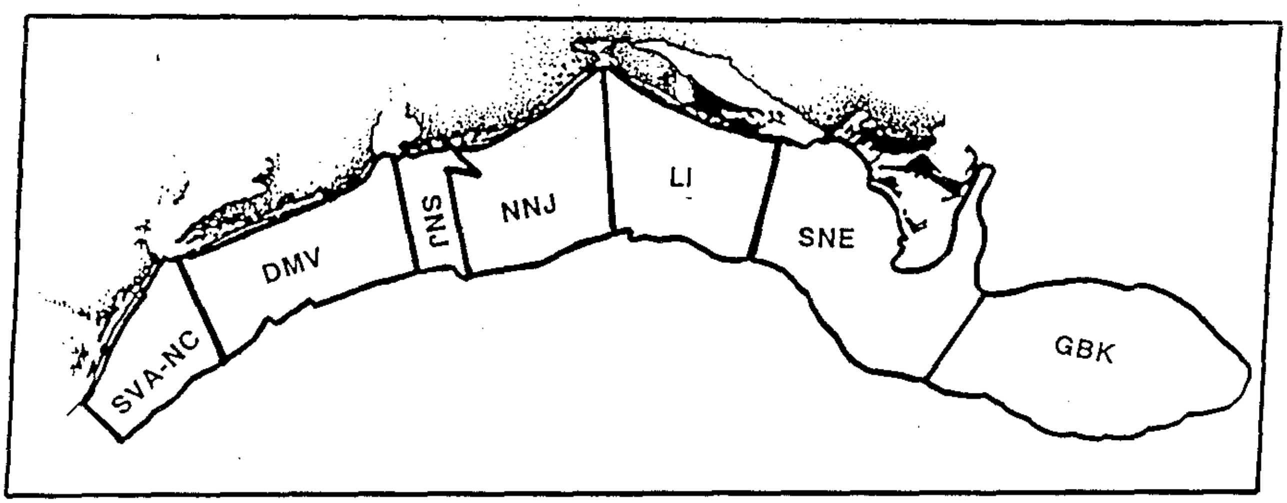


Figure A2. Ocean shellfish survey assessment areas off the Northeastern United States.

for the EEZ was set at 2,850 thousand bushels (22,000 mt of shucked meats) (Mid-Atlantic Fishery Management Council 1992).

Distribution of Landings and Landings per Unit Effort (LPUE)

Between 1990 and 1992, more than 99% of the commercial EEZ surfclam landings were taken from the Middle Atlantic area, and EEZ landings have been fairly stable in this region since 1983 (Table A2). Landings from Southern New England and Georges Bank have always been approximately one order of magnitude lower than the Middle Atlantic landings. While they have always been relatively low, Southern New England landings declined drastically in 1991 and 1992. Georges Bank has been closed since 1989 due to paralytic shellfish poisoning (PSP).

Table A3. EEZ surfclam landings and percent of catch from areas of the Mid-Atlantic region by year. Data are as reported in logbooks by each vessel.

Year	Mid-Atlantic Area LI mt	LI %	NNJ mt	NNJ %	SNJ mt	SNJ %	DMV mt	DMV %	SVA-NC mt	SVA-NC %
1980	-	-	1,244	(10.1)	504	(4.1)	10,556	(85.6)	33	(0.2)
1981	-	-	5,546	(45.5)	137	(1.1)	6,196	(50.8)	321	(2.6)
1982	-	-	3,879	(37.0)	692	(6.6)	4,886	(46.7)	1016	(9.7)
1983	8	(0.0)	5,634	(35.4)	802	(5.0)	7,170	(45.1)	2300	(14.5)
1984	0	(0.0)	8,964	(50.1)	1,501	(8.4)	6,127	(34.2)	1315	(7.3)
1985	0	(0.0)	8,504	(51.3)	899	(5.4)	6,630	(40.0)	558	(3.3)
1986	0	(0.0)	14,294	(75.0)	1,420	(7.4)	3,102	(16.3)	249	(1.3)
1987	0	(0.0)	16,815	(88.3)	560	(2.9)	1,545	(8.1)	139	(0.7)
1988	0	(0.0)	18,780	(91.5)	123	(0.6)	1,441	(7.0)	186	(0.9)
1989	1	(0.0)	15,907	(82.3)	59	(0.3)	3,347	(17.3)	14	(0.1)
1990	0	(0.0)	16,589	(75.2)	740	(3.4)	4,678	(21.2)	49	(0.2)
1991	0	(0.0)	17,092	(85.7)	1,234	(6.2)	1,625	(8.1)	0	(0.0)
1992[1]	0	(0.0)	17,657	(86.8)	2,158	(10.6)	537	(2.6)	0	(0.0)

[1] 1992 landings reported in logbook database as of October 20, 1992, and expanded by 1.245 to predict the entire year's landings.

The first full year of mandatory logbook submissions was 1978. In 1980, 86% of the Mid-Atlantic region's catch came from the Delmarva area (Table A3). Beginning in 1981, recruitment by an abundant 1976 cohort in Northern New Jersey was accompanied by increased fishing effort in that area. By 1984, the majority of the catch was being taken from Northern New Jersey. Since 1986, approximately 80% of the EEZ catch has been from Northern New Jersey (Table A3). The fishery has concentrated in Northern New Jersey because that area has had a greater proportion of large clams (>12.7 cm in length) (see section on Research Vessel Surveys) and, reportedly, because shucked meat yields per bushel were greater than those of Delmarva.

LPUE data are potentially valuable because they can provide an estimate of population abundance through time. In the case of surfclams, however, these data are difficult to interpret because several factors that affect LPUE, other than clam abundance, were not constant over time. The most significant of these are changes through time in discard rates, changes in fishing gear, and suspected changes in accuracy of reported time fishing. These changes are assumed to be due to changes in fishing regulations and growth of a cohort over the minimum size. In spite of these problems, LPUE has declined steadily since 1986 (Table A4; Figures A3-A5) in the region where the surfclam fishery is focused, the Mid-Atlantic (Table A2). Historically, this region has had higher LPUEs than other regions (Figure A3).

Large Class 3 vessels take the majority of landings (Table A4). LPUE of Class 3 vessels in the Mid-Atlantic has changed drastically through time (Figure A3). LPUE ranged from 200 to 700 kg/hr during 1978-1984. It increased to a range of 1,500 to 1,850 kg/hr during 1985-1990, and dropped to 900 to 1,110 kg/hr during 1991-1992. The increase in LPUE was primarily the result of recruitment to the fishery by clams born in the mid-1970s. The recent decline in LPUE probably reflects lower abundance and biomass per tow of surfclams in the Middle Atlantic region.

Most of the Mid-Atlantic catch is taken from the Northern New Jersey area; between 1986-1992 the average percentage of total Mid-Atlantic catch from this area was 84% (Table A3). The LPUE generally declined for all three vessel classes after 1986 off Northern New Jersey (Table A4; Figure A4).

Southern New Jersey is a relatively small area, that typically accounts for 3 to 10% of the landings from the Middle Atlantic. In contrast to Northern New Jersey, catch rates increased in recent years off Southern New Jersey.

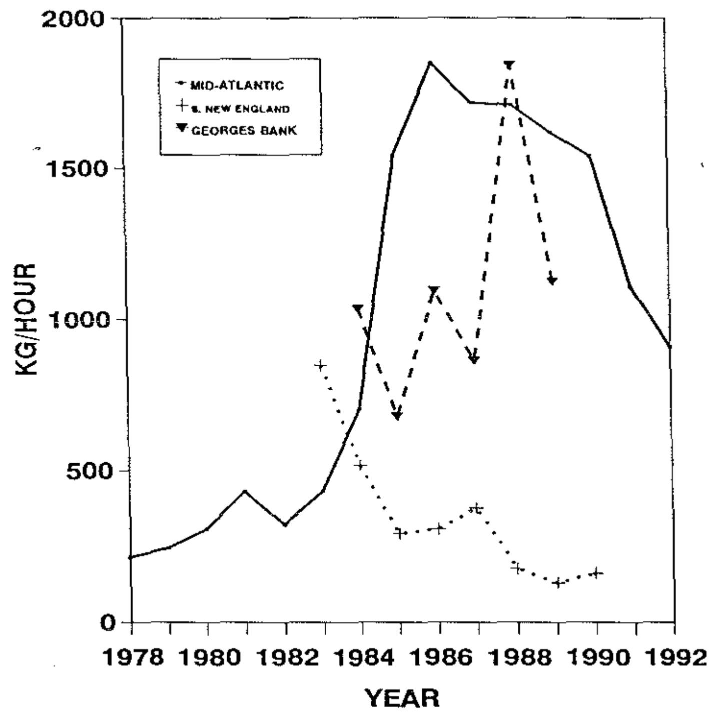
Table A4. Comparison of the Middle Atlantic surfclam landings per unit (LPUE) statistics, 1978-1992. LPUE data are ky of surfclams per hour of fishing time reported in mandatory logbooks submitted by each vessel.[1] Assessment areas are defined in the text. Data in parentheses are percentages of total catch by area taken by the various vessel size classes.[2]

YEAR/Area	Vessel Class 1		Vessel Class 2		Vessel Class 3	
	LPUE	%	LPUE	%	LPUE	%
Northern NJ						
1978	-	(0%)	123	(42%)	170	(58%)
1979	239	(8%)	185	(33%)	262	(58%)
1980	247	(6%)	362	(38%)	648	(56%)
1981	231	(4%)	370	(35%)	478	(61%)
1982	177	(4%)	208	(40%)	324	(55%)
1983	208	(6%)	347	(68%)	378	(26%)
1984	339	(5%)	571	(71%)	686	(23%)
1985	594	(4%)	979	(57%)	1218	(38%)
1986	740	(3%)	1303	(36%)	1851	(61%)
1987	733	(2%)	1211	(35%)	1712	(63%)
1988	725	(2%)	1157	(33%)	1696	(64%)
1989	748	(3%)	1172	(35%)	1550	(62%)
1990	733	(2%)	1187	(32%)	1565	(66%)
1991	401	(0%)	956	(29%)	1064	(71%)
1992	362	(0%)	1026	(24%)	864	(75%)
Southern NJ						
1978	93	(9%)	139	(33%)	177	(58%)
1979	177	(8%)	139	(33%)	200	(59%)
1980	93	(3%)	123	(40%)	324	(56%)
1981	69	(11%)	270	(33%)	339	(56%)
1982	93	(7%)	224	(36%)	270	(57%)
1983	123	(11%)	231	(48%)	424	(41%)
1984	270	(11%)	355	(24%)	601	(65%)
1985	578	(5%)	833	(11%)	1303	(84%)
1986	547	(3%)	1110	(16%)	1542	(81%)
1987	-	(0%)	941	(25%)	1550	(75%)
1988	-	(0%)	771	(38%)	1388	(62%)
1989	-	(0%)	864	(43%)	1342	(57%)
1990	231	(0%)	1072	(41%)	1157	(58%)
1991	247	(0%)	1465	(40%)	1866	(59%)
1992	-	(0%)	1581	(46%)	2090	(54%)
Delmarva						
1978	123	(4%)	154	(25%)	224	(71%)
1979	123	(3%)	147	(22%)	254	(75%)
1980	116	(2%)	154	(22%)	308	(76%)
1981	200	(2%)	216	(13%)	424	(85%)
1982	177	(4%)	200	(11%)	324	(85%)
1983	293	(4%)	231	(12%)	432	(83%)
1984	347	(4%)	447	(12%)	725	(84%)
1985	694	(3%)	1218	(11%)	1881	(86%)
1986	625	(3%)	1033	(10%)	2036	(87%)
1987	486	(2%)	733	(3%)	1920	(95%)
1988	532	(2%)	1681	(5%)	1897	(93%)
1989	563	(0%)	1403	(11%)	1951	(88%)
1990	-	(0%)	1303	(15%)	1527	(85%)
1991	-	(0%)	1010	(20%)	1403	(80%)
1992	-	(0%)	1126	(28%)	1195	(72%)

1 Values for 1978-1979 are from "Assessment Updates for Middle Atlantic, Southern New England, and Georges Bank Surf Clam Populations", Working Paper #4, 9th SAW, by S. A. Murawski. Values for 1980-1992 are from the S1032 logbook database as of Oct. 20, 1992.

2 For 1978-1979, class 1 = 1-50 GRT, class 2 = 51-100 GRT, class 3 = 101 + GRT. For 1980-1992, class 1 = 1-50 GRT, class 2 = 51-104 GRT, class 3 = 105+ GRT.

Figure A3. Landings per unit effort (kg per hour fishing) for Class 3 vessels (defined in Table A4) operating in Mid-Atlantic,. Southern New England, and Georges Bank waters, 1978-1992. Data were derived from vessel trip logbooks for all sizes of clams combined.



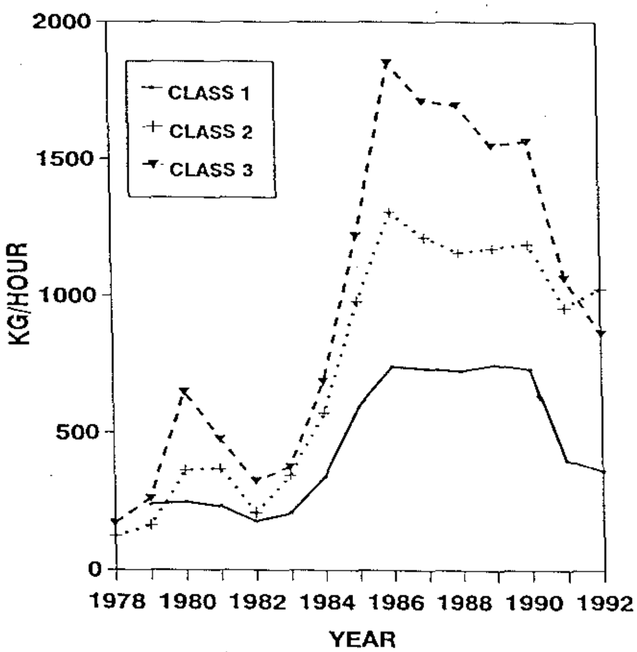


Figure A4. Landings per unit effort (kg per hour fishing) for three vessel size classes (defined in Table A4) operating off Northern New Jersey, 1978-1992. Data were derived from vessel trip logbooks and are for all sizes of clams landed.

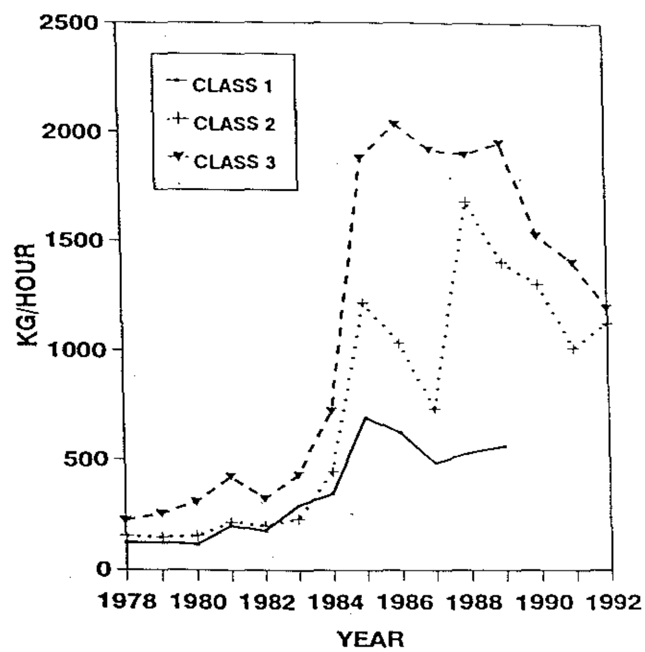


Figure A5. Landings per unit effort (kg per hour fishing) for three vessel size classes (defined in Table A4) operating off Delmarva, 1978-1992. Data were derived from vessel trip logbooks and are for all sizes of clams landed.

Table A5. Stratified mean number and weight (meats only, kg) per tow of surfclams from NMFS surveys off Northern New Jersey, 1965-1992. Data are standardized to a 60-in. wide dredge towed for 5 minutes.

	--Total	Index--	---<14	cm---	---->14	cm----	---%>14	cm---
Survey	Numbers	Weight	Numbers	Weight	Numbers	Weight	Numbers	Weight
May 1965	38.07	4.79	15.44	1.17	22.62	3.62	59	76
Oct 1965	35.73	5.27	6.18	0.51	29.55	4.76	83	90
Aug 1966	30.44	4.51	5.44	0.36	24.99	4.15	82	92
Jun 1969	34.26	5.37	3.93	0.30	30.33	5.07	89	94
Aug 1970	25.73	4.12	4.84	0.30	20.89	3.82	81	93
Jun 1974	21.40	3.37	2.75	0.19	18.66	3.17	87	94
Apr 1976	12.92	2.06	2.39	0.12	10.53	1.93	82	94
Jan 1977	2.45	0.23	1.39	0.05	1.06	0.19	43	81
Jan 1978	2.06	0.16	1.48	0.06	0.58	0.11	28	65
Dec 1978	44.88	1.20	43.85	1.03	1.01	0.17	2	15
Jan 1980	31.70	1.95	27.52	1.22	4.17	0.75	13	38
Aug 1980	53.56	3.74	50.66	3.24	2.90	0.50	5	14
Aug 1981	39.10	3.23	31.15	2.04	8.03	1.19	21	36
Aug 1982	112.79	8.78	101.53	7.11	11.26	1.67	10	19
Aug 1983	72.91	5.94	63.06	4.42	9.85	1.52	14	26
Jul 1984	64.88	5.47	52.71	3.70	12.17	1.77	19	32
Jul 1986	45.57	4.57	30.81	2.37	14.76	2.20	32	48
Jul 1989	58.89	5.71	35.95	2.77	19.94	2.94	34	51
Jul 1992	47.44	4.41	32.65	2.17	14.80	2.23	31	51

For Delmarva, the pattern of change in LPUE with time is similar to that described for the Northern New Jersey area (Table A4; Figure A5). LPUE was high for Class 3 vessels between 1985 and 1989, in the range of 1,881 to 2,036 kg/hr. LPUE fell steadily from 1989 to 1992. Current LPUE levels are slightly higher in Delmarva than Northern New Jersey. In the previous assessment (NEFC 1989), the Delmarva area was viewed as an unused supply of surfclams. While it is true that there has been relatively little exploitation from the Delmarva area to date, the reduction in LPUE (Table A4; Figure A5) suggests that natural mortality has reduced surfclam abundance in the Delmarva area (see section on Research Vessel Surveys.) Therefore, the resource will probably not be as large as had been expected.

There were no reported logbook landings from Southern New England in 1991 or 1992. In previous years, Southern New England LPUE was about an order of magnitude lower than the LPUEs from the Middle Atlantic and Georges Bank (Figure A3). Although LPUE on Georges Bank was relatively high, there are no estimates of LPUE after 1989 because the region has been closed to shellfishing due to PSP contamination. This fishery is still in an exploratory phase.

RESEARCH VESSEL SURVEYS

Stratified random research vessel surveys have been conducted to evaluate the distribution, relative abundance and size composition of surfclam populations in the Middle Atlantic, Southern New England and Georges Bank regions (Figure A2). Standardized sampling proce-

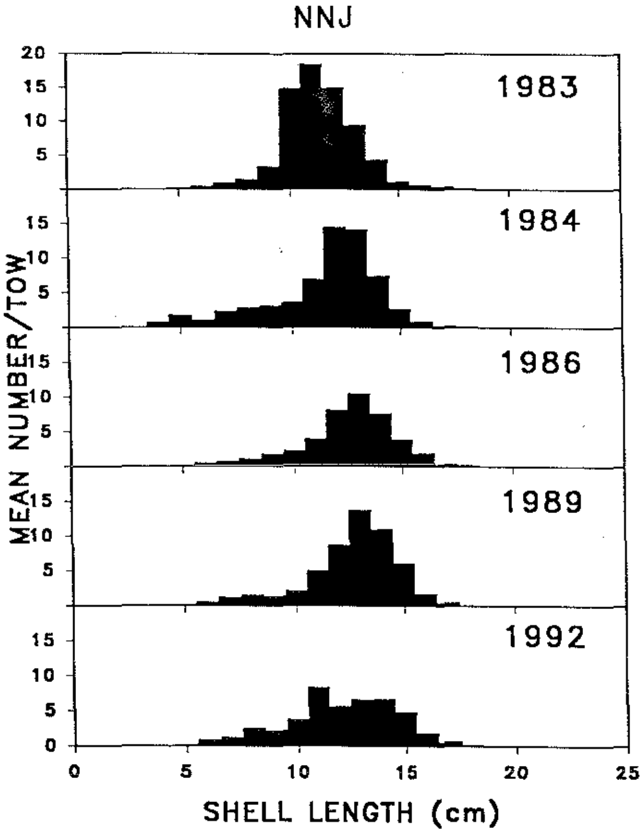


Figure A6. Stratified mean number of surfclams per standardized survey tow at each 1 cm length group in NMFS hydraulic dredge surveys off Northern New Jersey, 1983-1992.

dures used in these surveys are described in Murawski and Serchuk (1989).

Northern New Jersey

The total number and weight per tow declined slowly between 1965-1974, and then declined sharply between 1976 and 1978 (Table A5). The rapid decline is attributable to hypoxic water conditions in 1976 (Murawski and Serchuk 1989). Subsequent to that event, an abundant 1976 cohort has dominated the population. Stratified mean numbers per tow at length are shown in Figure A6. There is no evidence of another strong cohort that will recruit to the fishery and replace the 1976 cohort. Between 1982 and 1992, surfclam abundance declined from an average of 112 to 47 individuals per tow, and meat weight declined from 8.8 to 4.4 kg (Table A5).

Northern New Jersey is composed of five survey strata. Examining the average number of clams of a given length per tow in the 1992 survey for these five strata also demonstrated that small surfclams were generally absent from this area. For strata #21, #25, #88, #89, and #90, the average number of individuals per tow were 37.1, 20.3, 95.2, 88.7, and 0.0, respectively. For the same five strata, average number of individuals per tow smaller than 7 cm in shell length were 1.4, 2.7, 0.2, 1.3, and 0.0. Based on studies by Jones *et al.* (1978), surfclams from this region require approximately 3 years to attain a shell length of 7 cm.

A regression model was fit to ln(abundance) *vs* time to estimate the instantaneous rate of mortality, Z, under the assumption of no migration or recruitment between 1982 and 1992. Both assumptions are fairly reasonable because adult clams do not move, and there is no evidence of any substantial recruitment during the last ten years. The estimate of Z from these data is 0.06, or equivalently, a probability of annual survival, S, of 0.94. Because a minor amount of recruitment has occurred, 0.06 is probably an underestimate of Z. Furthermore, the estimate of Z is imprecise because the coefficient of determination, R2, for the regression model is only 55%.

Southern New Jersey

Average numbers and weights per tow off Southern New Jersey are currently much lower than in the 1960s (Table A6). Based on the 1992 survey, abundance off Southern New Jersey is substantially lower than off Northern New Jersey. Furthermore, the Southern New Jersey population is dominated by much larger clams than are found in other Middle Atlantic assessment areas (Figure A7). Most of the survey catches in this area are composed of individuals larger than 15 cm. While densities of recruits are low, there appears to have been some recruitment into the fishery between 1986 and 1992 (Figure A7).

Delmarva

Based on the 1992 survey, Delmarva has the second highest clam density of all areas (behind Northern New Jersey) (Table A7). Stratified mean numbers per tow at length are shown in Figure A8 for surveys conducted between 1983 and 1992. A recruitment event is evident from the 1984 survey, and numbers have declined steadily. There is no evidence from subsequent surveys of another new cohort that will recruit to the fishery

Table A6. Stratified mean number and weight (meats only, kg) per tow of surfclams from NMFS surveys off Southern New Jersey, 1965-1992. Data are standardized to a 60-in. wide dredge towed for 5 minutes.

	--Total	Index--	---<14	cm---	---->14	cm----	---%>14	cm---
Survey	Numbers	Weight	Numbers	Weight	Numbers	Weight	Numbers	Weight
May 1965	105.98	8.88	78.08	4.37	27.93	4.49	26	50
Oct 1965	82.84	10.64	33.32	2.73	49.52	7.93	60	74
Aug 1966	69.55	9.95	14.62	1.39	54.93	8.56	79	86
Jun 1969	59.73	9.08	5.46	0.42	54.27	8.66	91	95
Aug 1970	16.18	2.65	2.73	0.20	13.45	2.45	83	92
Jun 1974	49.31	8.85	2.22	0.16	47.10	8.69	96	98
Apr 1976	5.20	0.97	0.64	0.03	4.57	0.94	88	96
Jan 1977	2.25	0.23	1.22	0.03	1.03	0.20	46	89
Jan 1978	14.91	2.23	3.85	0.22	11.06	2.00	74	90
Dec 1978	8.60	0.97	4.45	0.23	4.15	0.75	48	76
Jan 1980	13.59	2.29	2.53	0.22	11.06	2.09	81	91
Aug 1980	14.57	2.59	2.95	0.20	11.62	2.39	80	92
Aug 1981	10.47	2.06	0.56	0.03	9.91	2.03	95	99
Aug 1982	20.61	3.51	3.62	0.19	16.99	3.32	83	95
Aug 1983	11.51	2.15	1.50	0.10	10.01	2.05	87	95
Jul 1984	10.30	1.93	0.84	0.06	9.46	1.87	92	97
Jun 1986	18.96	3.17	4.29	0.19	14.67	2.98	77	94
Jul 1989	13.20	1.96	3.80	0.20	9.40	1.76	71	90
Jul 1992	10.51	1.42	4.44	0.24	6.07	1.18	58	83

(Figure A8). Between 1984 and 1992, surfclam abundance declined from an average of 129 to 36 individuals per tow, and mean meat weight declined from 5.68 to 2.8 kg (Table A7).

The Delmarva area is composed of nine strata. Examining the average abundance per tow by size in the 1992 survey demonstrates that small surfclams are rare in these strata. For example, in strata #9, #10, #13, #14, #82, #83, #84, #85 and #86, the mean number of individuals per tow were 69.1, 0.3, 23.3, 0.0, 0.0, 1.0, 7.0, 11.8 and 0.3, respectively. For the same nine strata, mean numbers of clams that were smaller than 70 mm (*i.e.*, less than 3 years old) in shell length were 1.7, 0.0, 0.1, 0.0, 0.0, 0.5, 0.8, 0.4, 0.0.

A regression model was fit to ln(abundance) *vs* time to estimate Z, under the assumption of no migration or recruitment between 1984 and 1992. Both assumptions are fairly reasonable, for the same reasons stated earlier. The estimate of Z from these data is 0.17, or equivalently, S=0.84. This parameter estimate is more precise because the coefficient of determination, R2, for the regression model was 97%. Thus, it appears that the total mortality rate in this area has been greater than in the more heavily harvested area, Northern New Jersey.

Southern Virginia-North Carolina

The abundance per tow is approximately half that of Northern New Jersey (Table A8). Individuals less than 7 cm shell length are rare, as at other areas.

Table A7. Stratified mean number and weight (meats only, kg) per tow of surfclams from NMFS surveys off Delmarva, 1965-1992. Data are standardized to a 60-in. wide dredge towed for 5 minutes.

Survey		--Total Index--		---<14 cm---		---->14 cm----		---%>14 cm---	
		Numbers	Weight	Numbers	Weight	Numbers	Weight	Numbers	Weight
May	1965	27.68	2.26	15.82	0.83	11.86	1.44	43	63
Oct	1965	28.02	2.81	10.76	0.58	17.25	2.23	62	79
Aug	1966	32.53	3.54	10.75	0.64	21.78	2.90	67	82
Jun	1969	26.26	2.78	8.03	0.50	18.22	2.28	69	82
Aug	1970	19.64	2.34	4.71	0.30	14.93	2.04	76	88
Jun	1974	36.66	4.59	6.68	0.42	29.98	4.17	82	91
Apr	1976	21.93	2.37	7.30	0.25	14.63	2.12	67	90
Jan	1977	11.37	1.40	2.68	0.09	8.69	1.31	76	93
Jan	1978	11.61	1.15	4.90	0.17	6.71	1.00	58	85
Dec	1978	621.33	6.02	616.44	5.32	4.88	0.72	1	88
Jan	1980	68.50	3.17	58.07	1.62	10.44	1.54	15	49
Aug	1980	48.53	2.64	39.39	1.26	9.14	1.37	19	52
Aug	1981	162.89	6.91	156.86	6.02	6.02	0.89	4	13
Aug	1982	109.14	5.68	102.53	4.71	6.61	0.97	6	17
Aug	1983	51.39	3.79	39.36	2.14	12.03	1.65	23	44
Jul	1984	129.19	5.58	119.17	4.27	10.02	1.31	8	24
Jun	1986	104.62	7.28	94.49	5.91	10.13	1.37	10	19
Jul	1989	48.86	3.78	39.49	2.64	9.37	1.14	19	30
Jul	1992	36.31	2.81	28.18	1.75	8.13	1.06	22	38

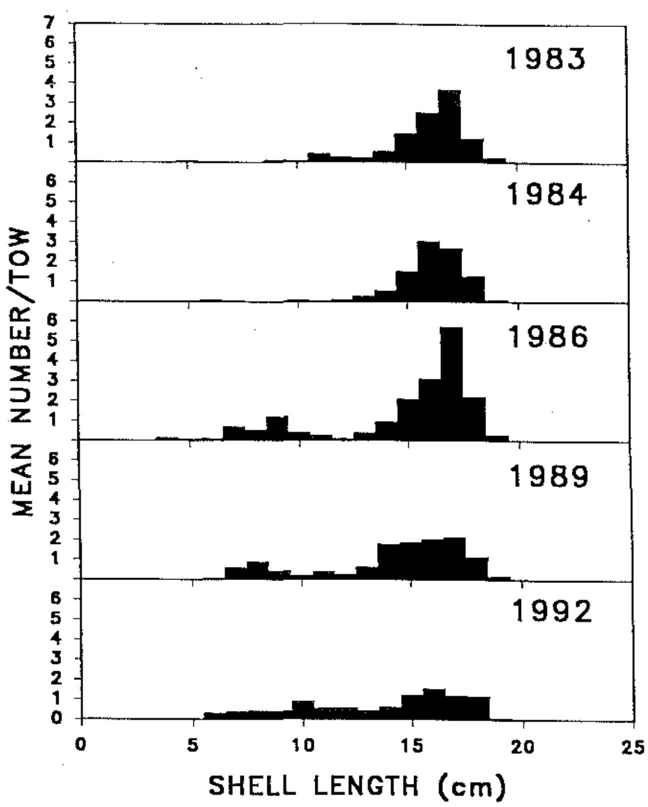


Figure A7. Stratified mean number of surfclams per standardized survey tow at each 1 cm length group in NMFS hydraulic dredge surveys off Southern New Jersey, 1983-1992.

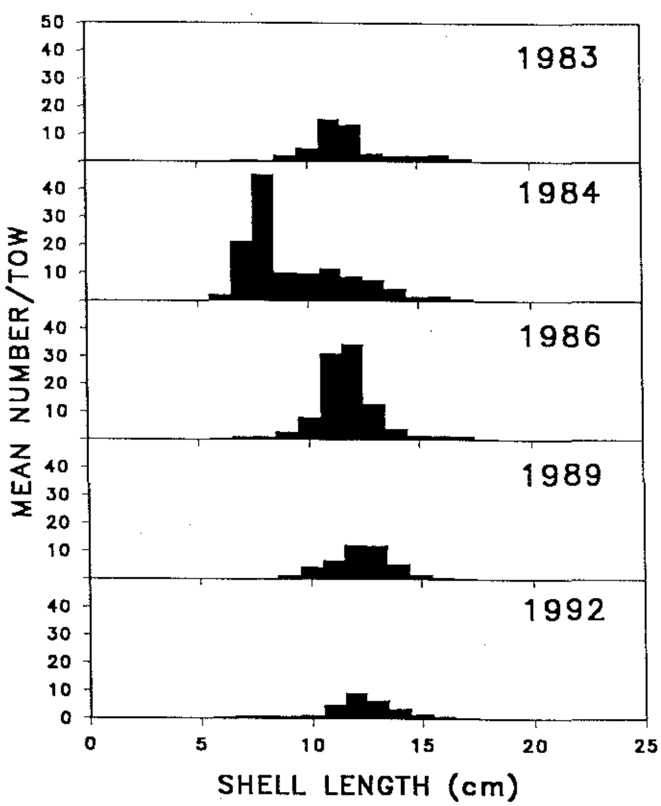


Figure A8. Stratified mean number of surfclams per standardized survey tow at each 1 cm length group in NMFS hydraulic dredge surveys off Delmarva, 1983-1992.

Table A8. Stratified mean number and weight (meats only, kg) per tow of surfclams from NMFS surveys off Southern Virginia-North Carolina, 1965-1992. Data are standardized to a 60-in. wide dredge towed for 5 minutes.

Survey		--Total Numbers	Index-- Weight	---<14 Numbers	cm--- Weight	---->14 Numbers	cm---- Weight	---%>14 Numbers	cm--- Weight
May	1965	3.77		2.78		0.90		24	
Oct	1965[1]	11.93		11.81		0.12		1	
Aug	1966[1]	17.56		16.28		1.27		7	
Jun	1969	80.02		78.68		1.34		2	
Aug	1970[1]	3.20		0.74		2.46		77	
Jun	1974	30.09		12.66		17.42		58	
Apr	1976	6.21		1.11		5.10		82	
Jan	1978	3.24		1.06		2.18		67	
Jan	1980[1]	87.02		86.15		0.87		1	
Aug	1981[1]	25.89		17.97		7.92		31	
Aug	1982[1]	2.06		1.18		0.88		43	
Aug	1983	10.25	0.55	9.11	0.44	1.14	0.11	11	20
Jul	1984	20.78	1.32	15.50	0.82	5.28	0.50	25	38
Jun	1986	16.56	1.14	12.91	0.83	3.65	0.31	22	27
Jul	1989	11.70	0.77	6.30	0.33	5.40	0.44	43	43
Jul	1992	22.67	1.26	20.12	1.05	2.55	0.26	11	17

[1]Only a portion of total assessment area surveyed.

Southern New England-Long Island-Georges Bank

Based on surveys conducted between 1986 and 1992, Southern New England and Long Island populations have low density and therefore, low weight per tow (Table A9).

Based on four surveys, Georges Bank has a relatively high abundance of surfclams (Table A9). Based on the 1992 survey, only 15% of the Georges Bank population is greater than 14 cm in shell length. Clams less than 7 cm make up a larger fraction of the Georges Bank population than in other areas surveyed. Strata with high surfclam abundance include #67, #68, #72 and #73.

Comparison of All Areas

For the three most recent research vessel surveys (1986, 1989, 1992), minimum 95% confidence intervals were computed for the stratified mean of each region (Figures A9 and A10). These are minimum sized intervals because the maximum possible degrees of freedom for the stratified means were used in the computations (see Cochran, 1977). While the size of the intervals might be reduced if they were recomputed using log transformed data, the intervals are in general wide. Therefore, apparent changes in stratified mean abundance or biomass per tow should be interpreted with caution. There appears to have been a decrease in surfclam density in the Delmarva region from 1986 to 1989-1992. Although 75 to 87% of the 1990-1992 surfclam landings were taken from Northern New Jersey, the decline in average abundance from 1989 to 1992 does not appear to be statistically significant (Figure A9).

Table A10 gives the minimum stock biomass in each geographical area sampled in the 1992 survey. With respect to biomass, the areas can be ranked from high to low as follows:

1. Northern New Jersey
2. Delmarva
3. Georges Bank
4. Southern Virginia-North Carolina
5. Southern New England
6. Southern New Jersey
7. Long Island

The depletion equation,

$$B_{t+1}=(B_t-C_t)e_{-m}$$

where

t=time,

B=stock biomass,

C=annual catch, and

m=instantaneous natural mortality rate,

Table A9. Stratified mean number and weight (meats only, kg) per tow of surfclams from NMFS surveys off Long Island and Southern New England, and off Georges Bank, 1984-1992. Data are standardized to a 60-in. wide dredge towed for 5 minutes.

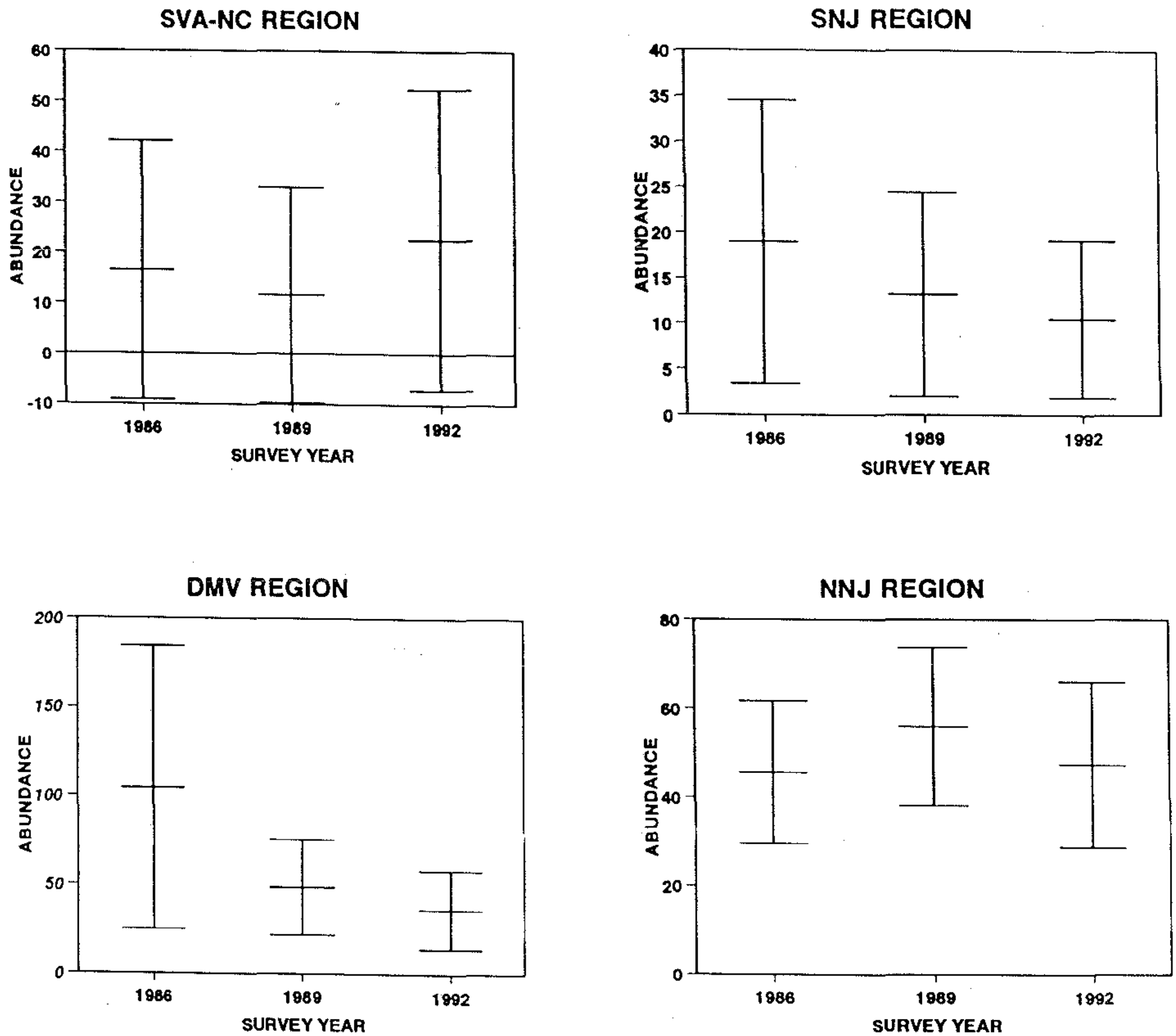
	--Total	Index--	---<14	cm---	---->14	cm----	---%>14	cm---
Survey	Numbers	Weight	Numbers	Weight	Numbers	Weight	Numbers	Weight
			Long	Island				
Jun 1986	1.79	0.23	0.58	0.03	1.20	0.21	67	88
Jul 1989	5.87	0.67	2.57	0.15	3.30	0.52	56	77
Jul 1992	6.20	0.46	5.53	0.35	0.67	0.10	11	23
			Southern	New England				
Jun 1986	6.34	0.84	1.51	0.06	4.83	0.78	76	93
Jul 1989	7.14	0.99	2.14	0.13	5.00	0.86	70	87
Jul 1992	3.75	0.43	1.37	0.04	2.38	0.39	63	90
			Georges	Bank				
Jul 1984	6.25	0.58	3.88	0.24	2.37	0.34	38	58
Jun 1986	19.77	1.31	17.21	0.93	2.56	0.38	13	29
Jul 1989	29.34	3.01	19.58	1.71	9.76	1.30	33	43
Jul 1992	23.71	1.63	20.20	1.13	3.52	0.49	15	30

was used to estimate how long the stock can support current rates of harvesting. Estimates were made for two values of m, both of which seem reasonable based on survey data. Although the equation does not consider growth, recruitment, or the possibility of rare but high m values in some years, the results suggest that the entire stock can support the fishery for 14 to 18 more years (Table A10). The biomass of the Mid-Atlantic can support its current annual catch for another 11 to 14 years. The biomass of the Northern New Jersey area can support its annual catch for 6 to 7 more years. Assuming m=0.06, the corresponding estimate for Delmarva is 30 years; however, if m is as high as 0.1, as suggested by the regression model (see section on Research Vessel Surveys, discussion of Delmarva), then the supply will last only 22 years at the current harvest rate.

OVERVIEW AND PROGNOSIS

Assuming natural mortality rates remain at their current low levels, commercial catch and research vessel survey data indicate that the Mid-Atlantic region can support its current level of catch for another 11 to 14 years. Almost 75% of surfclam stock biomass is in the Mid-Atlantic region. In recent years, landings per unit effort have decreased, and LPUE will continue to decrease by a substantial amount each year in the

Figure A9. Minimum 95% confidence intervals for the stratified mean of surfclam abundance per tow for Southern regions for three research vessel surveys (1986, 1989, 1992). Computations were made on untransformed data.



major clamming areas. Unless a major recruitment event takes place in the Mid-Atlantic region, those stocks of surfclams will become depleted. If a major recruitment event were to occur in 1993, it would take at least until 2000 for the clams to grow to the size at which they are typically harvested now. Although LPUE has declined, Northern New Jersey and Delmarva still have higher surfclam densities and weights per tow than other geographical areas (based on the 1992 survey); thus, it is unlikely that the fishery will migrate to a new area yet.

Considering the decline in LPUE in the Mid-Atlantic region, the Georges Bank surfclam population may be targeted for harvesting, assuming it is reopened. Surfclam biomass on Georges Bank is relatively high, and LPUE was historically almost as high as in the Middle Atlantic.

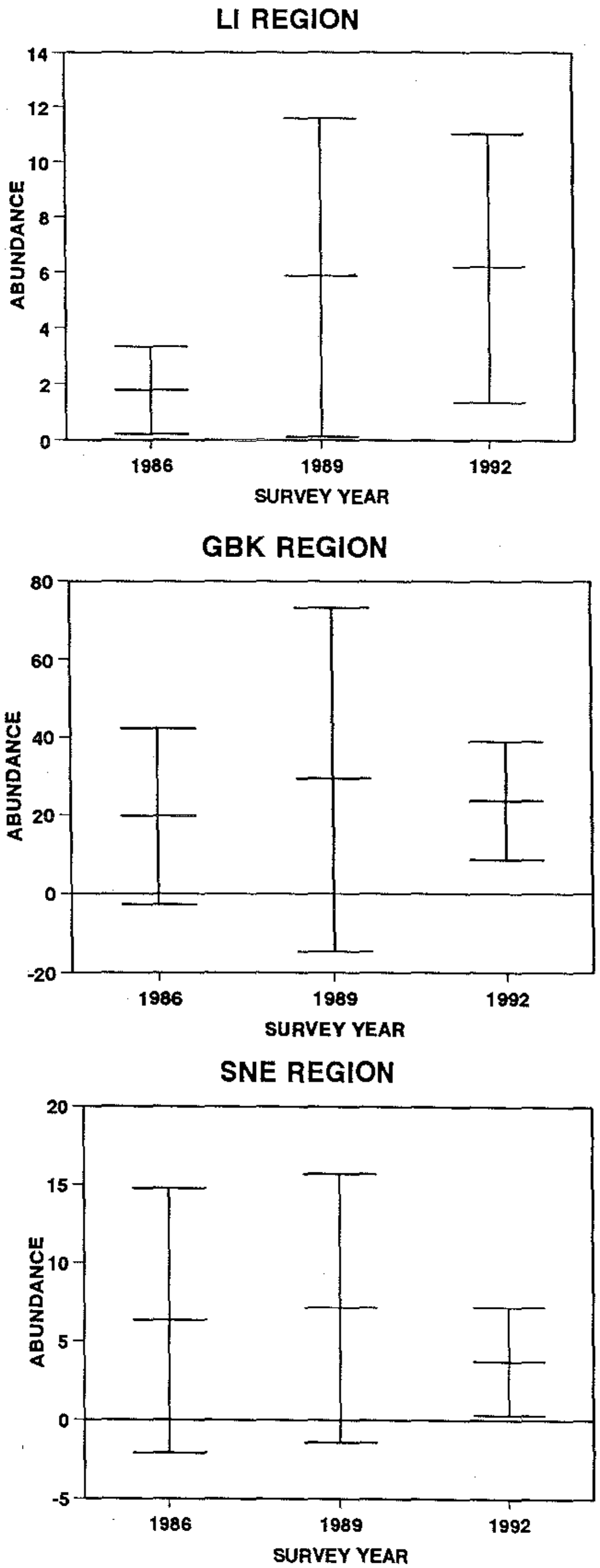


Figure A10. Minimum 95% confidence intervals for the stratified mean of surfclam abundance per tow for Northern regions for three research vessel surveys (1986, 1989, 1992). Computations were made on untransformed data.

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Table A10. Landings, biomass (mt), and current supplies of surfclams, expressed in number of years, by geographical area. Estimates of "supply years" are based on 1991 landing rates, unless there were no landings in 1991, and do not consider changes that might occur in the population in the future due to recruitment, growth, or catastrophic mortality. m = instantaneous rate of natural mortality.

Geographical Area	1991 Landings	Minimum Stock Biomass[1]	Supply Years m=0.02	Supply Years m=0.06
GBK	0	87,133	28[2]	20[2]
SNE	0	17,867	10[2]	9[2]
LI	0	12,590	7[2]	6[2]
NNJ	17,092	141,941	7	6
SNJ	1,234	16,344	11	9
DMV	1,625	133,745	48	30
SV_NC	0	35,261	18[2]	14[2]
Mid Atlantic[3]	19,952	339,881	14	11
Total	19,952	444,881	18	14

[1]Biomass values are derived from the research vessel survey of 1992.
[2]"Supply years" are based on 1990 annual quotas. Hypothetical annual landings by region are assumed to be 2,313 mtons (GBK), 1,542 mtons (SNE), 1,542 mtons (LI), and 1,542 mtons (SV_NC).
[3]The Mid Atlantic Region is the sum of the 1991 landings from LI, NNJ, SNJ, DMV, and SV_NC.

SURFCLAM RECOMMENDATIONS/RESEARCH NEEDS

1. Investigate the possibility of reduced survey sampling in Georges Bank, Southern New England and Long Island so that sampling and survey precision can be increased in the Mid-Atlantic.

2. Calculate precision estimates for R/V survey data using appropriate statistical transformations.

3. Explore logbook data on a vessel by vessel basis to determine whether LPUE has declined over time.

4. Investigate further the apparent differences in natural mortality rates between the assessment areas NNJ and DMV. Examine any data sets that might provide estimates of predation on surfclams.

5. Develop stock depletion models for surfclams, incorporating LPUE data (adjusted for discards), catch length frequency data, research survey data, and aging studies. The objective of these models is to estimate absolute stock size and fishing mortality rates.

6. May need to evaluate commercial length composition to determine if commercial size sampling is currently adequate.

B. OCEAN QUAHOG ASSESSMENT

INTRODUCTION

The status of the ocean quahog, *Arctica islandica*, off the Atlantic coast of the United States is updated through 1992. Commercial landings and effort data are analyzed, as well as results from NEFSC research vessel surveys. Spatial and temporal trends in resource abundance and size composition are presented, and a medium-term resource prognosis is provided.

This stock was last assessed at the 10th SAW in 1990 (NEFC 1990). The 1990 assessment indicated that commercial CPUE had declined in the Delmarva and New Jersey areas in both 1989 and 1990, although declines in abundance were not evident in the research vessel survey indices for these areas. Size composition data from the 1980-1989 surveys indicated a lack of significant recruitment of quahogs during the preceding 20 to 30 years.

Presently, the entire EEZ ocean quahog resource is managed under a single catch quota (Mid-Atlantic Fishery Management Council 1992). The 1992 quota for the EEZ is 5.3 million bushels [equivalent to 24,040 (mt) of shucked meats].

Table B1. Landings of ocean quahog (mt meats) from state waters and the Exclusive Economic Zone, 1967-1992.

Year	State Waters	EEZ	Total	Percent EEZ
1967	20	-	20	0
1968	102	-	102	0
1969	290	-	290	0
1970	792	-	792	0
1971	921	-	921	0
1972	634	-	634	0
1973	661	-	661	0
1974	365	-	365	0
1975	569	-	569	0
1976	656	1,854	2,510	74
1977	1,118	7,293	8,411	87
1978	1,218	9,197	10,415	88
1979	1,404	14,344	15,748	91
1980	1,458	13,885	15,343	90
1981	410	15,966	16,375	97
1982	207	15,572	15,779	99
1983	701	15,228	15,978	96
1984	1,200	16,401	17,602	93
1985	-	23,566	23,566	99
1986	814	19,771	20,585	96
1987	569	22,226	22,795	98
1988	412	20,594	21,006	98
1989	184	22,996	23,145	99
1990	116	21,079	21,195	99
1991	40	22,246	22,287	100
1992	NA	22,640[1]		

[1] Estimated

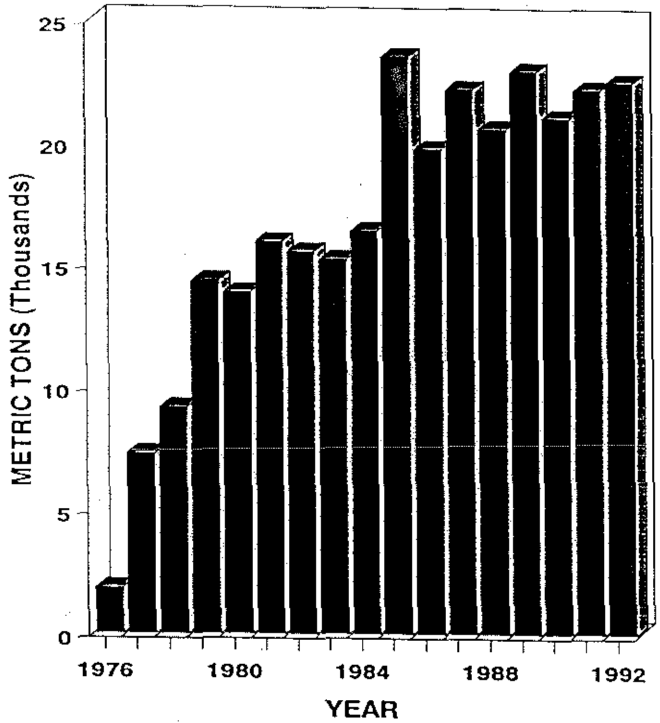

Figure B1. Landings of ocean quahog from the EEZ, 1976-1992. Data are given in 1,000 mt of shucked meats. Landings for 1992 are predicted for the entire year, based on logbook data available as of October 20, 1992 in the S1032 database.

ANALYSIS OF COMMERCIAL DATA

Commercial fishery data from 1980 onward were obtained from vessel logbooks required by all participants in the ocean quahog fishery. The logbooks contain information on landings, effort, catch location, and vessel characteristics.

A minor change was made in the vessel size class categories used in the current assessment *vs* those used in previous assessments. As well, data presented in all tables and figures are now given in metric units (1 bushel of ocean quahogs = 10 lbs = 4.536 kg).

COMMERCIAL FISHERY

Since the inception of the offshore ocean quahog fishery in 1976, cumulative landings of ocean quahogs from the Exclusive Economic Zone (EEZ) have totaled 283,752 mt of shucked meats (Table B1; Figure B1). EEZ landings increased from 21,079 mt in 1990 to 22,246 mt in 1991 (+5.5%). Landings from state waters decreased from 116 mt in 1990 to 40 mt in 1991 (-65.5%). Total ocean quahog landings in 1991 were 22,287 mt of shucked meats, representing a 5.2% increase from 1990.

Since 1977, the offshore fishery has been regulated by catch quotas under provisions of the Surf Clam and Ocean Quahog Fishery Management Plan (FMP) developed by the Mid-Atlantic Fishery Management Council. Since 1985, annual EEZ landings have remained fairly stable, ranging between 19,000 and 24,000 mt (Table B1;Figure B1).

Distribution of Landings and Catch per Unit Effort

During the last 10 years, the majority of ocean quahog landings have been from the Middle Atlantic Bight, especially off the coast of New Jersey and Delaware (Figure B2). This has been attributed to the proximity of land-based shucking facilities rather than to high quahog abundance. This fishery has expanded since 1983 to involve the entire Middle Atlantic region, as well as a portion of the Gulf of Maine (Figure B2). Less than 1% by weight of the 1992 quahog landings (Table B1) were taken from the Gulf of Maine.

Tables B2 and B3 and Figures B2-B6 provide data on catch, effort, and CPUE for various fishing areas during the 1979-1992 period. Annual landings from the Middle Atlantic region have been relatively stable since 1987, ranging between 19,000 and 21,000 mt (Table B2). During 1990-1992, Class 3 vessels accounted for about 80 to 85% of the total Middle Atlantic catch. Prior to 1990, landings and fishing effort were highest in the Delmarva area. Since 1990, however, most landings have come from the New Jersey area. In 1991, of the total Mid-Atlantic harvest of 19,708 mt of quahog meats, 39.1% was from the Delmarva area and 60.9% from New Jersey.

There have been no regulations regarding legal minimum landing sizes for quahogs, and little discarding occurs in the fishery. The recent shift in the fishery from Delmarva to New Jersey is related to changes in CPUE (Table B2; Figure B3). Although CPUE has been declining in both areas since 1988, CPUE in New Jersey has been greater (10%) than in Delmarva from 1990 onward (Table B2).

Estimates of the instantaneous rate of total mortality (Z) in each area were obtained by regressing ln(CPUE) *vs* time (1986-1992) [*e.g.*, the slope of the regression provides an estimate of Z]. For the Delmarva, New Jersey, and the total Mid-

Table B2. Summary of ocean quahog catch and CPUE data for the Middle Atlantic fishery, 1979-1992. **Landings** in mt; **Effort** in 1,000 hours fished; **CPUE** is kg per hour fished; **Sum** is sum of all landings by vessel class; **Catch** is catch by Class 3 vessels (101+ GRT) used in the CPUE index; **Eff** is effort.

	Total Area				Delmarva				New Jersey			
Year	**Sum**	**Catch**	**Eff**	**CPUE**	**SUM**	**Catch**	**Eff**	**CPUE**	**SUM**	**Catch**	**Eff**	**CPUE**
1979	12,859	8,759	14.5	603	3,125	1,941	2.8	699	9,680	6,772	11.6	585
1980	12,143	10,746	20.4	526	4,568	4,409	7.4	599	7,570	6,332	13.0	485
1981	9,598	8,845	15.2	585	3,656	3,620	5.7	635	5,869	5,166	9.3	553
1982	9,122	8,600	13.0	662	6,976	6,845	9.5	721	2,118	1,728	3.5	499
1983	13,630	12,923	19.4	667	9,675	9,430	13.0	721	3,960	3,493	6.4	549
1984	15,921	14,420	23.3	671	11,213	10,523	16.1	653	4,699	3,887	7.2	535
1985	18,048	16,456	25.1	653	10,891	10,120	14.7	689	6,994	6,164	10.3	599
1986	17,513	15,644	23.3	671	10,192	8,904	13.1	676	7,321	6,740	10.1	662
1987	20,416	18,824	28.2	667	12,936	11,984	17.8	671	7,480	6,840	10.4	658
1988	18,910	18,103	29.9	608	14,161	13,481	22.5	599	4,704	4,577	7.3	630
1989	20,697	18,157	32.5	558	11,975	10,188	18.5	549	8,723	7,965	14.0	567
1990	19,636	16,824	32.0	526	7,611	6,459	13.1	490	12,011	10,351	18.8	549
1991	19,708	16,864	37.4	449	7,706	6,473	15.6	413	12,002	10,392	21.7	476
1992[1]	9,480	7,607	16.9	449	3,279	2,708	6.5	417	6,201	4,894	10.4	467

[1] **Data through October 20, 1992 only**

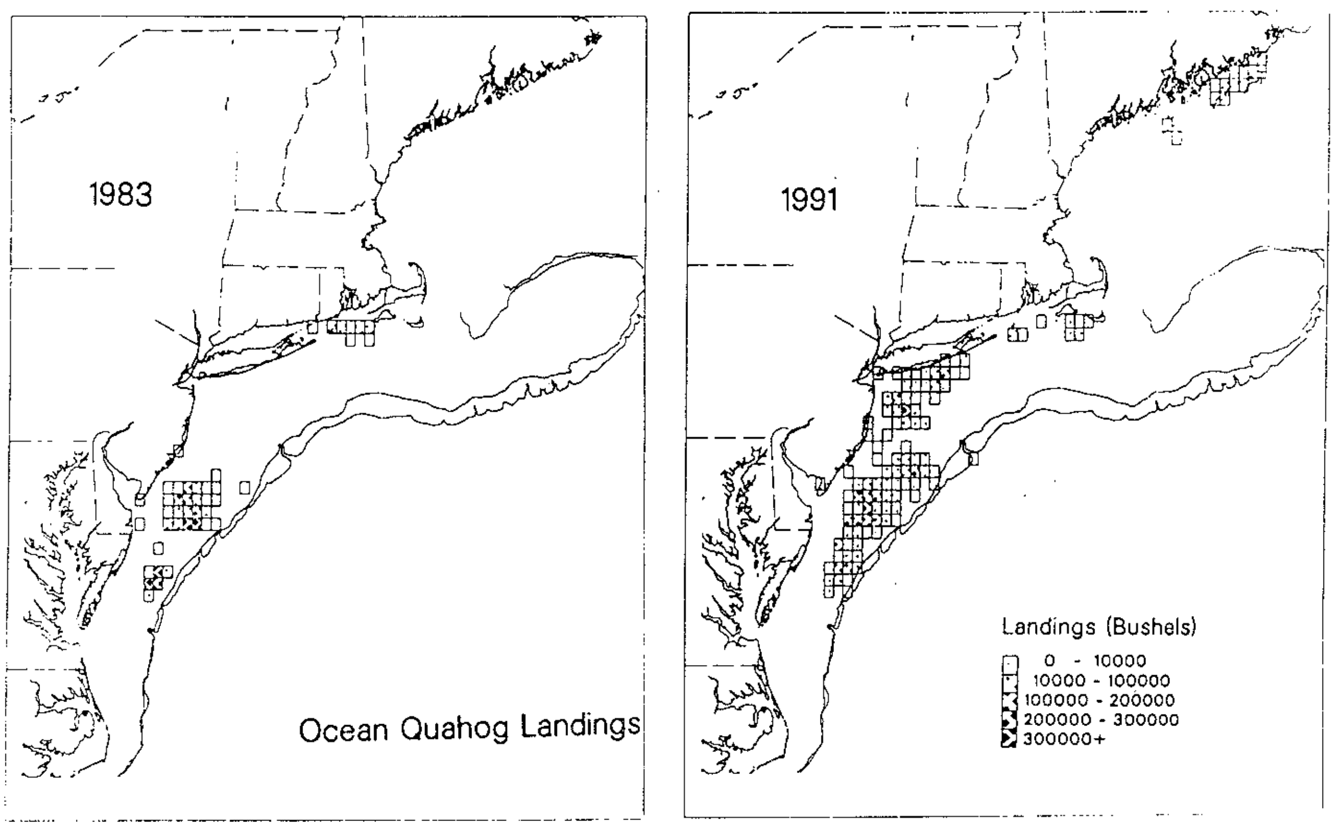

Figure B2. Geographic distribution of ocean quahog landings from the Middle Atlantic Bight to the Gulf of Maine, 1983 and 1991. Data were derived from mandatory logbook submissions and are expressed in bushels of quahogs landed by 10-min square.

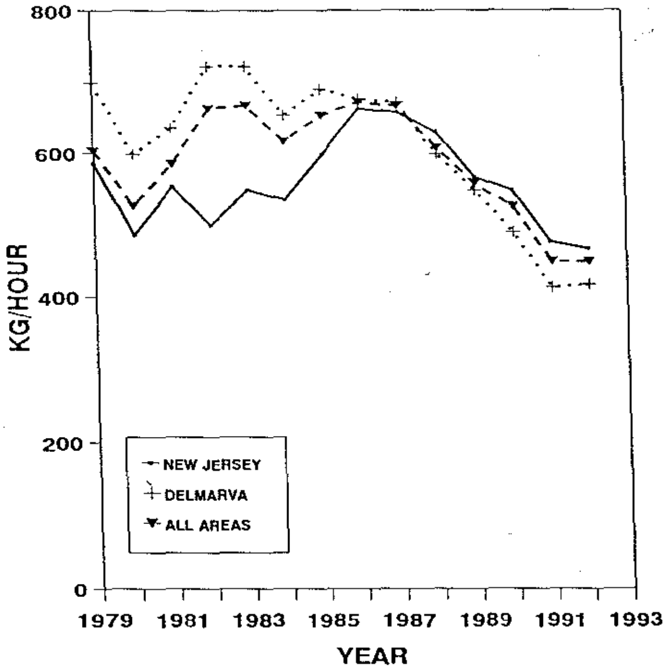

Figure B3. Catch per unit effort (CPUE, kg per hour fished) for Class 3 vessels (1979: 101+ GRT; 1980-1992: 105+ GRT), fishing in two areas of the Middle Atlantic Bight, 1979-1992. Data were derived from mandatory logbook submission data.

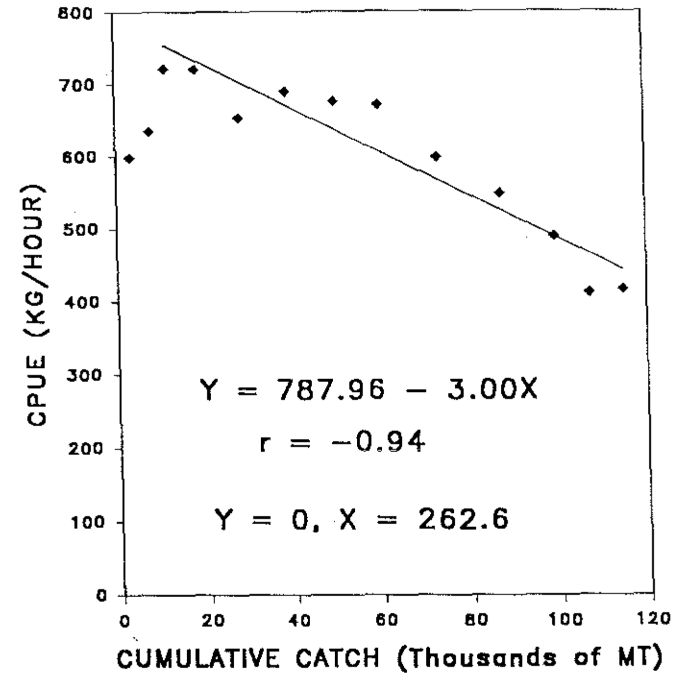

Figure B4. Relationship between CPUE (kg per hour fishing by Class 3 vessels, 105+ GRT) and cumulative ocean quahog catch in the Delmarva assessment area, 1982-1992. Regression statistics indicate the theoretical cumulative population extant at the beginning of the series to be 262,000 mt of meats. CPUE is for time t+1, while cumulative catch is for time 0 to t.

Atlantic areas, the regression analyses gave estimates of Z = 0.09, 0.06, and 0.08, respectively. In all three regressions, the data fit was good (*i.e.*, R2 >94%). Other estimates of Z, independent of those presented above, were derived using research survey data (see section on Research Vessel Surveys.)

A Leslie model was used to estimate the virgin biomass (how much resource was present when the quahog fishery began), and the fraction remaining today (Hilborn and Walters 1992). The analysis assumes no recruitment, balanced immigration/emigration and little or no growth. Although these assumptions are not strictly true, they are reasonable for ocean quahogs given the very slow growth rate of the species and the absence of significant recruitment in the Middle Atlantic region during 1979-1992. The estimation procedure involves regressing CPUE at time t+1 on cumulative catch at time t, and then extrapolating from the regression the cumulative catch when CPUE is 0. For the Delmarva area, cumulative catch to date has been 118,000 mt (Figure B4); the corresponding estimate of prefishery biomass (in 1982) is 263,000 mt. This result suggests that 45% (118/263) of the Delmarva resource has been harvested to date.

The same analysis was applied to six ten-minute squares in the Mid-Atlantic to derive estimates of past and present quahog biomass on a finer geographical scale (Figure B5). The ten-minute squares selected were areas in which intensive harvesting of quahogs has occurred (Table B3). For the three ten-minute squares analyzed in the Delmarva area, estimates of the percentage of resource harvested were 76.4%, 72.6%, and 52.8%. For the two Southern New Jersey squares, the estimates of resource harvested to date were 42.7% and 44.2%. The proportion removed from the single 10-minute square analyzed in Northern New Jersey was 34.5% (Figure B6). In five of the six cases, the data fit the models well, with R^2 values greater than 88%.

RESEARCH VESSEL SURVEYS

Stratified random research vessel surveys have been conducted between 1980 and 1992 to evaluate the distribution, relative abundance and size composition of ocean quahog populations in the Middle Atlantic, Southern New England, and Georges Bank regions (Figure B7). Standardized sampling procedures used in these surveys are described in Murawski and Serchuk (1989). In 1992, a set of nonrandom dredge hauls were also made in the Gulf of Maine.

Delmarva

The Delmarva area was the focus of the quahog fishery from 1982 to 1989. Survey abundance and biomass indices obtained during this period were relatively stable (Table B4), but markedly declined between 1989 and 1992 (number/tow: 45 *vs* 28). The highest survey abundances have been in sampling stratum # 14 (Table B7).

Between 1980-82 and 1992, mean weight per tow in the Delmarva area declined by 38% (Table B4: 1.68 to 1.04 kg/tow). Survey size composition data indicate that small quahogs (< 70 mm in shell length) are rare in the Delmarva area (Figure B8). Individuals may take as long as 20 years to attain a shell length of 70 mm (Ropes *et al.* 1984a,b). To estimate total mortality (Z) from the survey data, a regression model was fit to ln(survey abundance index) vs time (1981-1992), under the assumption that no migration or recruitment occurred of quahogs during this period. These assumptions are fairly reasonable since adult quahogs do not move, and there has been no evidence during the last ten years of any substantial recruitment. For the 1981-1992 period, Z is estimated to be 0.03 (implying an

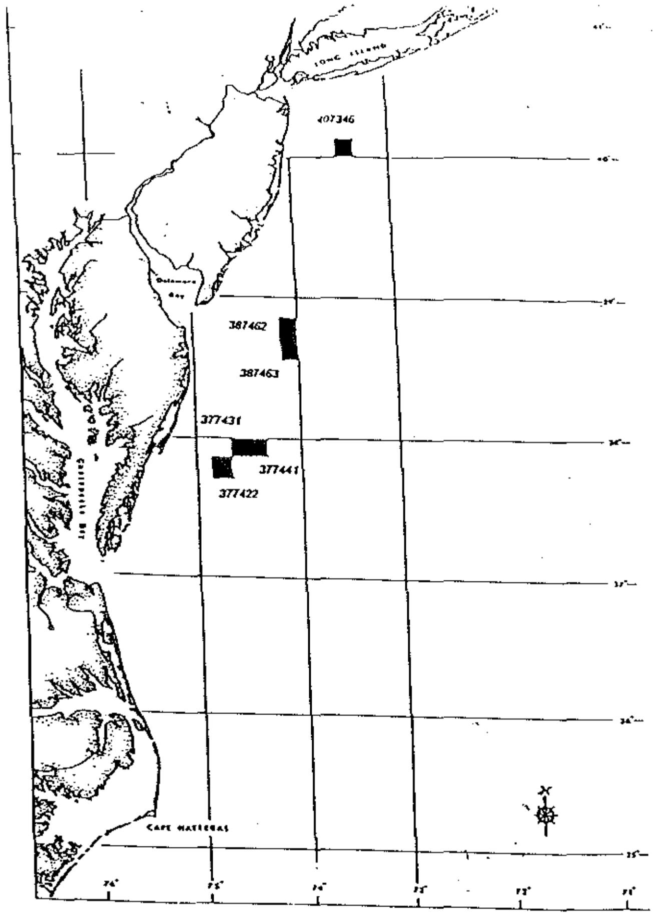

Figure B5. Locations of six 10-min squares for fine-scale analysis of the relationship between cumulative ocean quahog catch and CPUE (Figure B6). These squares represent locations of previous or current intensive harvesting.

Table B3. Cumulative ocean quahog catch (1,000 mt of meats) and CPUE (kg meats per hour) by Class 3 vessels for six 10-min squares (see Figure B5) in the Middle Atlântic Bight, 1983-1992

	Ten Minute Square											
	377422		377431		377441		387462		387463		407346	
Year	CUM	CPUE	CUM	CPUE	CUM	CPUE	CUM	CPUE	CUM	CPUE	CUM	CPUE
1983	1.68	814	1.94	816	0.06	862	0.38	619	1.42	740	-	-
1984	2.75	687	4.10	662	1.16	799	1.42	633	3.44	668	-	-
1985	3.76	782	6.00	742	3.66	852	3.91	604	4.73	644	0.15	841
1986	5.71	675	8.13	734	4.77	732	5.12	593	5.30	646	0.99	999
1987	7.56	753	10.84	718	6.87	637	6.42	607	5.91	597	1.70	625
1988	9.28	619	13.60	664	9.52	577	7.32	538	6.96	536	2.90	806
1989	9.54	439	14.12	514	10.81	497	9.59	513	8.40	545	3.99	728
1990	9.81	408	14.76	451	11.38	562	11.27	479	9.82	523	4.88	680
1991	10.04	259	15.55	362	12.24	404	12.43	396	10.67	435	6.44	672
1992	10.33	401	15.66	286	12.52	365	13.40	384	11.29	418	7.02	596

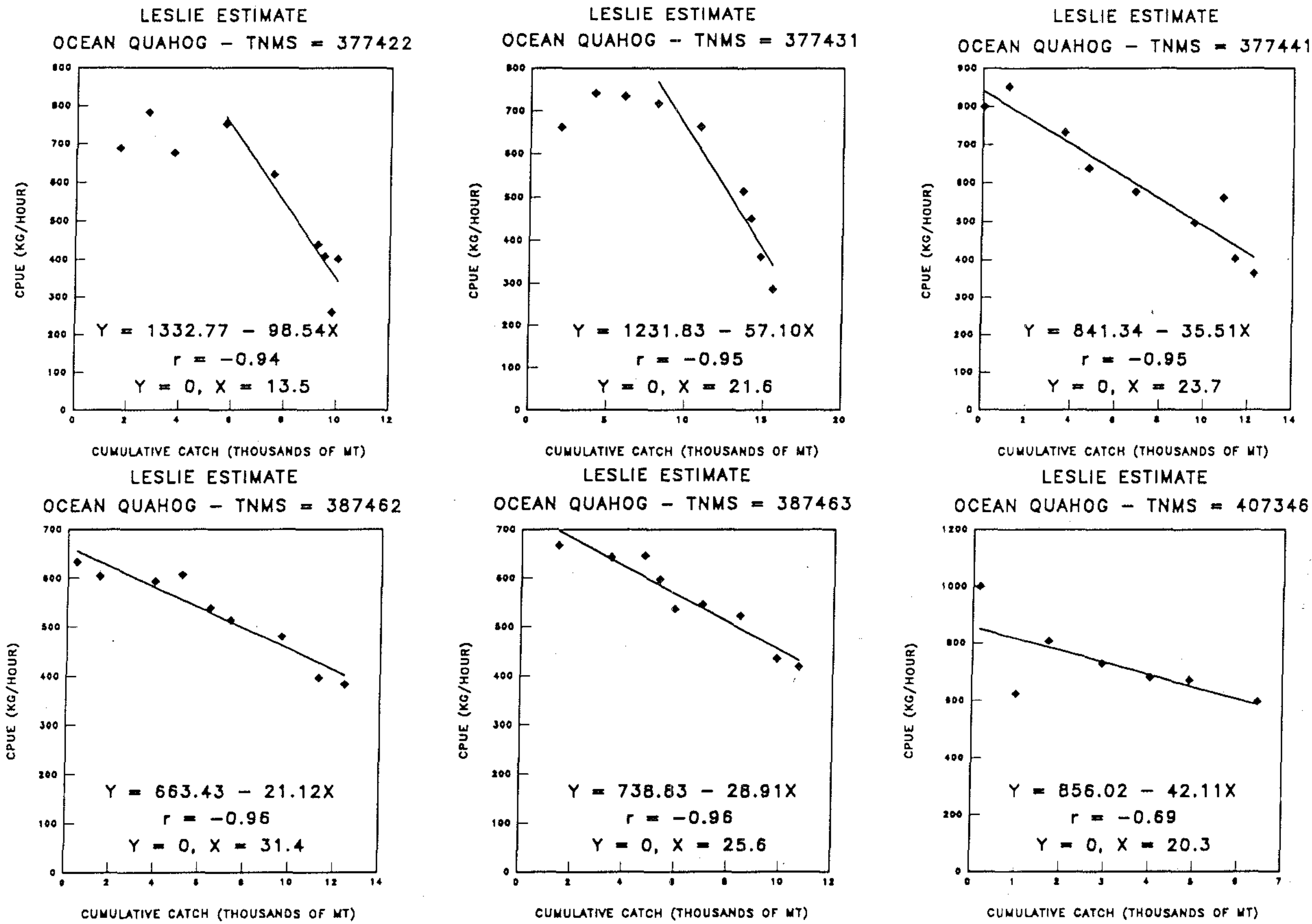

Figure B6. Relationship between cumulative ocean quahog catch (1,000 mt of meats) and Class 3 CPUE (kg per hour fished) for six 10-min. squares given in Figure B5. Class 3 is 105+ GRT; CPUE is for time t + 1, while cumulative catch is for time 0 to t.

Figure B7. Ocean shellfish survey strata off the Northeastern United States. Stratification plan is used both for surveys and for sea scallop dredge surveys.

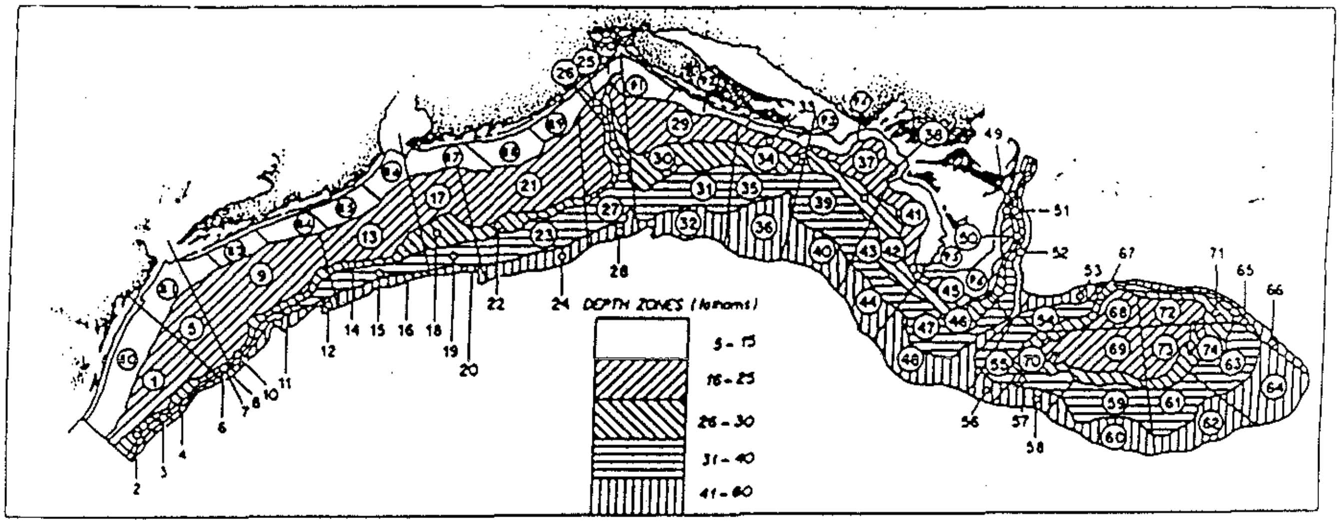

Table B4. Research vessel indices for ocean quahog in the Delmarva assessment area, 1980-1992. Data are stratified mean numbers and weights per standardized (5 min) survey tow.

Length Interval (mm)	Year of Survey Data 1980-1982	1986	1989	1992	All Data
10-19				0.12	0.02
20-29				0.00	0.00
30-39			0.03	0.01	0.01
40-49			0.06	0.01	0.01
50-59	0.07	0.13	0.04	0.07	0.07
60-69	0.75	0.21	0.63	0.02	0.50
70-79	7.42	6.21	21.59	1.68	8.53
80-89	15.30	15.47	11.94	8.66	13.48
90-99	16.07	15.09	6.27	11.73	13.36
100-109	7.18	4.84	3.93	5.25	6.03
110-119	0.80	1.49	0.52	0.66	0.86
120-129	0.03	0.14			0.04
130-139	0.47	0.01			0.00
Total	47.63	43.57	45.01	28.21	42.92
SD	9.99	10.54	27.67	9.40	7.03
CV	0.21	0.24	0.61	0.33	0.16
n	250	76	88	75	489
Area of Surveyed Strata (nm^2)	5,926	5,715	5,715	5,715	5,926
Mean Weight Per Tow (kg)	1.68	1.51	1.26	1.04	1.44

annual survival rate of 0.97). However, this estimate may be inaccurate because the coefficient of determination, R2, for the regression model was only 33%.

New Jersey

Since 1990, the New Jersey area has been the focus of the ocean quahog fishery. Survey abundance indices were high during 1980-82 and 1986 (Table B5) but have since been about 40% lower. Prior to 1989, quahog densities were highest in sampling stratum #18 (Table B7); by 1992, however, the abundance index for this stratum had declined 84% [from the 1980-82 level].

Between 1986 and 1992, mean weight per tow in the New Jersey area declined by 41%. (Table B5: 4.08 to 2.39 kg/tow). As in the Delmarva area, the 1980 to 1992 survey size composition data from New Jersey indicate that small quahogs have been virtually absent (Figure B9).

Total annual mortality of quahogs in the New Jersey area was estimated from regression analysis of the survey data to be Z=0.04 (S=0.96). The coefficient of determination, R2, for the regression model was 57%.

Table B5. Research vessel indices for ocean quahog in the New Jersey assessment area, 1980-1992. Data are stratified mean numbers and weights per standardized (5 min) survey tow.

Length	Year of Survey Data				
Interval (mm)	1980-1982	1986	1989	1992	All Data
10-19					
20-29			0.08		0.01
30-39	0.01	0.02	0.02	0.04	0.02
40-49	0.06	0.02	0.10	0.03	0.06
50-59	0.23	0.01	0.35	0.13	0.20
60-69	1.99	1.42	3.05	0.53	1.83
70-79	10.17	6.83	9.01	3.89	8.46
80-89	33.08	30.90	21.79	20.52	28.45
90-99	36.80	54.41	20.85	28.61	34.80
100-109	14.42	20.55	6.30	11.17	13.19
110-119	2.19	2.70	1.34	2.68	2.09
120-129	0.19	0.16	0.16	0.41	0.20
130-139	0.01	0.02		0.04	0.01
Total	99.16	117.05	63.06	68.05	89.34
SD	11.81	26.48	14.24	14.15	7.74
CV	0.12	0.23	0.23	0.21	0.09
n	360	105	111	104	680
Area of Surveyed Strata (nm^2)	7,601	6,856	7,332	6,856	7,601
Mean Weight Per Tow (kg)	3.25	4.08	1.92	2.39	2.96

Gulf of Maine and Massachusetts Bay

Nonrandom samples were collected during the 1992 survey to obtain initial estimates of the density and size structure of ocean quahog populations located north of Georges Bank. These estimates should be interpreted cautiously because samples were taken in commercial beds where quahogs were thought to be most dense.

Gulf of Maine samples averaged 170 quahogs per tow, but the mean weight per tow was very low, 0.4 kg (Table B6). The Gulf of Maine samples consisted of many small (<70 mm) individuals. Ocean quahogs from Maine have slow growth rates (Kraus and Beal 1990), similar to those from Georges Bank and Long Island. Given the predominance of small individuals in the Gulf of Maine survey tows, the quahogs sampled were probably relatively young individuals, 1 to 20 years of age.

The population density and size structure of the quahogs sampled in Massachusetts Bay were more similar to those from the Middle Atlantic Bight than from the Gulf of Maine (Table B6). Most individuals were larger than 70 mm. Massachusetts Bay survey catches averaged 64 quahogs per tow.

Table B6. Research vessel indices for ocean quahog in the Gulf of Maine (GOM) and Massachusetts Bay (MB), July 1992. Stations were not chosen at random. Data are mean abundance and weight (meats, kg) per standardized (5 min) survey tow

Length	Area	
Interval (mm)	GOM	MB
10-19	10.50	0.10
20-29	82.58	0.50
30-39	30.48	1.27
40-49	16.08	0.90
50-59	28.13	1.79
60-69	2.59	10.13
70-79		24.28
80-89		18.97
90-99		5.67
100-109		0.77
110-119		0.08
120-129		
130-139		
Total	170.37	64.45
n	41	108
Mean Weight per Tow (kg)	0.42	1.30

Comparison of All Areas

There is little interannual variability in ocean quahog population size or structure in the Middle Atlantic, Southern New England, or Georges Bank regions. This is due to absence of recruitment, slow adult growth rates and low rates of adult mortality. Accordingly, to derive a long-term depiction of the populations within each of these assessment areas, data from several different surveys were combined and analyzed (Table B8; Figure B10). Such pooling of survey data appears justified since these populations have not substantially changed over time spans of 3 to 6 years.

Each of the areas is dominated by individuals greater than 70 mm (Figures B8 and B9). With respect to mean catch (number) per tow, the six geographical areas can be ranked from high to low as follows (Table B8):

1. Southern New England
2. Long Island
3. Georges Bank
4. New Jersey
5. Delmarva
6. Southern Virginia-North Carolina

A similar ranking of areas also occurs based on average meat weight per tow (Table B8). Minimum swept-area biomass estimates for each area, derived from the survey results, are listed in Table B8 and plotted on a percentage basis in Figure B10. Areas with the highest biomass are Southern New England, Georges Bank, and Long Island. The New Jersey and Delmarva areas combined only account for 20% of the total region-wide biomass.

Abundance indices and size frequency distributions from the most recent (1992) survey are presented, by geographical area, in Figures B11-B13. The highest abundance indices were obtained in the Southern New England and Long Island areas, rather than in New Jersey or Delmarva where most of the present commercial fishery occurs (Figure B11). All areas, except for the Gulf of Maine, are characterized by unimodal size distributions comprised of mostly larger-sized individuals (Figures B12 and B13).

Table B7. Research vessel survey abundance indices for ocean quahog, by individual survey strata, 1980-1992. Data are mean numbers per standardized survey tow, coefficient of variation (SD/mean) is in parentheses, and number of survey tows is below estimate.

Survey Stratum	Year of Survey Data: 1980-1982	1986	1989	1992	All Data
Delmarva					
9	15.72(4.68) 103	3.45(4.45) 29	4.41(3.69) 37	4.30(4.21) 33	10.02(5.38) 202
10	77.00(1.33) 8	9.67(0.99) 3	28.33(1.67) 3	31.00(1.73) 3	48.41(1.61) 17
11	27.25(0.62) 4	16.50(0.81) 2	9.00(0.94) 2	23.00(0.61) 2	20.60(0.68) 10
13	66.45(2.82) 60	81.25(2.61) 20	40.85(1.74) 20	74.06(1.78) 17	65.71(2.58) 117
14	501.50(1.11) 8	449.67(0.23) 3	176.00(0.86) 3	221.33(1.28) 3	385.47(1.07) 17
15	106.17(1.59) 12	117.25(0.78) 4	397.75(1.92) 4	25.33(1.04) 3	148.26(2.24) 23
New Jersey					
17	193.16(1.51) 44	126.42(1.26) 12	190.42(1.64) 12	80.83(1.18) 12	165.89(1.55) 80
18	333.91(1.55) 11	250.67(1.25) 3	87.00(1.51) 3	54.66(0.66) 3	242.50(1.69) 20
19	115.22(1.43) 9	79.67(0.44) 3	35.00(1.54) 3	198.66(0.78) 3	109.83(1.24) 18

For the three most recent surveys (1986, 1989, 1992), minimum 95% confidence intervals (Cochran 1977) were calculated for the stratified mean number per tow index in each region (Table B9; Figure B14). In almost all cases, the confidence intervals are rather wide and overlap one another. Hence, temporal changes in mean abundance and biomass values should be interpreted with caution. However, in the New Jersey region [where most of the harvesting now takes place], quahog abundance appears to have declined between 1986 and 1989-92.

The depletion equation,

$B_{t+1}=(B_t-C_t)e^{-m}$ where
t = time,
B = stock biomass,
C = annual catch, and
m = natural mortality rate

was used to estimate how long the stock might support current rates of harvesting. Estimates were made for two values of m (0.02 and 0.06), both of which seem reasonable based on survey and CPUE data. Although the equation does not consider growth, recruitment, or the possibility of rare but high m values in some years, the results suggest that the entire stock can support annual landings at the 1991 level for 22 to 32 more years (Table B10). However, for this to occur, the quahog fishery will have to shift northward (to Southern New England/Long Island and Georges Bank) because, at current harvest levels, the New Jersey and Delmarva resources areestimated to last for only another 6 to 10 years.

OVERVIEW AND PROGNOSIS

At present, the total estimated biomass of ocean quahogs located between Georges Bank and North Carolina should be sufficient to support the fishery at the 1991 quota level for the next 2 to 3

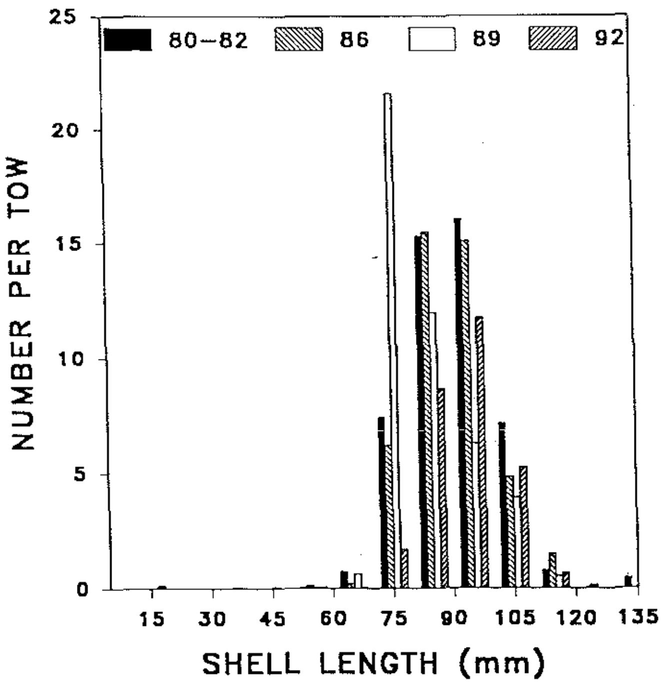

Figure B8. Survey length composition of ocean quahogs from the Delmarva assessment area during four time periods: 1980-1982, 1986, 1989, and 1992. Data are expressed as the stratified mean number per tow taken in each 1 cm size interval.

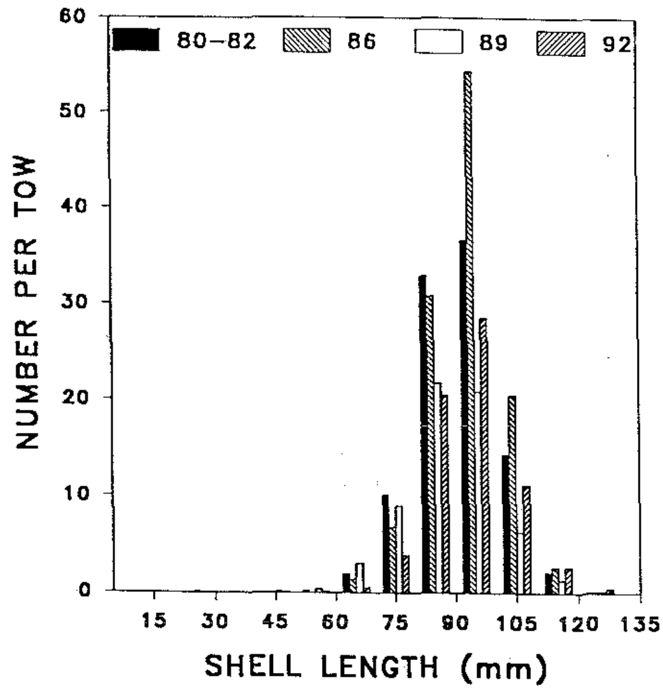

Figure B9. Survey length composition of ocean quahogs from the New Jersey assessment area during four time periods: 1980-1982, 1986, 1989, and 1992. Data are expressed as the stratified mean number per tow taken in each 1 cm size interval.

decades. However, ocean quahogs take at least 20 years to grow to 70 mm (*i.e.*, commercial size) and good recruitment events are very rare and unpredictable. These characteristics make the species very vulnerable to exploitation. Once depleted, ocean quahog stocks may take 50 to 100 years to replenish themselves.

The concentration of the fishery off of Delmarva and, more recently, off of New Jersey is causing local stock depletions and a reduction in CPUE. At current removal rates, quahog supplies in these two areas may be exhausted within ten years. To maintain performance during the next 5 to 10 years, the fishery will have to move north to less depleted areas.

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Table B8. Minimum population biomass estimates (mt of meats) by area for ocean quahog, based on swept-area estimates from NMFS hydraulic clam surveys, 1986-1992. **Minimum biomass** estimated, based on a standardized tow sweeping 0.0001069 square nautical miles. **Years** indicates which research vessel surveys were used to compute biomass.

Area	Years	Tows	Area (sq.naut.miles)	Mean no. per tow	CV	Mean Weight per tow (kg)	Minimum Biomass (mt meats)	%
S. VA-NC	1989, 1992	67	3,106	0.11	1.00	0.01	154	0.01
Delmarva	1989, 1992	163	5,715	38.18	0.41	1.18	62,999	6.01
New Jersey	1989, 1992	215	7,332	63.41	0.16	2.08	142,525	13.6 1
Long Island	1986-1992	119	4,478	236.08	0.15	5.61	235,139	22.46
S. New England	1986-1992	91	5,370	241.33	0.14	6.32	317,599	30.33
Georges Bank	1986, 1992	122	7,937	178.03	0.24	3.89	288,539	27.56
	Sum	777	33,938				1,046,954	100.00

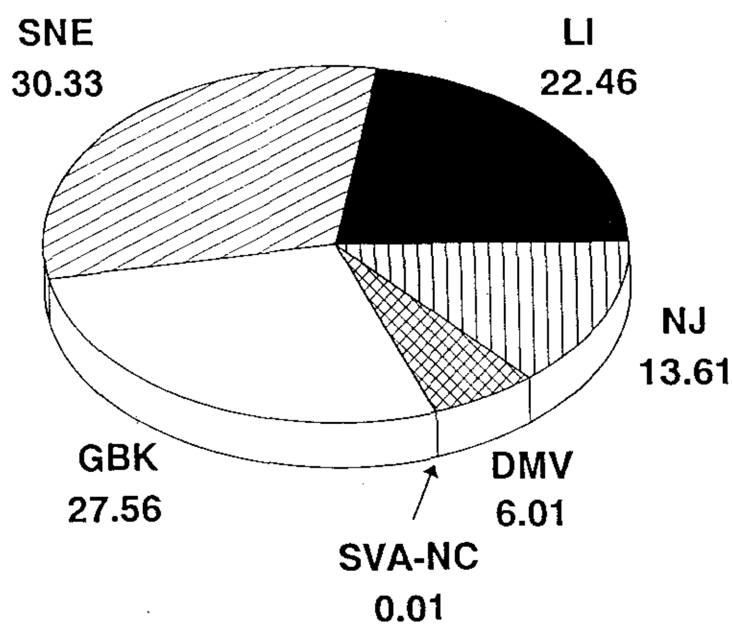


Figure B10. Relative distribution of ocean quahog biomass, based on research vessel survey data (Table B8). Total minimum swept-area biomass estiamte for the entire region is 1.047 million mt of shucked meats.

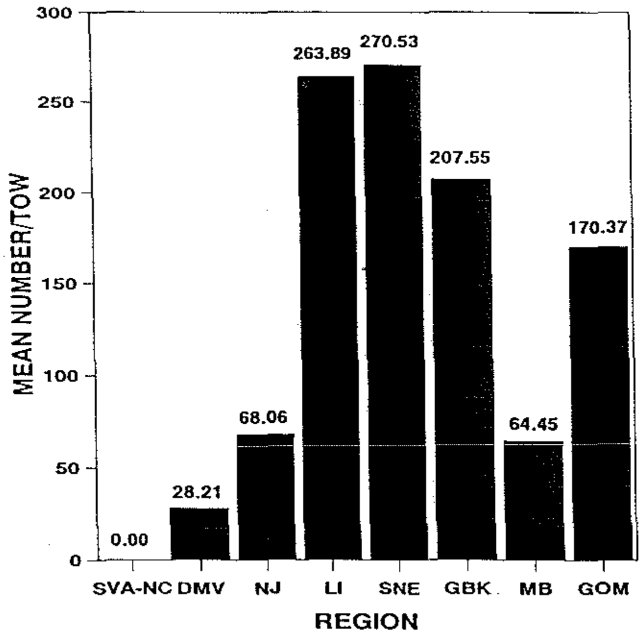


Figure B11. Ocean quahog abundance by region based on data from the 1992 survey.

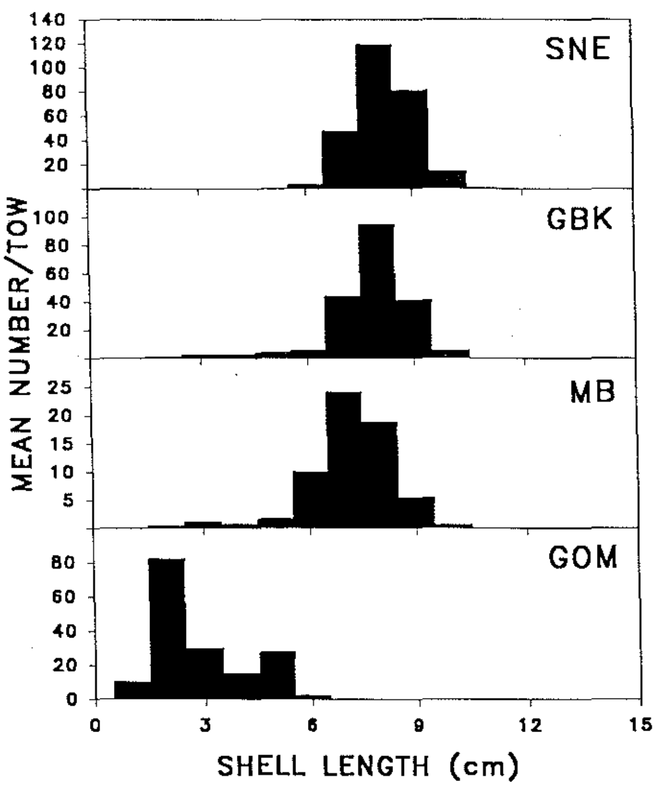


Figure B13. Size frequency distribution of ocean quahogs from Northern regions based on data from the 1992 survey.

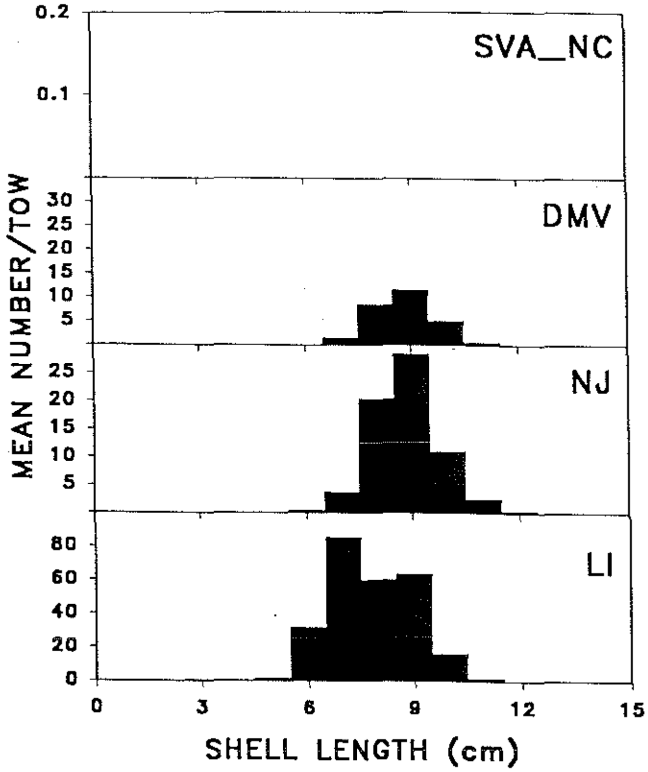


Figure B12. Size frequency distribution of ocean quahogs from Southern regions based on data from the 1992 survey.

Ropes, J. W., S. A. Murawski, and F. M. Serchuk. 1984b. Size, age, sexual maturity, and sex ratio in ocean quahogs, *Arctica islandica* Linne, off Long Island, New York. Fish. Bull. (U.S.) 82(2):253-267.

OCEAN QUAHOG RECOMMENDATIONS/ RESEARCH NEEDS

1. Investigate the possibility of reducing survey sampling on Georges Bank, Southern New England and Long Island so that sampling and survey precision can be increased in the Mid-Atlantic region.

2. For those areas where survey sampling is increased (see 1.), make detailed comparisons between the survey and commercial data sets regarding quahog abundance and size structure.

3. Calculate precision estimates for R/V survey data, using appropriate statistical transformations.

Table B9. Summary statistics for ocean quahog abundance by region and year. Computation made using untransformed data from three research vessel surveys.

REGION	YEAR	STRATIFIED MEAN PER TOW	STANDARD ERROR OF MEAN	N_max	MINIMUM 95% CI	UPPER LIMIT	LOWER LIMIT
DMV	1986	43.56	10.54	76	20.98	64.54	22.59
	1989	45.01	27.67	88	55.06	100.07	-10.05
	1992	28.21	9.40	75	18.71	46.92	9.50
NJ	1986	117.05	26.47	105	52.68	169.76	64.37
	1989	63.06	14.24	111	28.34	91.40	34.72
	1992	68.05	14.15	104	28.16	96.21	39.89
LI	1986	243.51	56.02	38	113.22	356.73	130.30
	1989	185.78	69.42	41	140.30	326.10	45.48
	1992	263.89	48.18	40	97.37	361.26	166.52
SNE	1986	208.64	63.78	28	130.88	339.52	77.76
	1989	208.75	49.27	28	101.10	309.85	107.65
	1992	270.53	55.49	35	112.70	383.23	157.83
GBK	1986	197.8	42.48	63	84.96	282.76	112.84
	1989	41.09	12.80	41	25.87	66.96	15.22
	1992	207.56	51.48	59	102.96	310.52	104.60

Table B10. Landings, biomass (mt meats), and current supplies of ocean quahogs, expressed in number of years, by geographical area. Estimates of **Supply Years** are based on 1991 landing rates, unless there were no landings in 1991, and do not consider changes that might occur in the population in the future due to recruitment, growth, catastrophic mortality or movement of fishing vessels to new areas; **m** is the instantaneous rate of natural mortality.

Geographical Area	1991 Landings	Minimum Stock Biomass	Supply Years m=0.02	Supply Years m=0.06
GOM	166.4	unknown	unknown	unknown
GBK	0.0	288,539	50+[1]	36+[1]
SNE+ LI	2,327.5	522,738	50+	45
NJ	12,732.0	142,525	10	8
DMV	7,738.9	62,999	7	6
SV-NC	0.0	154	0	0
Mid-Atlantic[2]	20,470.9	205,677	9	8
Total	**22,798.4**	**1,046,954**	**32**	**22**

[1] **Supply years are computed based on the 1991 landings fom SNE + LI. Adjacent areas, SNE and LI are treated as a single unit because they are underutilized and have high quahog biomass.**

[2]. **The Mid-Atlantic region is the sum of the 1991 landings from NJ, DMV and SV-NC**

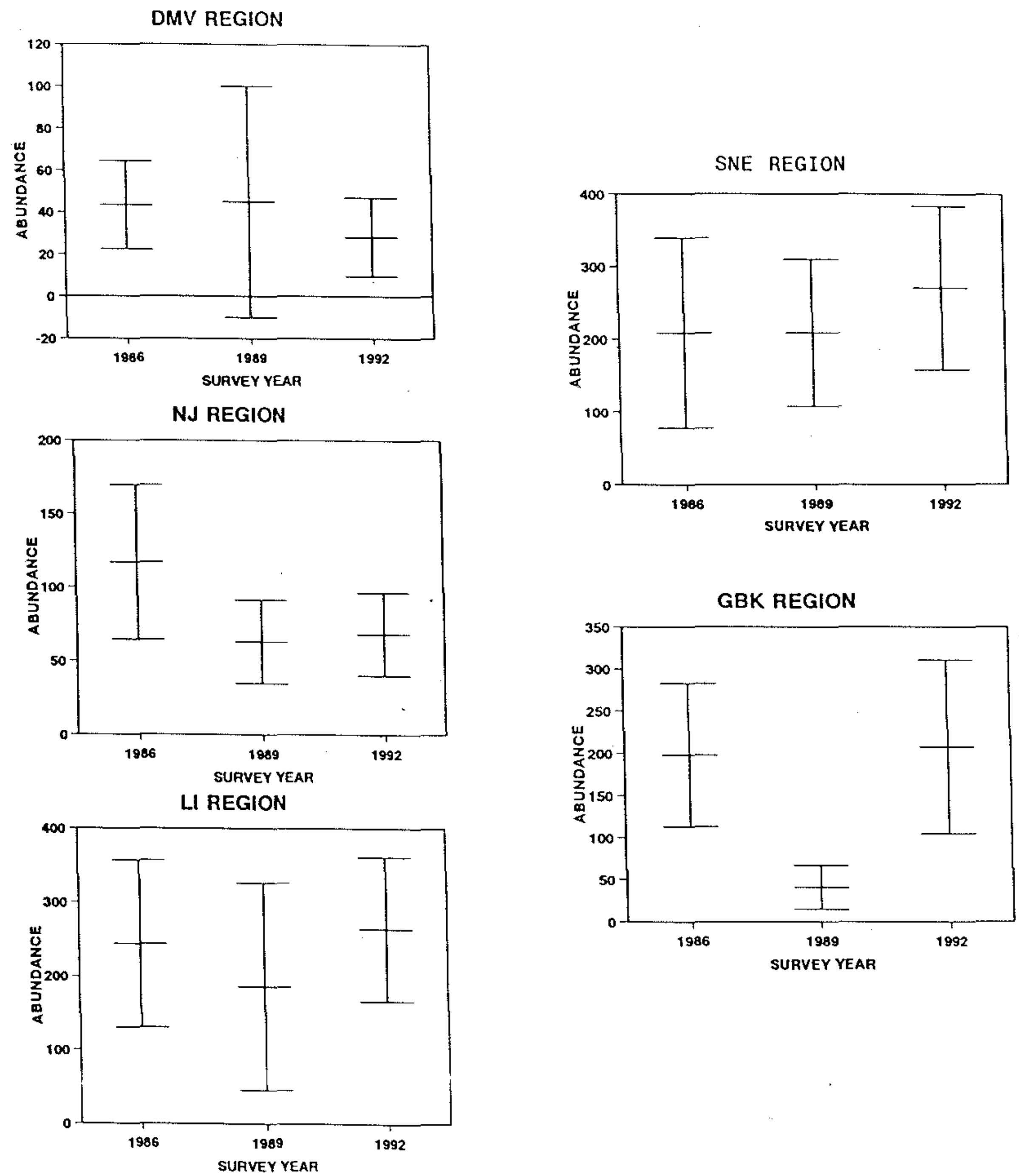
4. A survey should be made of the Gulf of Maine to determine the areal distribution, density, and size/age composition of the quahog populations.

5. Explore all existing data for insights into what conditions are necessary for successful recruitment. These include GOM data, MAFMC 1991 survey data, Rutgers survey data, and NEFSC data.

6. Analyze logbook data, on an individual vessel basis, to examine further the apparent decreases in CPUE.

7. Develop stock depletion models for ocean quahogs (incorporating LPUE data, catch length frequency data, research survey data, and aging studies) to estimate absolute stock size and fishing mortality rates.

Figure B14. Minimum 95% confidence intervals for the stratified mean of ocean quahog abundance per tow by region. Computations were made on untransformed data from three research vessel surveys: 1986, 1989, and 1992.



C. GULF OF MAINE-GEORGES BANK REDFISH UPDATE

INTRODUCTION

Recent trends in landings, abundance, and recruitment of Gulf of Maine and Georges Bank redfish were reviewed by the SARC. Estimates of F0.1, Fmax, and F20% were also reviewed, and the results from the most recent analytical assessment (NEFC 1986) were considered.

Relative abundance and biomass indices from autumn NEFSC bottom trawl surveys declined by more than 90% between the mid- to late 1960s and mid 1980s. Likewise, commercial CPUE in recent years has declined by more than 80% from levels observed during the 1960s. Since the late 1980s, spring and autumn survey indices have increased slightly. Landings have remained at historic low levels (< 1,000 t) since 1989, after declining from more than 13,000 t during 1977-1979.

As a consequence of extremely poor recruitment since the mid-1960s, the age structure of the population has narrowed considerably to only one or two significant year classes.

Background

Redfish, *Sebastes fasciatus* Storer, are relatively long-lived, slow growing fish compared to most highly exploited species. Growth studies have indicated maximum ages ranging from 50 to 60 years at lengths of 45 to 50 cm (18 to 20 in.) (Mayo *et al.* 1990). Consequently, an instantaneous natural mortality rate of 0.05 has been employed in virtual population, yield, and spawning stock biomass (SSB) per recruit analyses, consistent with the longevity of this species. The most recent estimates of redfish maturation suggest a median age of about 5.5 years (Mayo *et al.* 1990; O'Brien *et al.* in press).

Redfish have supported a substantial domestic fishery in the Gulf of Maine and the Georges Bank (Great South Channel) regions off the northeast coast of the United States (Northwest Atlantic Fisheries Organization [NAFO] Subarea 5) since the late 1930s, when the development of freezing techniques enabled widespread distribution of the frozen product throughout the country. Landings by domestic vessels rose rapidly, peaking at 56,000 t in 1942 in Subarea 5, then declined throughout the 1940s and 1950s (Table C1, Figure C1). As landings declined in local waters, U.S. fishing effort began to expand to the Scotian Shelf and the Gulf of St. Lawrence (NAFO Subarea 4), and finally to the Grand Bank of Newfoundland (NAFO Subarea 3) (Mayo *et al.* 1983). This expansion continued throughout the 1940s and early 1950s, culminating with a peak U.S catch of 130,000 t in 1952 (Figure C1). By the mid-1950s, redfish stocks throughout the Northwest Atlantic were heavily exploited by U.S and Canadian fleets (Atkinson 1987), and total landings began to decline in all Subareas.

Redfish have been harvested primarily by domestic vessels, although some distant-water fleets took considerable quantities for a brief period during the early 1970s. Redfish are harvested almost exclusively by otter trawlers fishing out of Maine and Massachusetts ports. United States landings have declined from more than 13,000 tons during 1977-1979, to less than 1,000 t since 1989. Landings in 1991 (525 t) reached a historic low level.

Data Sources

Commercial catch per unit effort (CPUE) indices for directed redfish trips, standardized by vessel tonnage class as described by Mayo *et al.* (1979) have declined steadily from more than 6 tons per day fished during the late 1960s to approximately one-half a ton per day fished after 1985 (Table C1). Total fishing effort, after peaking during the late 1970s (coincident with the highest estimates of fishing mortality [NEFC 1986]), appeared to stabilize during the mid-1980s before declining precipitously through 1989.

An evaluation of effort data is presented in Figure C2. Historically, 80 to 90% of the total redfish catch and 20 to 40% of the total number of trips on which redfish were taken were accounted for in the directed CPUE calculation (50% redfish trips). These percentages declined sharply between 1979 and 1982, and are now at levels that preclude any definitive interpretation of the CPUE and effort trends. Despite these limitations, it is clear that commercial CPUE remains extremely low relative to earlier periods.

The catch at age matrix based on all commercial length and age data from 1969 through 1985 is given in Table C2. The sharp discontinuity in the age structure of the population created by poor recruitment since the 1960s can be inferred

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

Year	Nominal Catch (Metric tons)			USA Catch per Unit Effort (tons/day)		Calculated Standard Effort (days fished)	
	USA	Others	Total	Actual	Standard	USA	Total
1934	519		519				
1935	7549		7549				
1936	23162		23162				
1937	14823		14823				
1938	20640		20640				
1939	25406		25406				
1940	26762		26762				
1941	50796		50796				
1942	55892		55892	6.9	6.9	8100	8100
1943	48348		48348	6.7	6.7	7216	7216
1944	50439		50439	5.4	5.4	9341	9341
1945	37912		37912	4.5	4.5	8425	8425
1946	42423		42423	4.7	4.7	9026	9026
1947	40160		40160	4.9	4.9	8196	8196
1948	43631		43631	5.4	5.4	8080	8080
1949	30743		30743	3.3	3.3	9316	9316
1950	34307		34307	4.1	4.1	8368	8368
1951	30077		30077	4.1	4.1	7336	7336
1952	21377		21377	3.5	3.4	6287	6287
1953	16791		16791	3.8	3.6	4664	4664
1954	12988		12988	3.4	3.1	4190	4190
1955	13914		13914	4.5	4.0	3479	3479
1956	14388		14388	4.4	3.8	3786	3786
1957	18490		18490	4.3	3.6	5136	5136
1958	16043	4	16047	4.4	3.6	4456	4458
1959	15521		15521	4.3	3.5	4435	4435
1960	11373	2	11375	3.8	3.0	3791	3792
1961	14040	61	14101	4.6	3.5	4011	4029
1962	12541	1593	14134	5.4	4.0	3135	3534
1963	8871	1175	10046	4.1	3.0	2957	3349
1964	7812	501	8313	4.3	2.9	2694	2867
1965	6986	1071	8057	7.0	4.4	1588	1831
1966	7204	1365	8569	11.7	6.4	1126	1339
1967	10442	422	10864	12.4	5.6	1865	1940
1968	6578	199	6777	14.7	6.1	1078	1111
1969	12041	414	12455	11.4	4.9	2457	2542
1970	15534	1207	16741	9.0	4.0	3884	4185
1971	16267	3767	20034	7.0	3.2	5083	6261
1972	13157	5938	19095	5.7	2.9	4537	6584
1973	11954	5406	17360	5.3	2.9	4122	5986
1974	8677	1794	10471	5.0	2.6	3337	4027
1975	9075	1497	10572	4.0	2.2	4125	4805
1976	10131	565	10696	4.6	2.3	4405	4650
1977	13012	211	13223	4.9	2.5	5205	5289
1978	13991	92	14083	4.8	2.4	5830	5868
1979	14722	33	14755	3.6	1.9	7748	7766
1980	10085	98	10183	3.2	1.6	6303	6364
1981	7896	19	7915	2.7	1.4	5640	5654
1982	6735	168	6903	2.7	1.5	4490	4602
1983	5215	113	5328	2.1	1.2	4346	4440
1984	4722	71	4793	1.9	1.1	4293	4357
1985	4164	118	4282	1.4	0.9	4627	4758
1986	2790	139	2929	1.0	0.6	4650	4882
1987	1859	35	1894	1.1	0.7	2656	2706
1988	1076	101	1177	0.9	0.5	2152	2354
1989	628	9	637	1.1	0.6	1047	1062
1990	588	13	601	**	**		
1991	525		525	**	**		
1992*	900		900	**	**		

* Preliminary

** CPUE and effort not calculated due to sharpreduction in directed redfish trips

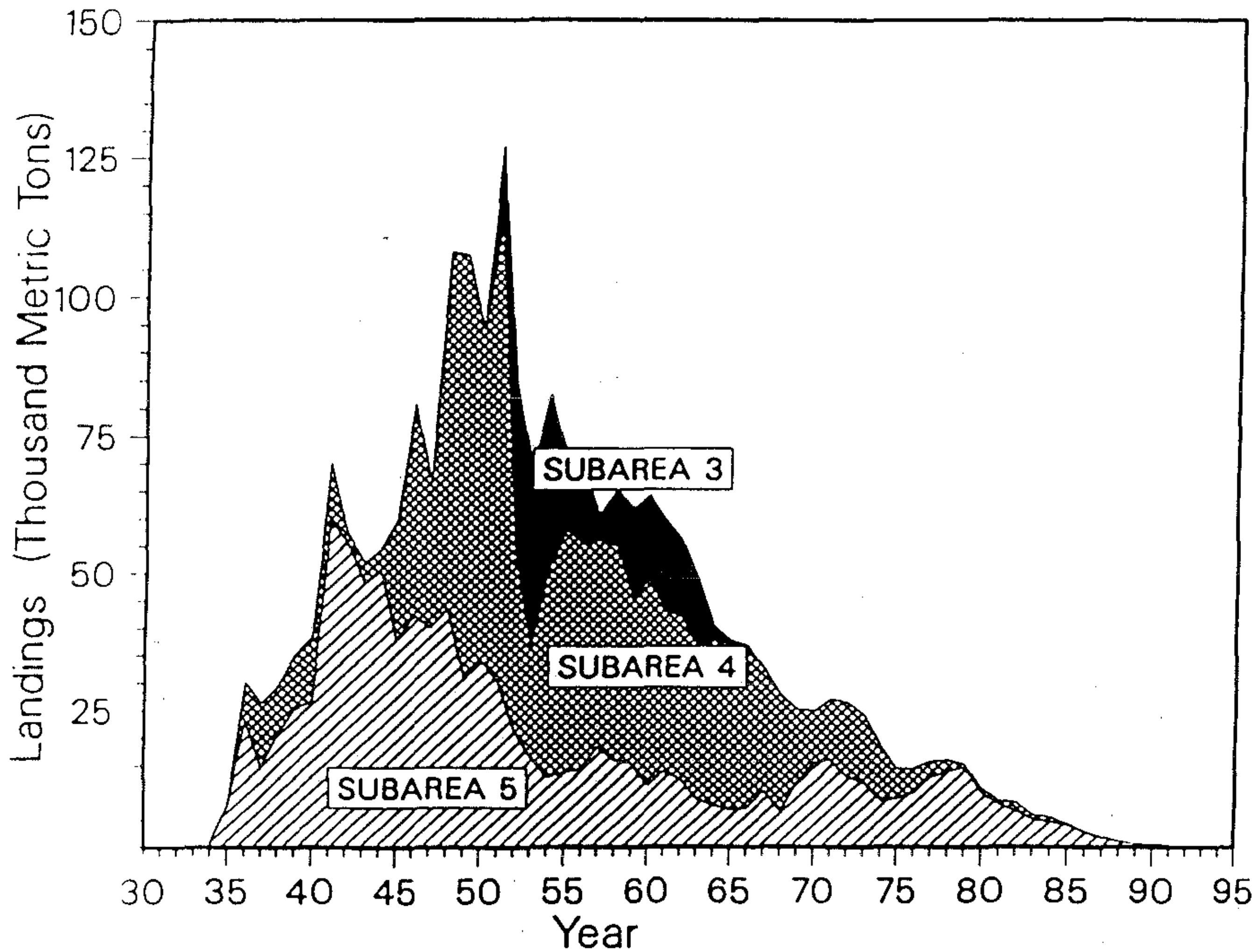


Figure C1. U.S. landings of redfish (1,000 t) from the Northwest Atlantic, 1934-1991. Subarea 3 - Grand Banks; Subarea 4 - Scotian Shelf and Gulf of St. Lawrence; Subarea 5 - Gulf of Maine and Georges Bank.

from the age composition of the catch. The most striking feature is the singular presence of the 1971 year class progressing through the fishery since 1974.

Bottom trawl surveys have been conducted by the Northeast Fisheries Science Center in the Gulf of Maine - Georges Bank region since the autumn of 1963 and the spring of 1968 (Azarovitz 1981). Abundance (stratified mean number per tow) and biomass (stratified mean weight per tow) indices have been calculated for inshore and offshore strata sets (Tables C3 and C4) in order to detect recruitment trends from Western Gulf of Maine coastal nursery areas as described by Mayo *et al.* (1990). Overall indices were also computed for both the spring and autumn surveys based on a combined strata set. Prerecruit indices, listed in Table C5, have been derived from the inshore autumn data by computing the summed stratified mean number per tow within prescribed length ranges corresponding to ages 1 to 3 as determined by inspection of historical length frequency data.

Yield and (SSB) per recruit were calculated according to the methods described by Thompson and Bell (1934) and Gabriel *et al.* (1989). Partial recruitment was taken from the most recently published VPA (NEFC 1986), which reflects the recruitment of the 1971 year class. Natural mortality was assumed to be 0.05. Mean weights at age for the yield per recruit calculations were taken as the 1969-1984 mean of the commercial mean weights at age (Table C2). Mean weight and maturation data for SSB/R analysis were taken from the female data presented by Mayo *et al.* (1990).

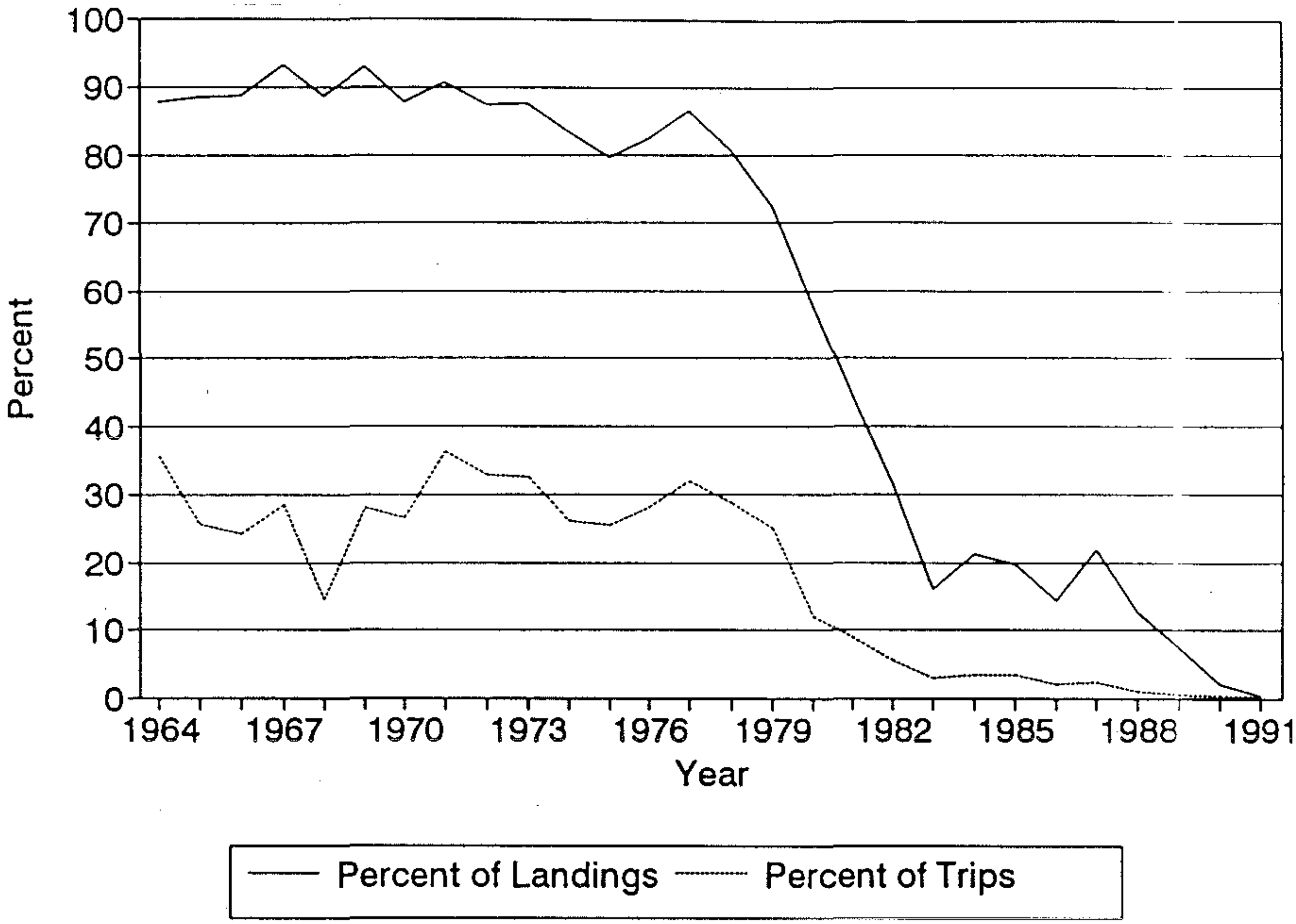


Figure C2. Percentage of total redfish landings and total trips in which redfish composed 50% or more of the total landings on a trip basis.

RESULTS

Relative abundance of redfish has declined sharply in both survey series, from peak levels of more than 100 fish per tow in the late 1960s and early 1970s to generally less than 10 fish per tow during the mid 1980s. The decline in biomass has been of the same order (Figures C3 and C4). Both series suggest a slight increase in abundance and biomass in 1990-1992, but the overall levels continue to remain well below historic values.

The 1965 year class appeared very strong in the autumn NEFSC surveys at ages 0 to 1, and the 1961 through 1965 year classes were very strong at age 2. When the good 1971 year class appeared in the surveys, it was very strong at age 0, but was not as evident at ages 1 and 2 as were year classes from the early 1960s (Table C5). Viewed in this perspective, the 1978 year class and those which have appeared since the mid-1980s are relatively weak.

The redfish population was composed of a relatively broad range of sizes in the 1960s (Figure C5). This resulted from consistent recruitment of year classes from the 1950s and 1960s. By the 1970s, however, abundance of large fish had declined substantially and the 1971 year class dominated the population size structure. Consistency of the survey indices began to erode by the beginning of the 1980s and, throughout the decade, only sporadic indications of the 1978 and subsequent year classes were evident. In 1992, however, substantial numbers of redfish

Table C2. Total catch at age and mean weights at age for Gulf of Maine-Georges Bank redfish, 1969-1985

Age

Number landed (000s)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26+
69	-	-	-	22	421	439	1008	6065	2513	6717	2660	3975	3287	2221	2820	1348	751	526	606	426	451	345	469	38	100	847
70	-	-	-	-	146	4055	4048	1060	9692	3221	8351	2734	4702	2672	2302	3489	1778	1640	393	662	368	529	572	488	64	1743
71	-	-	-	-	-	72	1941	4430	1536	7907	2767	6504	3088	4267	3680	2895	2206	2765	1347	1163	560	1048	559	282	138	2439
72	-	-	-	-	-	-	933	3296	7401	1712	7580	2782	2884	1994	3531	2449	1205	1276	2245	734	1011	1172	718	538	1280	2874
73	-	-	-	-	-	-	235	2463	7938	8391	2201	7337	2078	3100	2376	2024	1799	1380	864	933	411	590	426	295	289	1977
74	-	-	308	105	-	17	8	174	1886	4724	2945	2435	1709	1115	1302	935	1454	910	640	661	589	730	271	285	250	1755
75	-	-	4	695	72	11	-	30	124	1944	4360	2154	1932	1442	1009	1344	1360	1235	945	1116	608	887	492	294	298	1282
76	-	-	-	196	8961	439	-	-	21	48	467	2706	3375	1702	1725	1388	1233	1166	1424	608	769	681	323	672	94	2011
77	-	-	-	-	234	16747	311	-	-	-	81	2127	1262	4012	1823	2747	1466	1190	1064	461	706	541	117	571	1013	2157
78	-	-	-	-	-	271	24569	215	-	34	33	182	1689	1484	2948	1748	1310	866	899	1283	895	734	500	192	530	2220
79	-	-	-	-	25	205	849	23729	152	117	48	168	541	1228	1972	1299	1580	983	845	1008	798	594	532	538	427	2506
80	-	-	-	-	-	132	175	1110	16900	208	44	46	217	491	830	1221	860	664	564	452	473	370	349	294	265	1308
81	-	-	23	-	77	40	57	47	223	12380	84	22	-	44	317	364	1274	506	534	396	318	381	306	326	350	1540
82	-	-	3	271	123	60	92	30	-	15	7268	56	32	21	128	185	582	452	840	324	501	484	301	134	104	2270
83	-	-	-	11	1687	159	46	43	86	49	141	4959	58	106	64	42	85	319	270	551	169	224	314	195	131	1817
84	-	-	46	11	51	6674	-	20	40	-	35	15	3571	-	44	49	34	92	210	166	324	215	144	157	162	1807
85	-	-	27	146	33	31	3818	-	28	11	13	40	12	3202	-	25	11	101	116	260	230	187	197	142	107	1489

A dash (-) in the table indicates less than 1,000 individuals.

Mean weight (kg)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26+
69	.010	.020	.052	.113	.115	.142	.169	.195	.219	.260	.320	.339	.366	.404	.425	.473	.495	.457	.589	.497	.515	.594	.589	.705	.708	.591
70	.010	.020	.052	.092	.172	.168	.170	.189	.221	.236	.290	.339	.356	.367	.340	.418	.427	.438	.523	.579	.505	.450	.464	.476	.345	.541
71	.010	.020	.052	.092	.135	.172	.242	.244	.265	.304	.333	.369	.399	.437	.445	.468	.435	.449	.541	.553	.514	.544	.581	.481	.473	.540
72	.010	.020	.052	.092	.135	.171	.197	.240	.257	.289	.334	.367	.399	.427	.451	.472	.490	.515	.509	.562	.581	.565	.604	.489	.560	.668
73	.010	.020	.052	.092	.135	.171	.162	.213	.257	.281	.343	.341	.384	.402	.482	.454	.500	.492	.523	.525	.529	.641	.633	.568	.653	.620
74	.010	.020	.064	.080	.135	.195	.150	.233	.270	.326	.331	.378	.399	.427	.449	.442	.503	.527	.540	.565	.525	.578	.585	.641	.633	.642
75	.010	.020	.039	.098	.161	.221	.195	.383	.349	.317	.342	.394	.399	.420	.460	.469	.533	.527	.522	.550	.600	.547	.595	.607	.663	.662
76	.010	.020	.052	.076	.135	.199	.195	.245	.345	.278	.296	.347	.395	.389	.405	.427	.511	.469	.542	.517	.518	.552	.645	.577	.628	.630
77	.010	.020	.052	.092	.090	.173	.288	.245	.277	.297	.350	.413	.412	.408	.433	.454	.462	.534	.537	.610	.466	.595	.611	.544	.552	.605
78	.010	.020	.052	.092	.135	.135	.209	.300	.277	.311	.383	.468	.402	.433	.423	.458	.551	.504	.526	.547	.523	.537	.633	.551	.606	.641
79	.010	.020	.052	.092	.135	.200	.191	.251	.304	.295	.248	.402	.508	.472	.474	.564	.526	.543	.551	.617	.664	.597	.567	.605	.567	.647
80	.010	.020	.052	.092	.135	.108	.175	.188	.283	.371	.421	.362	.424	.454	.506	.478	.499	.518	.554	.595	.647	.664	.629	.599	.681	.695
81	.010	.020	.080	.092	.117	.150	.143	.195	.247	.318	.374	.466	.404	.532	.592	.543	.528	.499	.537	.550	.594	.617	.560	.633	.552	.650
82	.010	.020	.052	.142	.203	.256	.242	.252	.277	.383	.395	.491	.563	.383	.544	.475	.540	.504	.564	.583	.592	.563	.621	.499	.535	.699
83	.010	.020	.052	.107	.172	.198	.249	.329	.252	.368	.396	.425	.381	.471	.504	.595	.494	.579	.639	.580	.614	.647	.622	.630	.589	.682
84	.010	.020	.110	.092	.206	.197	.195	.311	.252	.297	.333	.377	.403	.420	.497	.630	.569	.529	.519	.499	.610	.547	.568	.600	.517	.619
85	.010	.020	.092	.146	.154	.177	.239	.245	.279	.345	.421	.362	.595	.443	.441	.591	.494	.545	.599	.552	.603	.635	.605	.699	.624	.692

Table C3. Spring NEFSC bottom trawl survey stratified mean catch per tow indices, mean weights and mean lengths of redfish in the Gulf of Maine-Georges Bank region

	INSHORE 1				OFFSHORE 2				COMBINED 3	
	Stratified Mean Catch per Tow		Ave. Wt.	Ave. Length	Stratified Mean Catch per Tow		Ave. Wt.	Ave. Length	Stratified Mean Catch per Tow	
Year	Number	kg	kg	cm	Number	kg	kg	cm	Number	kg
1968	7.9	1.2	0.152	17.9	51.7	19.8	0.383	26.4	45.2	17.0
1969	59.0	8.3	0.141	20.3	44.2	21.7	0.491	30.6	46.4	19.7
1970	29.7	9.3	0.313	24.4	59.1	20.6	0.349	26.4	54.7	18.9
1971	49.9	13.3	0.267	24.9	176.0	81.7	0.464	29.8	157.2	71.6
1972	23.8	4.6	0.193	18.6	114.7	51.3	0.447	28.9	101.2	44.4
1973	14.4	4.6	0.319	22.0	49.6	28.9	0.583	31.4	44.4	25.3
1974	25.7	6.1	0.237	19.7	35.8	21.0	0.587	31.5	34.3	18.8
1975	50.9	18.9	0.371	25.5	37.4	17.4	0.465	28.5	38.9	17.6
1976	45.9	6.4	0.139	19.8	65.1	29.6	0.455	29.2	62.2	26.2
1977	79.1	24.0	0.303	25.3	15.6	9.4	0.603	32.1	25.1	11.6
1978	33.7	10.4	0.309	25.0	22.3	12.5	0.561	30.2	24.0	12.2
1979	27.5	8.5	0.309	25.4	67.5	36.4	0.539	30.0	61.6	32.3
1980	8.5	2.2	0.259	25.3	33.5	23.5	0.701	32.4	29.8	20.3
1981	3.0	1.0	0.333	22.5	38.9	21.7	0.558	30.5	33.6	18.6
1982	5.0	1.4	0.280	24.7	19.0	10.8	0.568	30.1	16.9	9.4
1983	4.8	0.9	0.188	21.6	10.7	7.0	0.654	31.0	9.9	6.1
1984	5.4	1.6	0.296	25.1	4.9	2.9	0.592	30.2	5.0	2.7
1985	1.2	0.4	0.333	24.8	13.6	7.7	0.566	30.1	11.7	6.6
1986	9.5	5.4	0.568	29.9	4.5	2.8	0.622	31.4	5.3	3.2
1987	5.5	1.4	0.255	23.9	27.8	14.9	0.536	30.5	24.5	12.9
1988	11.7	2.6	0.222	23.0	7.5	3.4	0.453	28.4	8.1	3.3
1989	17.6	2.7	0.153	17.6	6.5	3.0	0.462	27.8	7.6	2.9
1990	0.8	0.2	0.250	23.1	14.4	8.0	0.556	30.2	12.3	6.8
1991	5.5	0.8	0.145	19.4	10.2	4.9	0.480	28.0	9.5	4.3
1992	76.8	15.8	0.206	23.5	31.0	9.8	0.316	26.1	37.8	10.7

1. Strata Set: 26, 27, 39, 40
2. Strata Set: 24, 28-30, 36-38
3. Strata Set: 24, 26-30, 36-40

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

Year	INSHORE 1 Stratified Mean Catch per Tow Number	INSHORE 1 Stratified Mean Catch per Tow kg	INSHORE 1 Ave. Wt. kg	INSHORE 1 Ave. Length cm	OFFSHORE 2 Stratified Mean Catch per Tow Number	OFFSHORE 2 Stratified Mean Catch per Tow kg	OFFSHORE 2 Ave. Wt. kg	OFFSHORE 2 Ave. Length cm	COMBINED 3 Stratified Mean Catch per Tow Number	COMBINED 3 Stratified Mean Catch per Tow kg
1963	86.3	7.6	0.088	17.4	87.5	27.0	0.309	26.4	87.3	24.1
1964	81.3	13.5	0.166	20.2	122.3	61.8	0.505	30.8	116.3	54.6
1965	189.5	22.3	0.118	17.7	33.9	11.5	0.339	25.3	57.0	13.1
1966	172.8	17.0	0.098	16.2	77.8	31.2	0.401	27.4	91.9	29.1
1967	62.9	5.3	0.084	17.7	107.1	27.6	0.258	23.6	100.5	24.3
1968	41.1	4.7	0.114	18.3	161.3	46.6	0.289	25.1	143.4	40.4
1969	105.9	16.0	0.151	20.7	65.2	24.8	0.380	27.4	71.2	23.5
1970	18.2	2.8	0.154	20.3	107.2	38.2	0.356	26.3	94.0	32.9
1971	20.7	4.7	0.227	21.8	52.8	26.7	0.506	29.7	48.0	23.4
1972	36.4	6.6	0.181	20.8	58.9	27.8	0.472	29.2	55.6	24.6
1973	26.2	2.1	0.080	15.6	41.4	19.7	0.476	29.7	39.2	17.0
1974	44.4	4.7	0.106	18.0	49.0	27.6	0.563	30.1	48.3	24.2
1975	45.7	6.0	0.131	19.6	79.9	45.9	0.574	30.6	74.8	39.9
1976	11.6	2.5	0.216	22.6	31.9	17.5	0.549	30.2	28.9	15.3
1977	54.6	12.3	0.225	23.4	37.9	18.1	0.478	28.5	40.4	17.3
1978	20.4	5.5	0.270	24.6	49.5	23.4	0.473	29.0	45.2	20.7
1979	6.2	2.1	0.339	26.5	32.8	18.4	0.561	30.5	28.9	16.0
1980	20.6	6.2	0.301	24.6	20.6	13.8	0.670	31.8	20.6	12.6
1981	6.8	1.9	0.279	24.9	22.7	14.0	0.617	31.8	20.4	12.2
1982	28.2	4.6	0.163	21.2	5.6	3.2	0.571	31.5	9.0	3.4
1983	30.2	8.7	0.288	24.8	6.5	3.3	0.508	29.1	10.0	4.1
1984	7.7	3.2	0.416	27.9	7.8	4.1	0.526	29.0	7.8	3.9
1985	7.2	2.1	0.292	24.8	14.0	6.3	0.450	28.0	13.0	5.7
1986	67.6	15.3	0.226	23.3	18.8	6.7	0.356	26.1	26.1	8.0
1987	26.5	4.8	0.181	21.9	11.5	5.6	0.487	29.2	13.7	5.5
1988	18.5	5.1	0.276	21.9	11.4	6.5	0.570	29.1	12.4	6.3
1989	14.0	2.9	0.207	22.6	21.3	7.5	0.352	25.9	20.3	6.8
1990	57.6	14.5	0.252	23.8	31.7	11.7	0.369	26.7	35.5	12.2
1991	7.2	1.1	0.153	20.4	21.1	9.6	0.455	28.5	19.1	8.4
1992*	9.1	2.1	0.231		23.9	9.3	0.389		21.7	8.2

* preliminary

1. Strata Set: 26, 27, 39, 40
2. Strata Set: 24, 28-30, 36-38
3. Strata Set: 24, 26-30, 36-40

Table C5. Prerecruit indices for Gulf of Maine redfish derived from NEFSC autumn surveys conducted in western Gulf of Maine inshore strata (26, 27, 39, and 40)

	Age 0		Age 1		Age 2	
Year	Length Range (cm	No/tow	Length Range (cm	No/tow	Length Range (cm	No/tow
1963	4-7	0.621	8-12	1.772	13-16	40.426
1964	4-7	0.975	8-12	1.303	13-16	21.252
1965	3-7	2.555	8-12	21.729	13-16	52.540
1966	4-7	0.467	8-12	44.896	13-16	63.257
1967	4-7	0.067	8-12	1.731	13-16	24.910
1968	4-7	0.000	8-12	0.617	13-16	14.870
1969	4-7	0.000	8-12	0.063	13-16	6.976
1970	4-7	0.000	8-12	0.063	13-16	2.633
1971	4-7	1.750	8-12	0.000	13-16	0.806
1972	4-7	0.000	8-12	6.560	13-16	0.911
1973	4-7	0.000	8-12	3.402	13-16	18.433
1974	4-7	0.000	8-12	0.511	13-15	6.658
1975	4-7	0.000	8-12	0.000	13-16	4.606
1976	4-7	0.000	8-12	0.095	13-16	0.761
1977	4-7	0.000	8-12	0.000	13-16	0.179
1978	4-7	0.034	8-12	0.000	13-16	0.022
1979	4-7	0.000	8-12	0.057	13-16	0.000
1980	4-7	0.000	8-12	0.964	13-16	2.185
1981	4-7	0.000	8-12	0.000	13-16	0.934
1982	4-7	0.000	8-12	0.111	13-16	0.356
1983	4-7	0.000	8-12	0.479	13-17	1.993
1984	4-7	0.000	8-12	0.000	13-18	0.701
1985	4-7	0.000	8-12	0.067	13-17	0.497
1986	4-7	0.133	8-12	0.067	13-16	0.318
1987	4-7	0.000	8-12	0.189	13-16	1.086
1988	4-7	0.134	8-12	1.370	13-17	3.840
1989	4-7	0.063	8-12	0.308	13-17	0.992
1990	3-7	0.222	8-12	1.125	13-17	6.503

between 20 and 26 cm, from the 1986 or 1987 year classes, appeared in survey catches.

Estimates of $F_{0.1}$ and F_{max} are 0.06 and 0.13, respectively. F at 20% of maximum spawning potential was estimated as 0.12 (Table C6, Figure C6), slightly below the estimate of F_{max}.

The most recent VPA was performed in 1986 using catch at age data from 1969 to 1983. It indicated that age 9+ fishing mortality rates ranged from 0.12 to 0.26 during the 1970s and early 1980s (Figure C7) (NEFC 1986). Exploitable biomass (age 5+) had been reduced by 75% from 1969 to 1984. The VPA was discontinued after 1986; recent declines in redfish landings suggest that F is now likely to be rather low (possibly in the range of M), causing the convergence of a VPA to be a lengthy process.

SARC REVIEW

The steep decline in directed redfish trips since 1986 led to the conclusion that calculations of 1991 and 1992, and perhaps 1990 CPUE and total effort were not useful. Examination of recent survey data revealed an apparent trend, where increases or decreases in age 2 abundance indices coincide with similar changes in age 1 indices. There was some concern that it may be related to changes in survey vessel and doors. The 1992 spring survey data suggests that the 1986 year class may be better than other year classes.

Figure C3. Gulf of Maine-Georges Bank redfish NEFSC spring bottom trawl indices

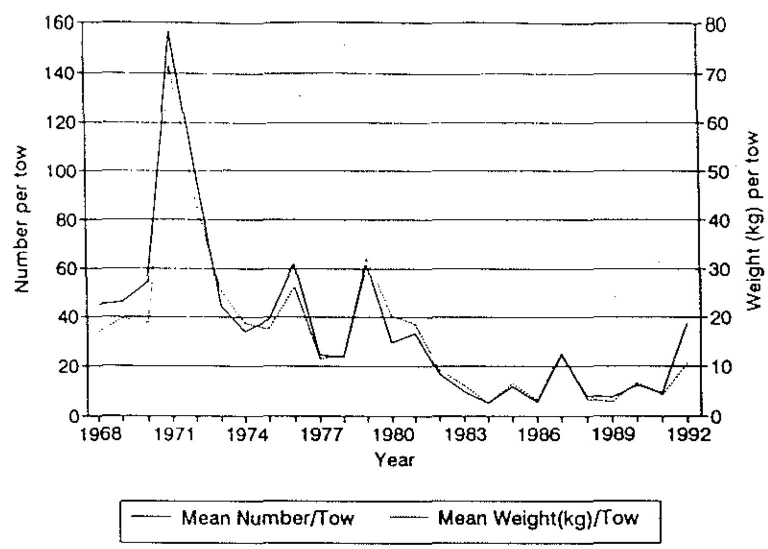


Figure C4. Gulf of Maine-Georges Bank redfish NEFSC autumn bottom trawl indices

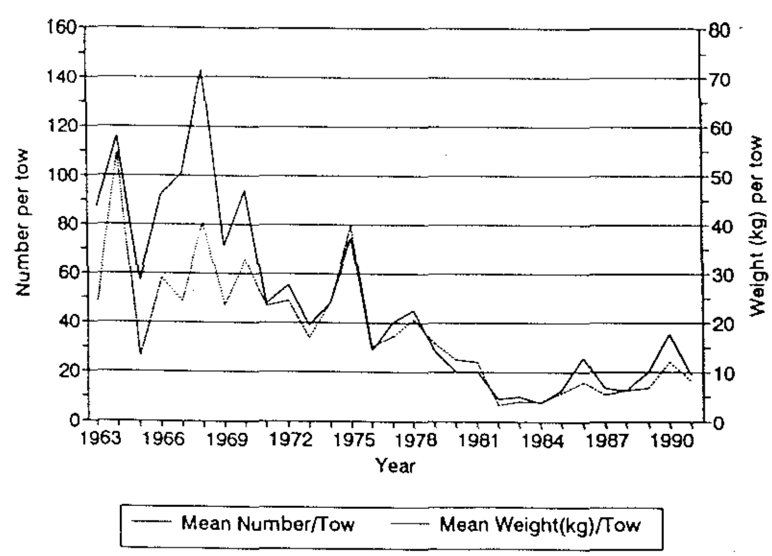


Figure C5. Gulf of Maine redfish length composition, stratified mean number per tow from spring and autumn bottom trawl surveys, 1963-1991.

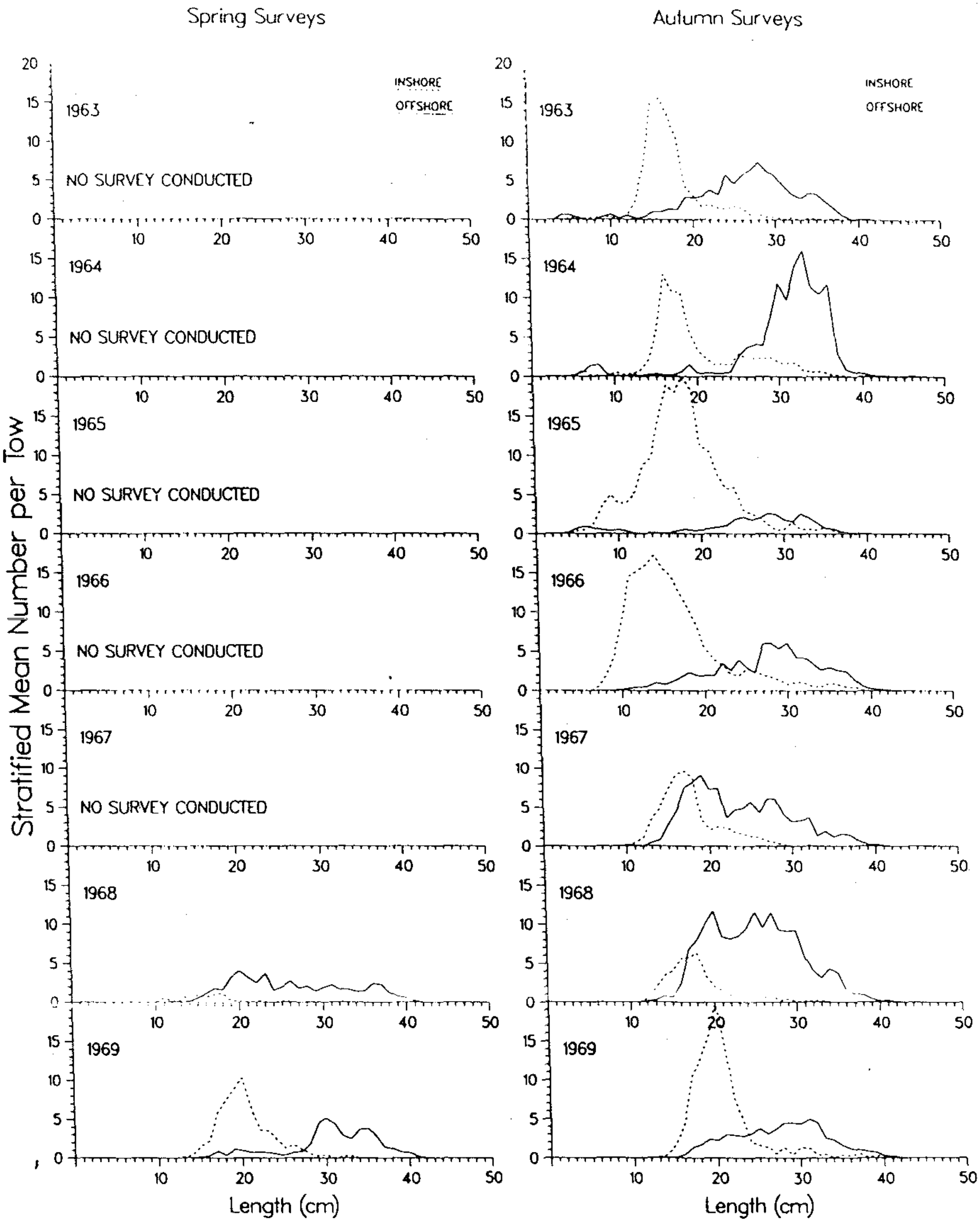


Figure C5. Continued.

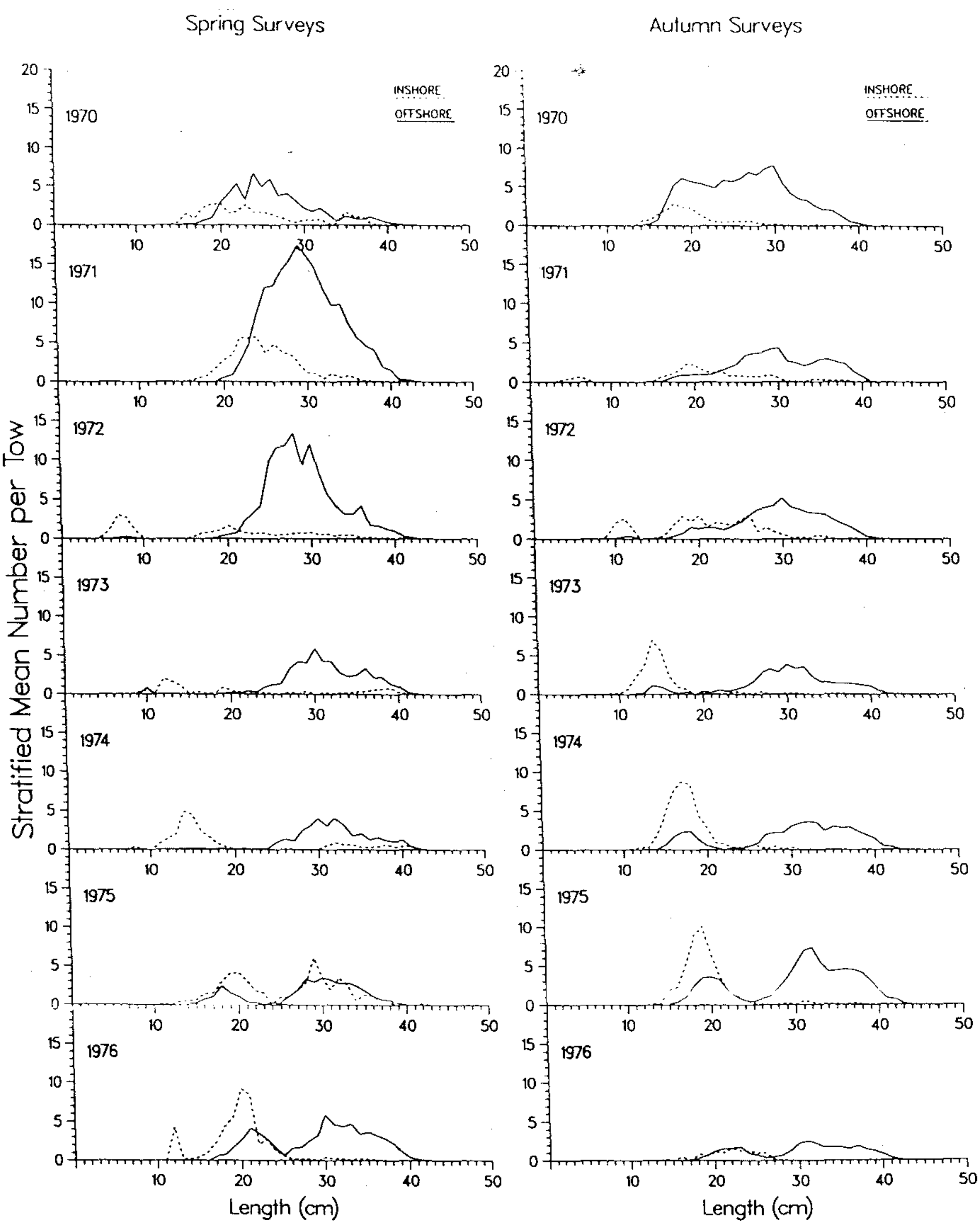


Figure C5. Continued.

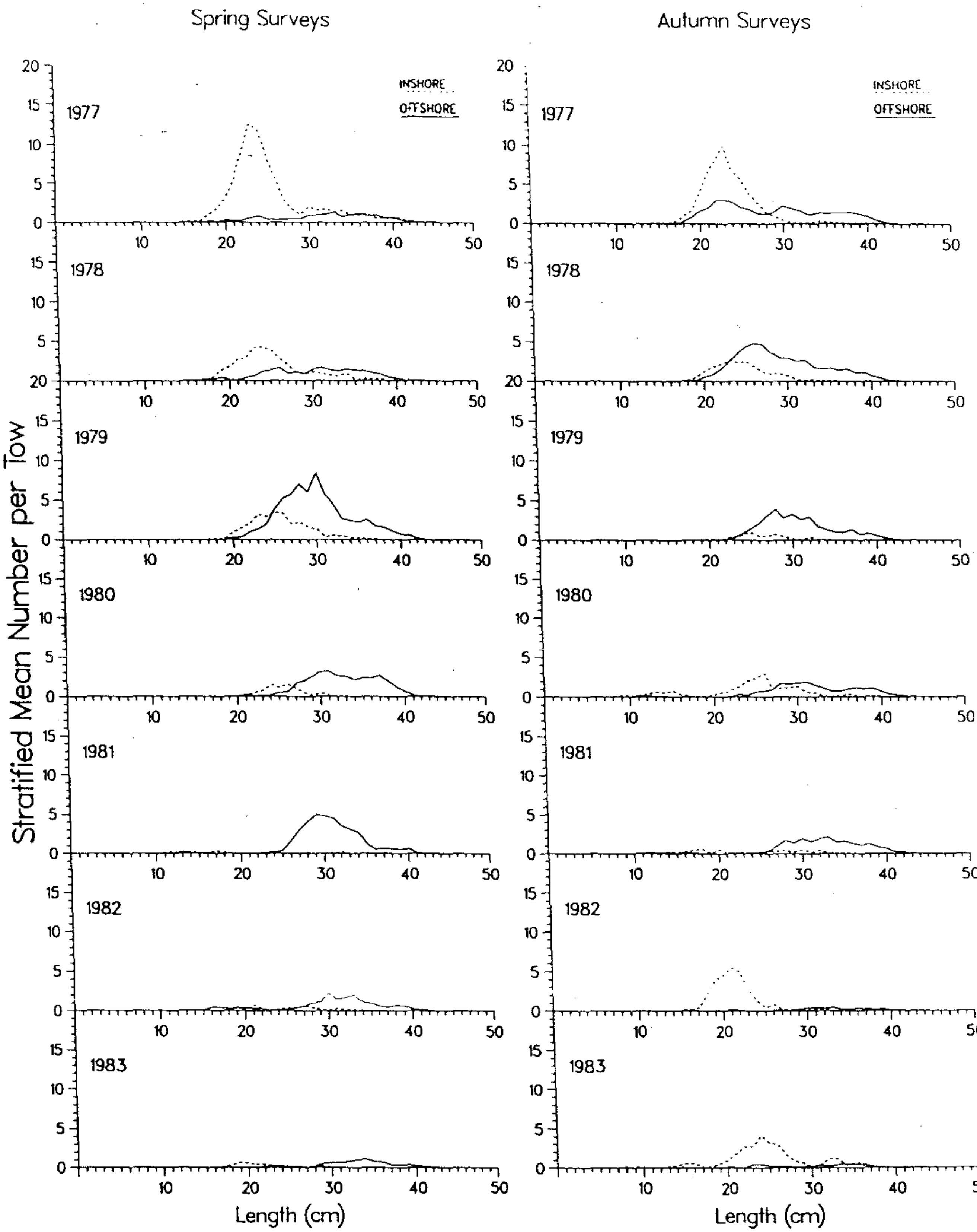


Figure C5. Continued.

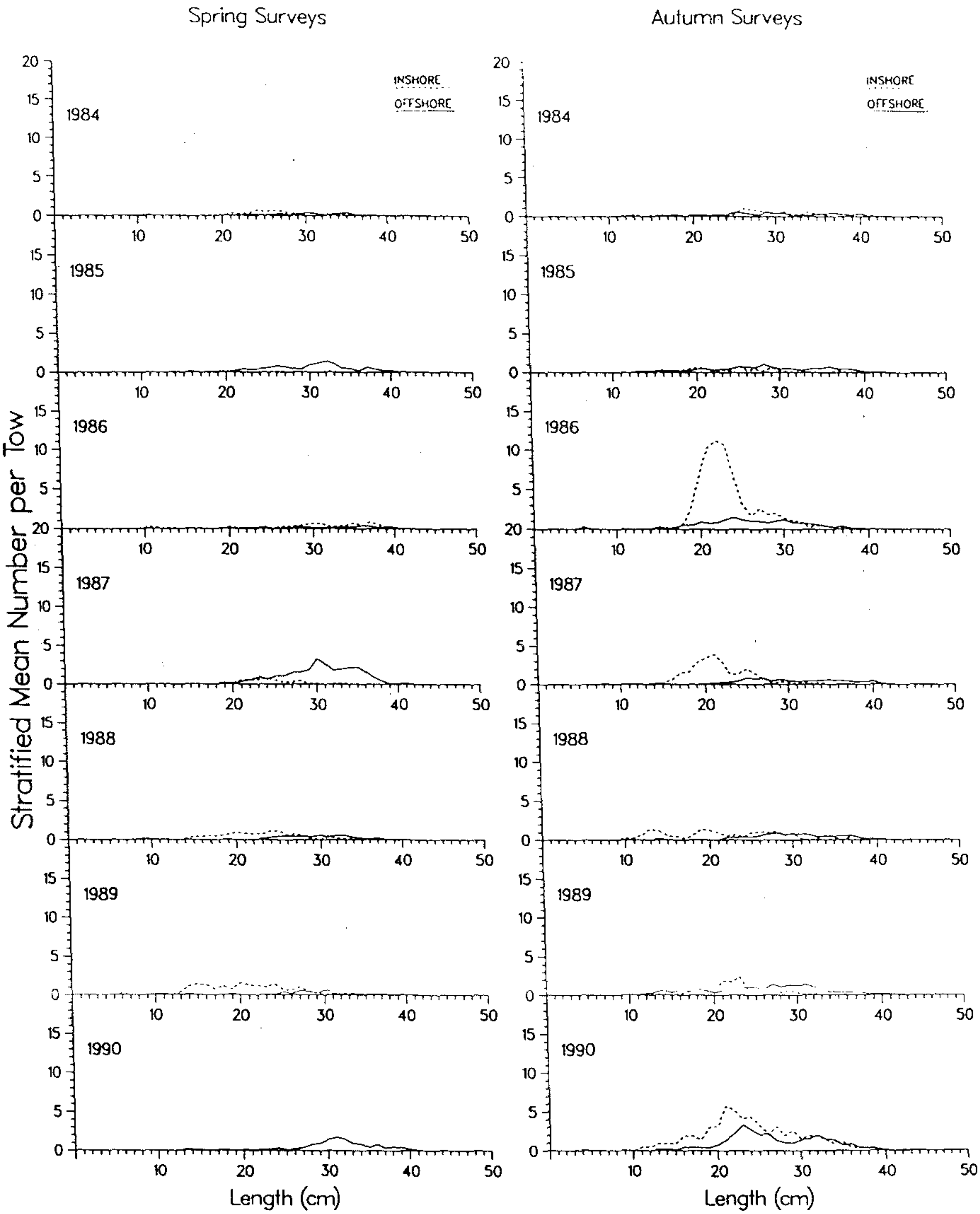


Figure C5. Continued.

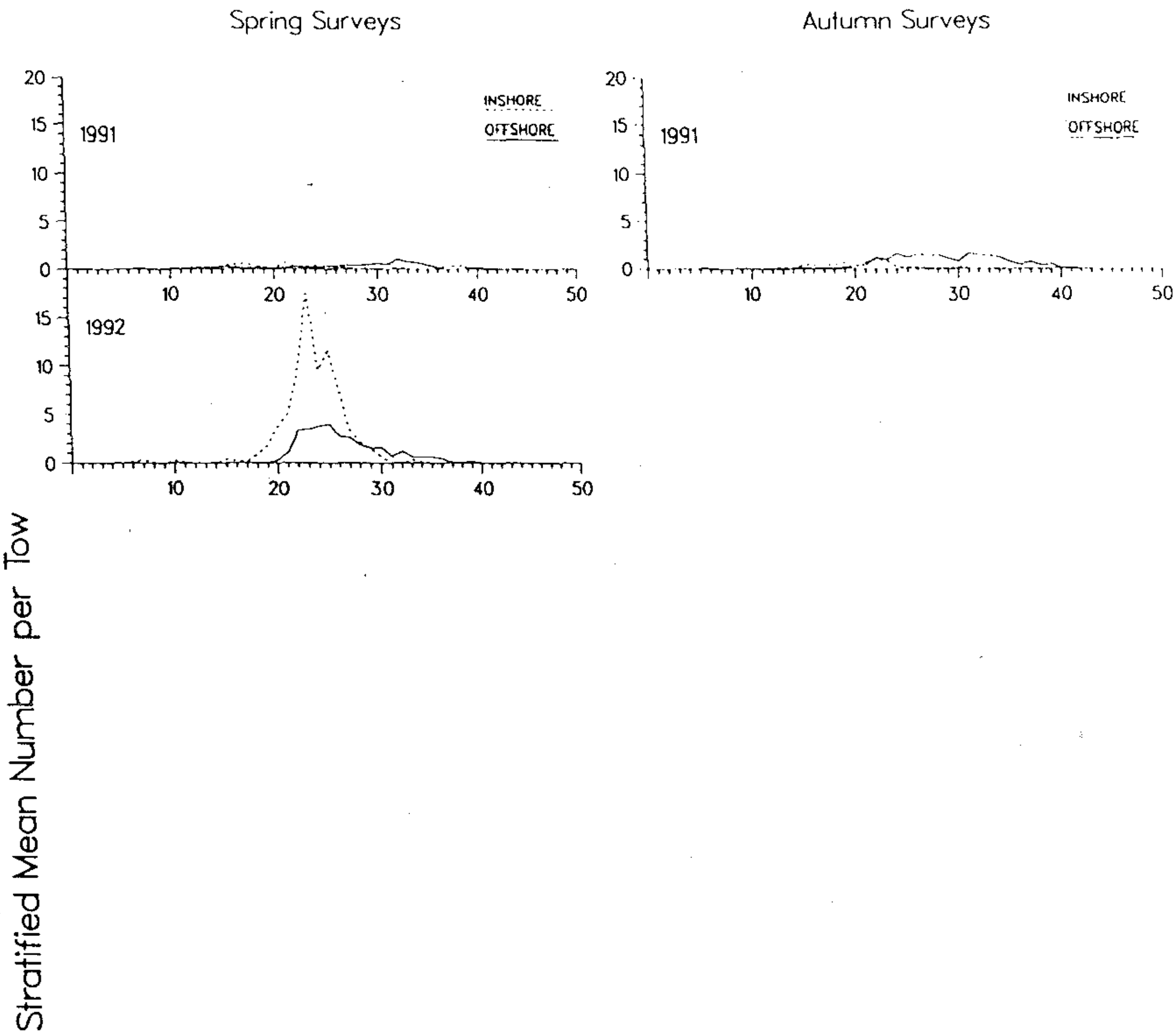


Table C6. Yield and SSB per recruit analysis for Gulf of Maine redfish

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992

Run Date: 23-11-1992; Time: 12:51:50.48
REDFISH UPDATED AVE WTS, MAT VECTOR (MAYO ET AL. 1990), 1971 YC FPAT

Proportion of F before spawning: .4000
Proportion of M before spawning: .4000
Natural Mortality is Constant at: .050
Initial age is: 1; Last age is: 30
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> YRRED.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	.0000	1.0000	.0100	.002	.002
2	.0000	1.0000	.0200	.012	.012
3	.0230	1.0000	.0500	.074	.033
4	.0580	1.0000	.1500	.097	.064
5	.3260	1.0000	.3600	.153	.103
6	.5230	1.0000	.6400	.179	.148
7	.8660	1.0000	.8500	.199	.196
8	.9650	1.0000	.9500	.253	.246
9	1.0000	1.0000	.9800	.271	.295
10	1.0000	1.0000	.9900	.310	.343
11	1.0000	1.0000	1.0000	.341	.388
12	1.0000	1.0000	1.0000	.394	.430
13	1.0000	1.0000	1.0000	.413	.469
14	1.0000	1.0000	1.0000	.428	.505
15	1.0000	1.0000	1.0000	.464	.537
16	1.0000	1.0000	1.0000	.489	.566
17	1.0000	1.0000	1.0000	.504	.592
18	1.0000	1.0000	1.0000	.505	.615
19	1.0000	1.0000	1.0000	.545	.636
20	1.0000	1.0000	1.0000	.558	.654
21	1.0000	1.0000	1.0000	.562	.669
22	1.0000	1.0000	1.0000	.577	.683
23	1.0000	1.0000	1.0000	.594	.696
24	1.0000	1.0000	1.0000	.575	.706
25	1.0000	1.0000	1.0000	.588	.716
26	1.0000	1.0000	1.0000	.624	.724
27	1.0000	1.0000	1.0000	.624	.731
28	1.0000	1.0000	1.0000	.624	.737
29	1.0000	1.0000	1.0000	.624	.742
30+	1.0000	1.0000	1.0000	.624	.760

Summary of Yield per Recruit Analysis for:
REDFISH UPDATED AVE WTS, MAT VECTOR (MAYO ET AL. 1990), 1971 YC FPAT

Slope of the Yield/Recruit Curve at F=0.00: --> 7.4657
F level at slope=1/10 of the above slope (F0.1): -----> .060
Yield/Recruit corresponding to F0.1: -----> .1639
F level to produce Maximum Yield/Recruit (Fmax): -----> .132
Yield/Recruit corresponding to Fmax: -----> .1819
F level at 20 % of Max Spawning Potential (F20): -----> .116
SSB/Recruit corresponding to F20: --------> 1.7605

Listing of Yield per Recruit Results for:
REDFISH UPDATED AVE WTS, MAT VECTOR (MAYO ET AL. 1990), 1971 YC FPAT

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	20.5042	9.2038	15.7030	8.8055	100.00
	.025	.25729	.11261	15.3600	5.6199	10.5714	5.2426	59.54
	.050	.38630	.15495	12.7813	3.9256	8.0049	3.5651	40.49
F0.1	.060	.42199	.16394	12.0681	3.4774	7.2965	3.1229	35.47
	.075	.46399	.17253	11.2289	2.9656	6.4643	2.6189	29.74
	.100	.51602	.17961	10.1898	2.3604	5.4367	2.0253	23.00
F20%	.116	.54048	.18132	9.7014	2.0893	4.9553	1.7605	19.99
	.125	.55337	.18176	9.4441	1.9506	4.7023	1.6253	18.46
Fmax	.132	.56220	.18186	9.2679	1.8572	4.5292	1.5345	17.43
	.150	.58155	.18148	8.8819	1.6582	4.1510	1.3415	15.23
	.175	.60361	.17999	8.4421	1.4412	3.7218	1.1319	12.85
	.200	.62138	.17791	8.0880	1.2750	3.3781	.9723	11.04
	.225	.63602	.17558	7.7963	1.1443	3.0965	.8475	9.63
	.250	.64833	.17318	7.5514	1.0394	2.8616	.7479	8.49
	.275	.65882	.17081	7.3427	.9536	2.6625	.6670	7.57
	.300	.66790	.16851	7.1623	.8823	2.4916	.6002	6.82
	.325	.67583	.16632	7.0047	.8223	2.3433	.5443	6.18
	.350	.68284	.16425	6.8655	.7712	2.2133	.4969	5.64
	.375	.68909	.16230	6.7417	.7272	2.0983	.4565	5.18
	.400	.69469	.16046	6.6306	.6889	1.9959	.4215	4.79
	.425	.69976	.15874	6.5303	.6554	1.9041	.3911	4.44
	.450	.70436	.15712	6.4391	.6258	1.8214	.3645	4.14
	.475	.70857	.15560	6.3559	.5995	1.7463	.3409	3.87
	.500	.71244	.15417	6.2794	.5759	1.6779	.3200	3.63
	.550	.71932	.15155	6.1436	.5356	1.5578	.2846	3.23
	.600	.72526	.14922	6.0264	.5023	1.4557	.2558	2.90
	.650	.73047	.14714	5.9238	.4744	1.3677	.2319	2.63
	.700	.73509	.14526	5.8331	.4506	1.2911	.2119	2.41
	.750	.73921	.14356	5.7520	.4301	1.2237	.1949	2.21
	.800	.74294	.14201	5.6789	.4121	1.1639	.1803	2.05
	.850	.74632	.14060	5.6126	.3964	1.1105	.1676	1.90
	.900	.74941	.13930	5.5521	.3824	1.0624	.1565	1.78
	.950	.75226	.13809	5.4964	.3698	1.0189	.1467	1.67
	1.000	.75488	.13698	5.4451	.3585	.9793	.1380	1.57

Figure C6. Yield and spawning stock biomass per recruit results for Gulf of Maine-Georges Bank redfish.

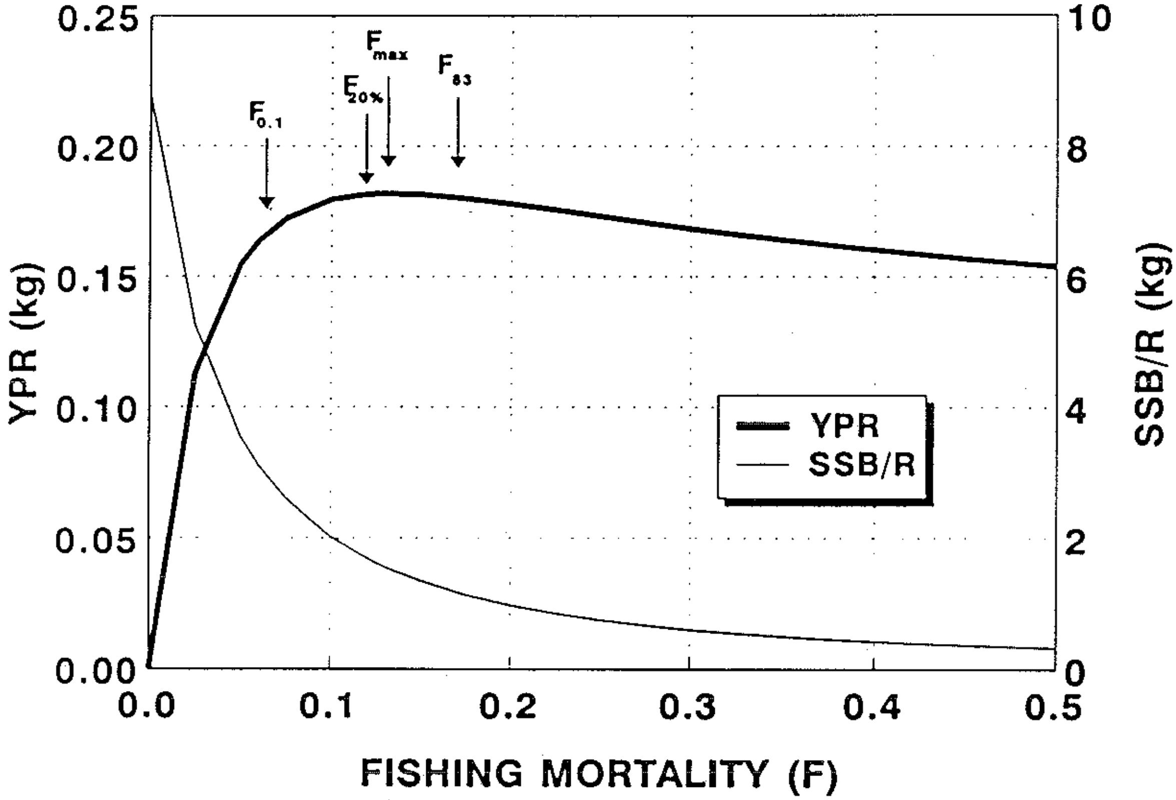
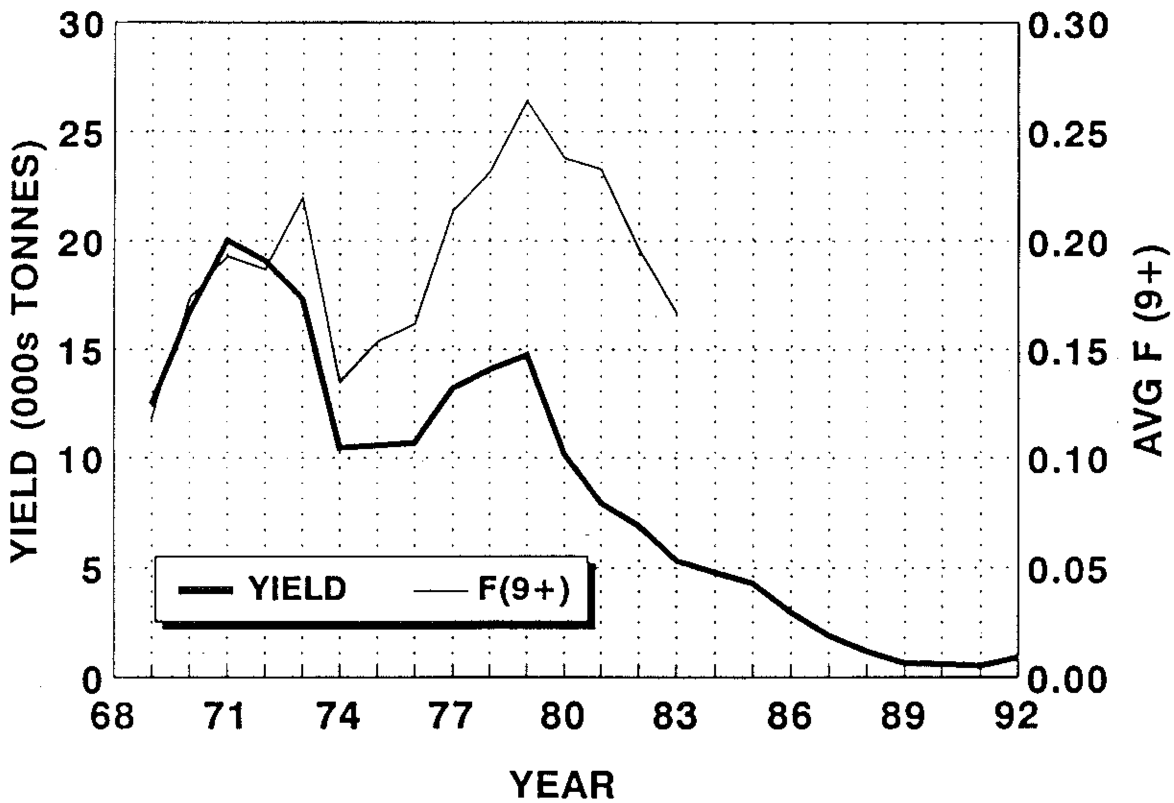


Figure C7. Trends in yield (1,000 t) and instantaneous fishing mortality (F) for Gulf of Maine-Georges Bank redfish, 1969-1992.



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GULF OF MAINE-GEORGES BANK REDFISH RECOMMENDATIONS/RESEARCH NEEDS

1. Shrimp fishery sea sampling data should be examined to determine age or size composition and discard rates.
2. Gulf of Maine summer survey should be examined.
3. Survey vessel and door conversion factors should be examined to determine if they affect the apparent trend in Age 1 and 2 survey indices.
4. A sufficient sample of redfish otoliths should be aged to update the catch at age matrix.

D. GULF OF MAINE COD ASSESSMENT

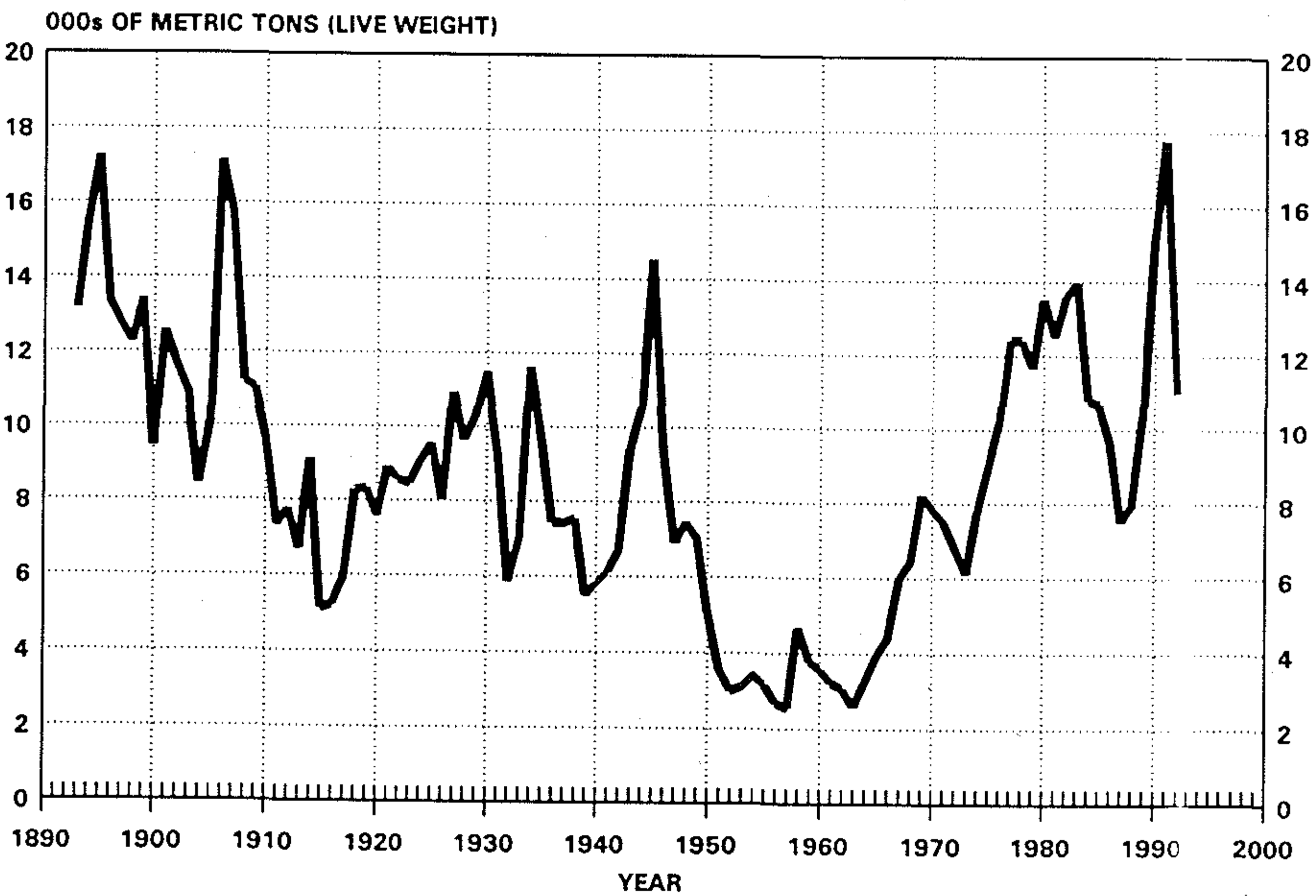
INTRODUCTION

Atlantic cod *(Gadus morhua)* in the Gulf of Maine region have been commercially exploited since the 17th Century. Reliable landings statistics are available since 1893. Historically, the Gulf of Maine fishery can be separated into four periods (Figure D1):

(1) an early era from 1893-1915 in which record-high landings (> 17,000 t) in 1895 and 1906 were followed by about 10 years of sharply-reduced catches
(2) a later period from 1916-1940 in which annual landings were relatively stable, fluctuating between 5,000 and 11,500 t and averaging 8,300 t per year
(3) a period from 1941-1963 when landings sharply increased (1945: 14,500 tons) and then rapidly decreased, reaching a record low of 2,600 t in 1957
(4) the most recent period, from 1964 onward, during which Gulf of Maine landings have generally increased. Total landings doubled between 1964 and 1968, doubled again between 1968 and 1977, and averaged 12,200 t per year during 1976-1985 (Table D1). Although Gulf of Maine landings declined between 1984 and 1987, landings have since increased, reaching 17,800 t in 1991, the highest level since the early 1900s.

This report presents an updated and revised analytical assessment of the Gulf of Maine cod stock (NAFO Division 5Y) for the period 1982-1991 based on analyses of commercial and research vessel survey data through 1991. More specific details regarding the assessment are presented by Mayo *et al.* (1993). An initial analytical assessment of this stock was presented at the Seventh NEFC Stock Assessment Workshop in November, 1988 (NEFC 1989) and a subsequent revision was presented at the Twelfth Northeast Regional Stock

Figure D1. Total commercial landings of Gulf of Maine cod, NAFO Division 5Y, 1893-1992.



Assessment Workshop in June, 1991 (NEFSC 1991).

COMMERCIAL FISHERY LANDINGS

Total commercial landings in 1991 were 17,781 t, 15% greater than in 1990 and 71% greater than in 1989 (Table D1), the highest catch on record. Since 1977, the U.S. fishery has accounted for all of the commercial catch. Canadian landings reported as Gulf of Maine catch during 1977-1990 are believed, by Canadian scientists, to be misreported catches from the Scotian Shelf stock (Campana and Simon 1985; Campana and Hamel 1990).

Otter trawl catches accounted for most (74%, by weight) of the 1991 landings (Table D2). Gill net catches, which comprised about 40% of the total landings during 1987-1989, accounted for only 23% in 1991.

CATCH COMPOSITION

U.S. length frequency sampling averaged one sample per 155 to 200 t landed during 1983-1987 but, since 1988, has decreased (1990: 1 sample per 387 t; 1991: 1 sample per 318 t). Virtually all of the U.S. samples have been taken from otter trawl landings, but sampling is proportionally stratified by market category (scrod, market, and large). Of the 56 samples collected in 1991, 19 were scrod samples (34%), 30 were market (54%), and 7 were large (13%). Compared with the 1991 market category landings distribution (by weight - scrod: 26%; market: 51%; large: 20%), 'scrod cod' were slightly oversampled and 'large cod' undersampled.

Table D1. Commercial landings (mt, live) of Atlantic cod the Gulf of Maine (NAFO Division 5Y), 1960-1992[1]

	Gulf of Maine				
Year	USA	Canada	USSR	Other	Total
1960	3448	129	-	-	3577
1961	3216	18	-	-	3234
1962	2989	83	-	-	3072
1963	2595	3	133	-	2731
1964	3226	25	-	-	3251
1965	3780	148	-	-	3928
1966	4008	384	-	-	4392
1967	5676	297	-	-	5973
1968	6360	61	-	-	6421
1969	8157	59	-	268	8484
1970	7812	26	-	423	8261
1971	7380	119	-	163	7662
1972	6776	53	11	77	6917
1973	6069	68	-	9	6146
1974	7639	120	-	5	7764
1975	8903	86	-	26	9015
1976	10172	16	-	-	10188
1977	12426	-	-	-	12426
1978	12426	-	-	-	12426
1979	11680	-	-	-	11680
1980	13528	-	-	-	13528
1981	12534	-	-	-	12534
1982	13582	-	-	-	13582
1983	13981	-	-	-	13981
1984	10806	-	-	-	10806
1985	10693	-	-	-	10693
1986	9664	-	-	-	9664
1987	7527	-	-	-	7527
1988	7958	-	-	-	7958
1989	10397	-	-	-	10397
1990	15154	-	-	-	15154
1991	17781	-	-	-	17781
1992	11000	-	-	-	11000

[1] **U.S. landings from NMFS, NEFC Detailed Weighout Files and Canvass data.**

* **Provisional**

Age Composition

Age composition of landings during 1982-1991 was estimated, by market category, from monthly length frequency and age samples, pooled by calendar quarter. Quarterly mean weights, by market category, were obtained by applying the U.S. cod length-weight equation ($\ln \text{Weight}_{(kg,live)} = -11.7231 + 3.0521 \ln \text{Length}_{(cm)}$) to the quarterly market category sample length frequencies. Mean weight values were then divided into quarterly market category landings to derive estimated numbers landed by quarter, by market category. Quarterly age/length keys were then applied to the quarterly market category numbers at length distributions to provide numbers at age. These values were summed over market categories and quarters to derive the annual catch-at-age matrix (Table D3). Derivation of catch by quarter, rather than by month, was performed since not all months had at least two length frequency samples per market category (*i.e.*, minimum desired for monthly catch estimates).

For many of the length frequency samples, sample weights were also available. These were converted (x 1.17) to live weights and compared to the calculated weights from the length-weight equation. In most cases, the differences were small (<5%) implying that use of the length-weight equation to derive the number of fish landed imparted little, if any, bias to the calculation of catch in numbers. Gulf of Maine cod

Table D2. Distribution of U.S. commercial landings (mt, live) of Atlantic cod from the Gulf of Maine (Area 5Y), by gear type, 1965-1991. The percentage of total U.S. commercial landings of Atlantic cod from the Gulf of Maine, by gear type, is also presented for each year. Data only reflect Gulf of Maine cod landings that could be identified by gear type.

	Landings (mt, live)						**Percentage of Annual Landings**					
Year	**Otter Trawl**	**Sink Gillnet**	**Line Trawl**	**Handline**	**Other Gear**	**Total**	**Otter Trawl**	**Sink Gillnet**	**Line Trawl**	**Handline**	**Other Gear**	**Total**
1965	2480	501	462	168	1	3612	68.7	13.9	12.8	4.6	-	100.0
1966	2549	830	308	150	4	3841	66.4	21.6	8.0	3.9	0.1	100.0
1967	4312	734	206	274	<1	5526	78.0	13.3	3.7	5.0	-	100.0
1968	4143	1377	213	339	4	6076	68.2	22.7	3.5	5.6	-	100.0
1969	6553	851	258	162	4	7828	83.7	10.9	3.3	2.1	-	100.0
1970	5967	951	407	178	9	7512	79.4	12.7	5.4	2.4	0.1	100.0
1971	5117	1043	927	98	8	7193	71.1	14.5	12.9	1.4	0.1	100.0
1972	4004	1492	1234	54	2	6786	59.0	22.0	18.2	0.8	-	100.0
1973	3542	1182	1305	23	9	6061	58.4	19.5	21.5	0.4	0.2	100.0
1974	5056	1412	904	36	17	7425	68.1	19.0	12.2	0.5	0.2	100.0
1975	6255	1480	920	12	8	8675	72.1	17.1	10.6	0.1	0.1	100.0
1976	6701	2511	621	4	41	9878	67.8	25.4	6.3	0.1	0.4	100.0
1977	8415	2872	534	6	166[a]	11993	70.2	23.9	4.5	-	1.4	100.0
1978	7958	3438	393	10	91[b]	11890	66.9	28.9	3.3	0.1	0.8	100.0
1979	7567	2900	334	19	167[c]	10987	68.9	26.4	3.0	0.2	1.5	100.0
1980	8420	3733	251	48	61	12513	67.3	29.8	2.0	0.4	0.5	100.0
1981	7937	4102	276	23	45	12383	64.1	33.1	2.2	0.2	0.4	100.0
1982	9758	3453	188	46	34	13479	72.4	25.6	1.4	0.3	0.3	100.0
1983	9975	3744	77	4	67	13867	71.9	27.0	0.6	-	0.5	100.0
1984	6646	3985	22	3	69	10725	62.0	37.2	0.2	-	0.6	100.0
1985	7119	3090	55	6	326[d]	10596	67.2	29.1	0.5	0.1	3.1	100.0
1986	6664	2692	56	12	180[e]	9604	69.4	28.0	0.6	0.1	1.9	100.0
1987	4356	2994	70	13	68	7501	58.1	39.9	0.9	0.2	0.9	100.0
1988	4513	3308	68	27	22	7938	56.9	41.7	0.8	0.3	0.3	100.0
1989	6152	4000	72	36	119[f]	10379	59.3	38.5	0.7	0.4	1.1	100.0
1990	10420	4343	126	20	186[g]	15095	69.0	28.8	0.8	0.1	1.2	100.0
1991	13049	4158	212	59	266[h]	17744	73.5	23.4	1.2	0.3	1.5	100.0

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

landings in 1991 were dominated by fish from the 1987 year class with secondary contributions from the 1986 and 1988 year classes (Table D3). Together these three cohorts accounted for 91% of the total catch, by number, and 87% by weight.

Mean Weights at Age

Mean weights at-age in the catch for ages 1 to 11+ during 1982-1991 are given in Table D3 and, based on landings patterns, are considered mid-year values. Apart from 1990, only slight variations are apparent among years with no consistent trends evident. In 1990, mean weights at age for age groups 2 to 4 were the lowest in the nine-year time series while mean weights for age groups 6 and 7 were the highest. These changes, however, may be artifacts of the reduced sampling intensity of the landings in 1990 as indicated by the increase in mean weights at ages 2 and 4 in 1991. Catch at age and recalculated mean weights at age for the 8+ group which are used in the VPA are given in Table D4. Mean weights at age for calculating stock biomass at the beginning of the year are provided in Table D5. These values were derived from the catch mean weight at age data (Table D3) using the procedures described by Rivard (1980).

Table D3. Catch at age (thousands of fish; mt) and mean weight (kg) and mean length (cm) at age of total commercial landings of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982-1991

	Age											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**	**Total**
					Total Commercial Catch in Numbers (000's) at Age							
1982	30	1380	1633	1143	633	69	91	61	41	4	33	5118
1983	-	866	2357	1058	638	422	47	61	23	9	15	5496
1984	4	446	1240	1500	437	194	74	19	15	11	17	3957
1985	-	407	1445	991	630	128	78	32	4	11	11	3737
1986	-	84	2164	813	250	177	39	24	20	4	8	3583
1987	2	216	595	1109	277	66	51	9	8	8	3	2344
1988	-	160	1443	953	406	43	9	17	1	2	1	3035
1989	-	337	1583	1454	449	81	35	6	3	5	7	3960
1990	-	205	3425	2064	430	157	27	30	10	15	17	6380
1991	-	344	934	4161	851	143	41	30	6	1	1	6512
					Total Commercial Catch in Weight (Tons) at Age							
1982	24	1595	2717	3160	3019	461	813	608	531	41	613	13582
1983	-	1009	3913	2619	2410	2518	271	643	227	102	269	13981
1984	3	516	2071	4080	1607	1145	603	186	193	152	250	10816
1985	-	513	2523	2816	2814	705	615	363	51	141	152	10693
1986	-	110	3976	2375	1153	1072	296	243	253	54	132	9664
1987	2	283	1001	3641	1340	451	455	88	116	110	40	7527
1988	-	203	2715	2311	2097	295	85	191	11	36	14	7958
1989	-	420	2811	4351	1737	325	323	67	43	87	163	10397
1990	-	219	5794	4687	1834	1200	290	354	153	214	350	15095
1991	-	388	1463	10455	3520	1045	399	369	93	32	17	17781
					Total Commercial Catch Mean Weight (kg) at Age							
1982	0.801	1.156	1.664	2.764	4.770	6.739	8.944	9.931	12.922	10.618	18.456	2.654[a]
1983	-	1.164	1.660	2.475	3.778	5.962	5.808	10.522	10.089	10.898	17.813	2.544
1984	0.589	1.159	1.670	2.721	3.677	5.898	8.119	9.595	12.889	13.951	15.028	2.731
1985	-	1.260	1.746	2.840	4.466	5.525	7.901	11.218	11.420	13.386	14.523	2.861
1986	-	1.304	1.837	2.923	4.619	6.067	7.669	10.030	12.463	12.907	16.554	2.698
1987	1.028	1.313	1.684	3.283	4.831	6.824	8.878	10.023	13.752	14.738	14.596	3.212
1988	-	1.268	1.881	2.426	5.166	6.767	9.932	11.126	14.960	15.763	20.356	2.622
1989	-	1.247	1.776	2.993	3.864	4.872	9.267	11.938	14.806	18.196	21.521	2.626
1990	-	1.071	1.692	2.271	4.265	7.645	10.734	11.758	15.015	14.784	20.295	2.366
1991	-	1.130	1.568	2.512	4.136	7.309	9.642	12.322	15.547	24.328	21.885	2.731
					Total Commercial Catch Mean Length (cm) at Age							
1982	43.2	48.3	53.8	63.4	76.8	86.1	94.6	97.9	107.4	101.0	120.7	59.9[b]
1983	-	48.6	53.8	61.4	70.8	82.4	80.5	98.8	97.5	100.0	118.7	59.8
1984	39.0	48.4	54.1	63.4	69.7	81.8	91.5	96.7	106.9	109.6	112.0	61.6
1985	-	49.8	55.1	64.6	74.9	80.3	90.8	101.9	103.1	108.2	109.7	62.8
1986	-	50.3	55.9	65.0	75.4	82.6	89.9	98.7	105.8	107.5	116.2	61.6
1987	47.0	50.4	54.4	67.8	76.9	86.5	93.8	98.7	109.5	111.7	111.3	65.4
1988	-	50.1	56.4	61.1	78.7	86.4	98.6	102.3	113.0	114.8	125.0	61.4
1989	-	49.8	55.5	65.7	71.5	76.7	95.8	103.4	112.6	120.4	126.8	61.7
1990	-	47.5	54.8	60.0	73.7	90.0	100.9	104.0	111.8	112.6	124.6	59.2
1991	-	47.7	52.6	61.8	72.6	88.6	97.2	105.0	113.3	132.5	128.0	62.2

[a] Mean weight
[b] Mean length

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial Catch Rates

U.S. commercial CPUE indices (catch per unit effort, expressed in metric tons landed per day fished) were calculated, by tonnage class (Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT), from otter trawl trips landing cod from the Gulf of Maine (Division 5Y). Indices were derived based on all trips landing cod, and for "directed" trips in which cod comprised 50% or more of the total trip catch by weight (Table D6). "Directed trips" have generally accounted

Table D4. Catch at age (thousands of fish; mt) and mean weight (kg) and mean length (cm) at age of total commercial landings of Atlantic cod from the Gulf of Maine stock (NAFO Division 5Y), 1982 - 1991

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**Total**
			Total Commercial Catch in Numbers (000's) at Age						
1982	30	1380	1633	1143	633	69	91	139	5118
1983	-	866	2357	1058	638	422	47	108	5496
1984	4	446	1240	1500	437	194	74	62	3957
1985	-	407	1445	991	630	128	78	58	3737
1986	-	84	2164	813	250	177	39	56	3583
1987	2	216	595	1109	277	66	51	28	2344
1988	-	160	1443	953	406	43	9	21	3035
1989	-	337	1583	1454	449	81	35	21	3960
1990	-	205	3425	2064	430	157	27	72	6380
1991	-	344	934	4161	851	143	41	38	6512
			Total Commercial Catch in Weight (Tons) at Age						
1982	24	1595	2717	3160	3019	461	813	1793	13582
1983	-	1009	3913	2619	2410	2518	271	1241	13981
1984	3	516	2071	4080	1607	1145	603	781	10816
1985	-	513	2523	2816	2814	705	615	707	10693
1986	-	110	3976	2375	1153	1072	296	682	9664
1987	2	283	1001	3641	1340	451	455	354	7527
1988	-	203	2715	2311	2097	295	85	252	7958
1989	-	420	2811	4351	1737	325	323	360	10397
1990	-	219	5794	4687	1834	1200	290	1071	15095
1991	-	388	1463	10455	3520	1045	399	511	17781
			Total Commercial Catch Mean Weight (kg) at Age						
1982	0.801	1.156	1.664	2.764	4.770	6.739	8.944	12.892	2.654[a]
1983	-	1.164	1.660	2.475	3.778	5.962	5.808	11.473	2.544
1984	0.589	1.159	1.670	2.721	3.677	5.898	8.119	12.631	2.731
1985	-	1.260	1.746	2.840	4.466	5.525	7.901	12.169	2.861
1986	-	1.304	1.837	2.923	4.619	6.067	7.669	12.124	2.698
1987	1.028	1.313	1.684	3.283	4.831	6.824	8.878	12.724	3.212
1988	-	1.268	1.881	2.426	5.166	6.767	9.932	11.791	2.622
1989	-	1.247	1.776	2.993	3.864	4.872	9.267	17.088	2.626
1990	-	1.071	1.692	2.271	4.2657.645	10.734	14.877	2.366	
1991	-	1.130	1.568	2.512	4.136	7.309	9.642	13.399	2.731
			Total Commercial Catch Mean Length (cm) at Age						
1982	43.2	48.3	53.8	63.4	76.8	86.1	94.6	106.2	59.9[b]
1983	-	48.6	53.8	61.4	70.8	82.4	80.5	101.5	59.8
1984	39.0	48.4	54.1	63.4	69.7	81.8	91.5	105.8	61.6
1985	-	49.8	55.1	64.6	74.9	80.3	90.8	104.6	62.8
1986	-	50.3	55.9	65.0	75.4	82.6	89.9	104.3	61.6
1987	47.0	50.4	54.4	67.8	76.9	86.5	93.8	106.8	65.4
1988	-	50.1	56.4	61.1	78.7	86.4	98.6	105.0	61.4
1989	-	49.8	55.5	65.7	71.5	76.7	95.8	116.6	61.7
1990	-	47.5	54.8	60.0	73.7	90.0	100.9	111.8	59.2
1991	-	47.7	52.6	61.8	72.6	88.6	97.2	107.6	62.2

[a] **Mean weight**
[b] **Mean length**

Table D5. Mean weight at age (kg) at the beginning of the year (January 1) for Atlantic cod from the Gulf of Maine cod stock (NAFO Division 5Y), 1982 - 1991. Values derived from catch mean weight-at-data (mid-year) using procedures described by Rivard (1980)

Year	Age 1	2	3	4	5	6	7	8	9	10+[a]
1982	0.791	0.965	1.364	2.364	(3.750)[b]	(5.600)	(7.400)	9.853	(11.650)	16.000
1983	0.793	1.024	1.385	2.029	3.231	5.333	6.256	9.701	10.010	16.000
1984	0.761	1.021	1.394	2.125	3.017	4.720	6.957	(9.670)	11.646	16.000
1985	0.748	1.065	1.423	2.178	3.486	4.507	6.826	9.544	10.468	16.000
1986	0.745	1.083	1.521	2.259	3.622	5.205	6.509	8.902	11.824	16.000
1987	0.758	1.087	1.482	2.456	3.758	5.614	7.339	8.767	11.744	16.000
1988	0.765	1.068	1.572	2.021	4.118	5.718	8.233	9.939	12.245	16.000
1989	0.825	1.059	1.501	2.373	3.062	5.017	7.919	10.889	12.835	16.000
1990	0.803	0.982	1.453	2.008	3.573	.435	7.232	10.438	13.388	16.000
1991	0.803	1.008	1.296	2.062	3.065	5.583	8.586	11.501	13.520	16.000
Mean Values										
89-91	0.814	1.016	1.417	2.148	3.233	5.345	7.912	10.943	13.248	16.000
82-91	0.779	1.036	1.439	2.188	3.468	5.273	7.326	9.921	11.753	16.000

[a] Mean weight-at-age values for 10+ set equal to mean (1982-1990) catch (mid-year) weight at age value for 10+.
[b] Values in parentheses are modified from calculated values.

for less than 45% (and as low as 14%) of U.S. Gulf of Maine otter trawl landings of cod but since 1988 "directed trips" have accounted for an increasing percentage of the total catch (Table D7). "Directed trips" accounted for 35% of the otter trawl catch in 1988, 49% in 1989, 67% in 1990, and 71% in 1991. This trend is apparent within and among vessel class categories.

Both total and directed U.S. CPUE indices have generally exhibited similar trends (Table D6, Figure D2). CPUE values increased during the late 1960s, declined during the early 1970s, sharply increased in 1974, and then stabilized during 1975-1983 at a relatively high level. After 1983, CPUE indices trended downward, reaching record-low levels in 1987. Subsequently, both total and directed CPUE indices have increased. In 1991, the total CPUE index was the highest since 1977 (and among the highest in the time series) while the directed index declined from the 1990 level and remains among the lowest in the time series. Between 1988 and 1991, the percentage of total trips qualifying as directed trips quadrupled (Table D7: 8% to 33%). While the total number of cod trips remained low in 1991 relative to 1988, the number of directed trips increased sevenfold over the past three years (Table D6: 300 trips in 1988 *vs* 2147 trips in 1991). This suggests that the very high total CPUE index for 1990 and 1991 is inflated due to a marked change in fleet "directivity", particularly by Class 4 vessels. In 1988, 5% of Class 4 cod trips were "directed" while in 1991, 57% of Class 4 trips qualified as "directed" (Table D7).

In terms of calculated effort (total landings/total U.S. CPUE index), total fishing effort peaked at a record-high level in 1987 but has since declined (Table D8). To the extent that the 1990 and 1991 total CPUE indices are 'inflated' (due to increased fleet directivity for cod), the calculated effort values for 1990 and 1991 are underestimated.

Fishing effort was standardized by applying a four-factor (year, tonnage class, area, and depth) general linear model (GLM) to log CPUE data derived for all otter trawl trips taking cod from 1982 through 1991 (Table D9). The model accounted for just over 20% of the total sum of squares, although all four factors were highly significant. Retransformed log year coefficients were multiplied by the 1982 base year CPUE and divided into the annual total landings (from Table D8) to derive effort values (Table D9). Both series of effort estimates (Table D8 and Table D9) show the same trends over time with peak effort occurring in 1987 followed by a decline in 1989 and 1990. The GLM standardized series shows a subsequent increase (+17%) in effort in 1991 over 1990 compared to the effort trend estimated from the calculated LPUE indices (Figure D3).

Research Vessel Survey Indices

Indices of cod abundance (stratified mean catch per tow in numbers) and biomass (stratified mean weight per tow in kilograms), developed from Northeast Fisheries Science Center (NEFSC) and State of Massachusetts research vessel bot-

Table D6. U.S. commercial landings (L)[1], days fished (DF), and landings per day fished (L/DF)[2], by vessel tonnage class (Class 2 = 2 to 50 GRT; Class 3 = 51 to 150 GRT; Class 4 = 151-500 GRT), of Atlantic cod for otter trawl trips catching cod from the Gulf of Maine (NAFO Division 5Y), 1965-1991. Data are also provided for otter trawl trips in which cod composed 50% or more of the total trip catch by weight ('directed trips').

Year	Class 2			Class 3			Class 4			Totals	
	L	DF	L/DF	L	DF	L/DF	L	DF	L/DF	L	L/DF[3]
					ALL TRIPS						
1965	1412	2691	0.52	935	965	0.97	46	92	0.50	2393	0.70
1966	1265	2379	0.53	1093	938	1.17	113	83	1.36	2471	0.85
1967	1790	2175	0.82	2341	1232	1.90	108	196	0.55	4239	1.41
1968	1839	2696	0.68	1955	1266	1.54	219	182	1.20	4013	1.13
1969	2992	3301	0.91	2874	1497	1.92	549	337	1.63	6415	1.42
1970	3359	4834	0.69	2010	1666	1.21	389	425	0.92	5758	0.89
1971	2917	4000	0.73	1727	1475	1.17	293	422	0.69	4937	0.88
1972	2190	4104	0.53	1463	1637	0.89	192	244	0.79	3845	0.68
1973	2018	3915	0.52	1172	1430	0.82	194	252	0.77	3384	0.64
1974	2292	3954	0.58	2108	1455	1.45	458	367	1.25	4858	1.02
1975	3108	4423	0.70	2599	1818	1.43	311	373	0.83	6018	1.02
1976	3168	4404	0.72	3143	2096	1.50	262	527	0.50	6573	1.08
1977	3816	4354	0.88	3903	2448	1.59	341	631	0.54	8060	1.21
1978	3859	5063	0.76	3334	2618	1.27	489	809	0.60	7682	0.97
1979	3731	5623	0.66	3169	2425	1.31	475	779	0.61	7375	0.94
1980	3967	6252	0.63	3497	3181	1.10	571	908	0.63	8035	0.83
1981	3722	4912	0.76	3253	3277	0.99	737	986	0.75	7712	0.86
1982	3619	6086	0.59	4466	4343	1.03	1281	1448	0.88	9366	0.84
1983	3473	5512	0.63	4874	4731	1.03	1326	1782	0.74	9673	0.85
1984	2188	5444	0.40	3217	5042	0.64	883	1668	0.53	6288	0.54
1985	1801	4890	0.37	3457	5921	0.58	1515	2675	0.57	6773	0.52
1986	1638	4721	0.35	3088	6149	0.50	1513	2990	0.51	6239	0.46
1987	1131	4782	0.24	2005	6417	0.31	1012	2724	0.37	4148	0.31
1988	1327	5089	0.26	2137	5446	0.39	830	2105	0.39	4294	0.35
1989	1559	4060	0.38	2885	4969	0.58	1334	1882	0.71	5778	0.56
1990	2004	4282	0.47	4749	5351	0.89	3212	2029	1.58	9965	1.03
1991	2466	4460	0.55	5272	6042	0.87	4318	2532	1.71	12056	1.11
					50% TRIPS						
1965	394	183	2.15	310	74	4.19	1	1	1.00	705	3.05
1966	253	92	2.75	329	85	3.87	12	4	3.00	594	3.38
1967	656	179	3.66	1202	270	4.45	1	1	1.00	1859	4.17
1968	656	155	4.23	995	224	4.44	50	16	3.13	1701	4.32
1969	1399	324	4.32	1384	292	4.74	104	38	2.74	2887	4.46
1970	1369	395	3.47	719	152	4.73	46	15	3.07	2134	3.89
1971	1033	370	2.79	540	124	4.35	74	24	3.08	1647	3.31
1972	621	283	2.19	322	88	3.66	46	11	4.18	989	2.76
1973	380	179	2.12	96	33	2.91	1	1	1.00	477	2.28
1974	467	186	2.51	529	92	5.75	181	31	5.84	1177	4.48
1975	1047	331	3.16	1039	232	4.48	66	14	4.71	2152	3.84
1976	1197	384	3.12	1277	308	4.15	22	6	3.67	2496	3.65
1977	1390	386	3.60	1825	334	5.46	44	6	7.33	3259	4.69
1978	1314	421	3.12	1373	297	4.62	48	7	6.86	2735	3.94
1979	1114	382	2.92	1233	287	4.30	46	7	6.57	2393	3.70
1980	1198	360	3.33	1205	283	4.26	99	22	4.50	2502	3.82
1981	1587	317	5.01	1218	273	4.46	98	15	6.53	2903	4.83
1982	1354	381	3.55	2296	499	4.60	334	54	6.19	3984	4.38
1983	1399	397	3.52	2609	603	4.33	224	29	7.72	4232	4.24
1984	478	215	2.22	941	313	3.01	21	5	4.20	1440	2.77
1985	438	269	1.63	1024	319	3.21	205	67	3.06	1667	2.78
1986	398	249	1.60	602	295	2.04	143	49	2.92	1143	2.00
1987	253	180	1.41	273	206	1.33	79	41	1.93	605	1.44
1988	426	366	1.16	936	551	1.70	136	74	1.84	1498	1.56
1989	829	601	1.38	1579	1049	1.51	435	281	1.55	2843	1.48
1990	1265	920	1.38	3404	1800	1.89	2015	814	2.48	6684	1.97
1991	1693	1307	1.30	3749	2391	1.57	3150	1410	2.23	8592	1.76

[1] **Metric tons, live weight.**

[2] **Days fished with trawl on bottom; derived by dividing hours fished with trawl on bottom by 24.**

[3] **Total L/DF was derived by weighting individual tonnage class L/DF values by the percentage of total landings accounted for by each vessel class and summing over the three vessel class categories.**

Table D7. Percentage, within vessel tonnage class[1], of Atlantic cod otter trawl landings (L)[2], vessel trips (T), and effort (DF)[3] from the Gulf of Maine (NAFO Division 5Y) accounted for by otter-trawl trips in which cod composed 50% or more of the total trip catch by weight ('directed trips'), 1965-1991.

Year	Class 2 L	Class 2 T	Class 2 DF	Class 3 L	Class 3 T	Class 3 DF	Class4 L	Class4 T	Class4 DF	Totals L	Totals T	Totals DF
1965	27.9	9.2	14.6	33.2	10.1	7.7	2.2	3.3	1.1	29.5	9.3	12.5
1966	20.0	5.2	<0.1	30.1	9.0	9.0	10.6	5.3	4.8	24.0	5.9	10.0
1967	36.6	10.7	30.2	51.3	18.1	21.9	0.9	1.0	0.5	43.9	12.3	25.7
1968	35.7	10.8	24.3	50.9	19.4	17.7	22.8	7.1	8.8	42.4	12.9	21.6
1969	46.8	17.5	42.4	48.2	21.8	19.5	18.9	8.1	11.3	45.0	18.4	33.7
1970	40.8	16.0	28.3	35.8	13.7	9.1	11.8	5.1	3.5	37.1	15.0	22.2
1971	35.4	14.1	25.8	31.3	15.2	8.4	25.3	3.4	5.7	33.4	13.9	20.0
1972	28.4	12.5	15.1	22.0	10.1	5.4	24.0	6.9	4.5	25.7	11.8	12.0
1973	18.8	7.6	9.7	8.2	4.4	2.3	0.5	1.4	0.4	14.1	6.7	7.4
1974	20.4	9.5	11.8	25.1	7.7	6.3	39.5	8.8	8.4	24.2	9.2	10.2
1975	33.7	12.3	23.7	40.0	15.2	12.8	21.2	5.6	3.8	35.8	12.7	19.5
1976	37.8	11.7	27.2	40.6	19.8	14.7	8.4	2.6	1.1	38.0	13.4	21.5
1977	36.4	10.5	31.9	46.8	19.5	13.6	12.9	3.4	1.0	40.4	12.8	23.3
1978	34.1	9.9	26.0	41.2	16.0	11.3	9.8	1.4	0.9	35.6	10.9	19.1
1979	29.9	9.7	19.8	38.9	18.6	11.8	9.7	2.2	0.9	32.4	11.4	16.0
1980	30.2	9.4	19.2	34.5	16.1	8.9	17.3	3.0	2.4	31.1	10.9	14.5
1981	42.6	10.5	32.3	37.4	13.5	8.3	13.3	3.4	1.5	37.6	11.1	20.4
1982	37.4	10.4	22.2	51.4	17.9	11.5	26.1	5.1	3.7	42.5	12.3	16.1
1983	40.3	12.2	25.4	53.5	23.9	12.7	16.9	5.4	1.6	43.8	15.6	16.9
1984	21.8	6.1	3.9	29.3	9.4	6.2	2.4	0.2	0.3	22.9	7.0	4.4
1985	24.3	6.4	5.5	29.6	9.2	5.4	13.5	2.8	2.5	24.6	7.1	4.9
1986	24.3	4.9	5.3	19.5	6.5	4.8	9.5	2.3	1.6	18.3	5.3	4.3
1987	22.4	4.0	3.8	13.6	4.0	3.2	7.8	2.5	1.5	14.6	3.9	3.1
1988	32.1	6.4	7.2	43.8	11.5	10.1	16.4	4.7	3.5	34.9	8.3	7.8
1989	53.2	13.5	14.8	54.7	21.4	21.1	32.6	15.8	14.9	49.2	16.7	17.7
1990	63.1	17.6	21.5	71.7	35.4	33.6	62.7	43.9	40.1	67.1	26.7	30.3
1991	68.7	27.3	29.3	71.1	37.1	39.6	73.0	56.9	55.7	71.3	33.0	39.2

[1] **Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT.**
[2] **Metric tons, live weight.**
[3] **Effort expressed as days fished with trawl on bottom; derived by dividing hours fished with trawl on bottom by 24.**

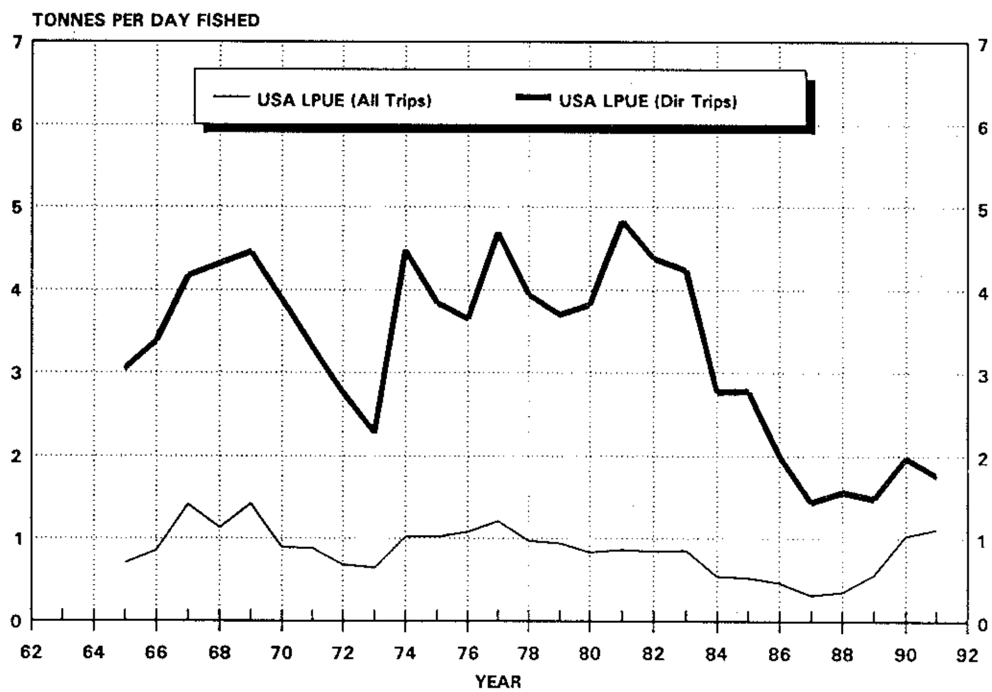


Figure D2. Trends in U.S. commercial LPUE (landings per day fished) of Gulf of Maine cod, 1965-1991. Data are based on all otter trawl trips in which cod were caught (All Trips) and on otter trawl trips in which cod composed 50% or more of the trip catch by weight (Directed Trips).

Table D8. Total and U.S. commercial landings, U.S. catch per unit of effort indices (CPUE, all cod trips), and derived effort indices for Gulf of Maine cod, 1965-1991

Year	Total Landings (mt)	U.S. Landings (mt)	U.S. CPUe Index (All cod trips)	Total Calculated Days Fished	U.S. Calculated Days Fished
1965	3928	3780	0.6954	5649	5436
1966	4392	4008	0.8510	5161	4710
1967	5973	5676	1.4096	4237	4027
1968	6421	6360	1.1273	5696	5642
1969	8484	8157	1.4241	5957	5728
1970	8261	7812	0.8871	9312	8806
1971	7662	7380	0.8815	8692	8372
1972	6917	6776	0.6800	10172	9965
1973	6146	6069	0.6382	9630	9510
1974	7764	7639	1.0207	7607	7484
1975	9015	8903	1.0220	8821	8711
1976	10188	10172	1.0842	9397	9382
1977	12426	12426	1.2094	10275	10275
1978	12426	12426	0.9712	12794	12794
1979	11680	11680	0.9361	12477	12477
1980	13528	13528	0.8346	16209	16209
1981	12534	12534	0.8561	14641	14641
1982	13582	13582	0.8395	16179	16179
1983	13981	13981	0.8466	16514	16514
1984	10806	10806	0.5410	19974	19974
1985	10693	10693	0.5219	20489	20489
1986	9664	9664	0.4630	20873	20873
1987	7527	7527	0.3056	24630	24630
1988	7958	7958	0.3498	22750	22750
1989	10397	10397	0.5561	18696	18696
1990	15154	15154	1.0279	14743	14743
1991	17781	17781	1.1054	16086	16086

tom trawl surveys, have been used to monitor changes and assess trends in population size and recruitment of U.S. cod populations since 1963. Prior to 1985, BMV oval doors (550 kg) were used in all NEFSC surveys; since 1985, Portuguese polyvalent doors (450 kg) have been used. Details on NEFSC survey sampling design and procedures are provided in Azarovitz (1981) and Clark (1981). The State of Massachusetts inshore bottom trawl sampling program is described in Howe *et al.* (1981). No adjustments in the survey catch per tow data for cod have been made for any of the trawl differences, but vessel and door coefficients have been applied to adjust the stratified means (number and weight per tow) as described in Table D10. Standardized catch per tow (number) at age indices from NEFSC spring and autumn surveys are listed in Table D11. Catch per tow (number) at age indices from Massachusetts spring and autumn surveys are listed in Table D12.

NEFSC spring and autumn offshore catch per tow indices for Gulf of Maine cod have generally exhibited similar trends throughout the survey time series (Table D10, Figure D4). Number per tow indices declined during the mid- and late 1960s but since 1972-1973 have fluctuated as a result of a series of recruitment pulses. Sharp increases in the number per tow indices reflect above average recruitment of the 1971, 1973, 1977-1980, 1983, and 1985-1987 year classes at ages 1 and 2 (Table D11, Figure D5). The sequential dominance of these cohorts at older ages can be discerned from number per tow at age values in both spring and autumn NEFSC surveys (Table D11).

Spring NEFSC number per tow indices have remained relatively stable since 1985 at a level below the 1981-1984 period (Table D10); spring weight per tow indices have also remained relatively low through 1991 but the index increased substantially in 1992 due to a large contribution from the 1987 year class (Table D11). Autumn number and weight per tow indices declined sharply in 1990 to a record low level, and remain low through 1992.

The increases in the 1988 and 1989 autumn number per tow indices, due to recruitment of the

Table D9. Gulf of Maine cod effort (days) standardization. Standard - Year = 82, TC = 25; Area = 514; Depth = 3, using all unsummed data, no exclusions.

DEPENDENT VARIABLE: LCPE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	25	9908.15332392	396.32613296	246.74	0.0	0.200955	19.4383
ERROR	24527	39397.29203143	1.60628255		ROOT MSE		LCPE MEAN
CORRECTED TOTAL	24552	49305.44535535			1.26739203		6.52007997

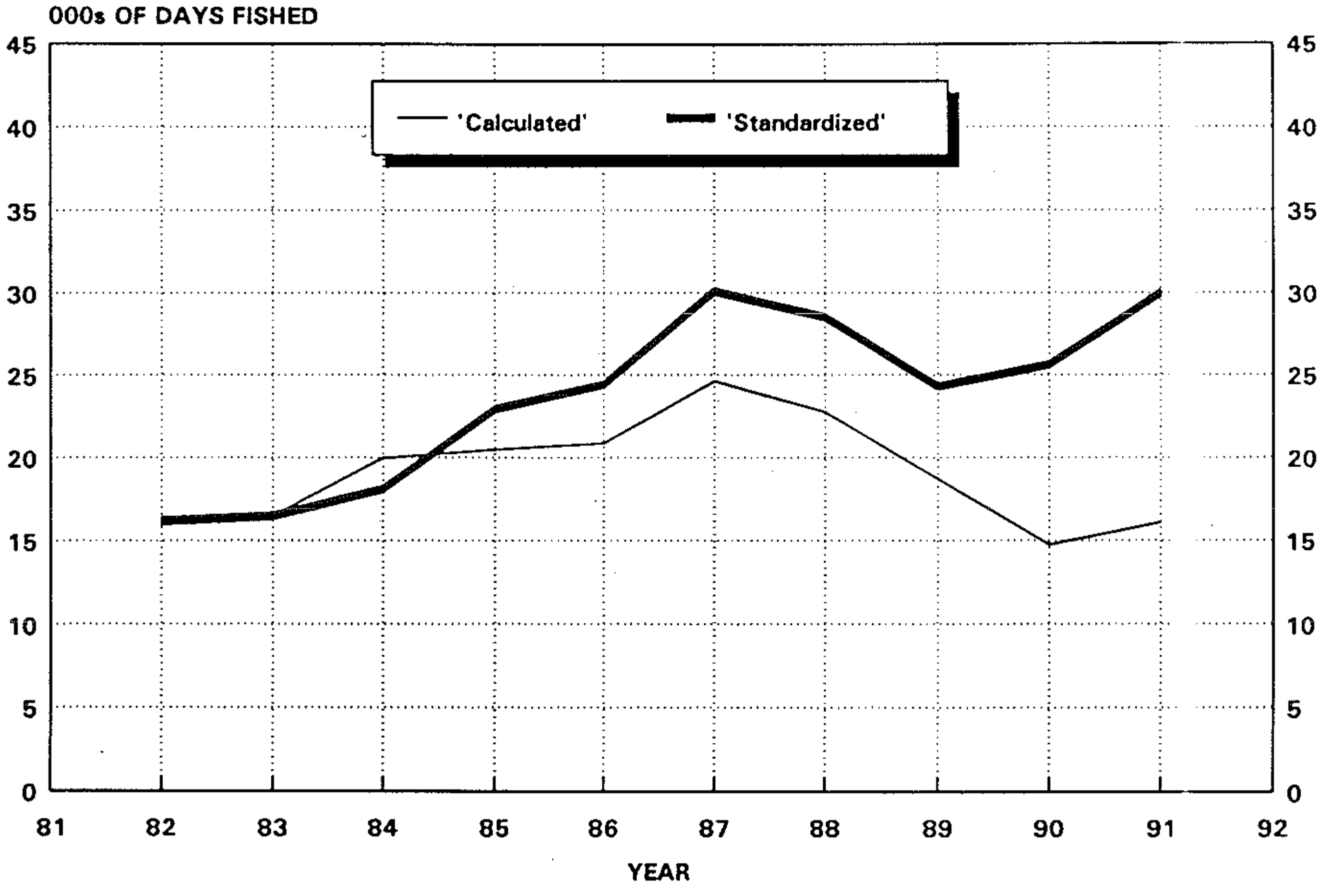
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE II SS	F VALUE	PR > F
YEAR	9	3941.02391770	272.61	0.0	9	3856.03244858	266.73	0.0
TC2	8	3449.60824843	268.45	0.0	8	4828.89313684	375.78	0.0
AREA	4	629.15341636	97.92	0.0	4	237.33398628	36.94	0.0001
DEPTH	4	1888.36774144	293.90	0.0	4	1888.36774144	293.90	0.0

SOURCE	DF	TYPE III SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
YEAR	9	3856.03244858	266.73	0.0	9	3856.03244858	266.73	0.0
TC2	8	4828.89313684	375.78	0.0	8	4828.89313684	375.78	0.0
AREA	4	237.33398628	36.94	0.0001	4	237.33398628	36.94	0.0001
DEPTH	4	1888.36774144	293.90	0.0	4	1888.36774144	293.90	0.0

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		6.39120886 B	163.71	0.0	0.03903990
YEAR	83	0.00942655 B	0.26	0.7968	0.03660082
	84	-0.34164384 B	-9.03	0.0001	0.03782350
	85	-0.58924208 B	-15.90	0.0	0.03704764
	86	-0.75317122 B	-21.02	0.0	0.03583169
	87	-1.21118871 B	-32.72	0.0	0.03701233
	88	-1.10178094 B	-29.84	0.0	0.03692410
	89	-0.67544341 B	-16.86	0.0	0.04006213
	90	-0.35543452 B	-9.13	0.0001	0.03891575
	91	-0.34816807 B	-9.01	0.0001	0.03862816
	82	0.00000000 B	.	.	.

Year	Re-transformed Year Coefficient	Standardized Effort (days)
82	1	16178.68
83	1.010148	16486.66
84	0.71111	18101.22
85	0.555129	22944.86
86	0.471173	24431.8
87	0.298047	30082.68
88	0.332505	28509.18
89	0.509339	24315.32
90	0.7014	25635.78
91	0.706507	29979.12

Figure D3. Trends in calculated and standardized U.S. fishing effort for Gulf of Maine cod, 1982-1991.



strong 1986 and 1987 year classes, were dissipated by 1990 and 1991, resulting in the sharp declines in the overall index. This reduction, combined with a general paucity of large fish in the survey indices (Table D11) in recent years has resulted in the sharp decline in the weight per tow indices in 1990 and 1991 as well. Overall, the 1987 year class appears to have been one of the strongest ever produced; catch per tow indices of this cohort at ages 1-3 in the NEFSC autumn surveys and at ages 0 and 1 in the Massachusetts autumn inshore surveys were nearly all record-high values (Tables D11 and D12).

Based on NEFSC survey catch per tow indices in 1989-1992, the 1988-1991 year classes of Gulf of Maine cod appear to be average or below-average.

MORTALITY

Natural Mortality

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

Total Mortality Estimates

Pooled estimates of instantaneous total mortality (Z) were calculated for eight time periods

Table D10. Standardized mean catch per tow in numbers and weight (kg) for Atlantic cod from NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine (strata 26-30 and 36-40), 1963-1992. [a,b]

	Gulf of Maine[c]			
	Spring		Autumn	
Year	No/Tow	Wt/Tow	No/Tow	Wt/Tow
1963	-	-	5.92	17.9
1964	-	-	4.00	22.8
1965	-	-	4.49	12.0
1966	-	-	3.78	12.9
1967	-	-	2.56	9.2
1968	5.44	17.9	4.34	19.4
1969	3.25	13.2	2.76	15.4
1970	2.21	11.1	4.90	16.4
1971	1.43	7.0	4.37	16.5
1972	2.06	8.0	9.31	13.0
1973	7.54	18.8	4.46	8.7
1974	2.91	7.4	4.33	9.0
1975	2.51	6.0	6.15	8.6
1976	2.78	7.6	2.15	6.7
1977	3.88	8.5	3.08	10.2
1978	2.06	7.7	5.75	12.9
1979	4.27	9.5	3.49	17.5
1980	2.15	6.2	7.04	14.2
1981	4.86	10.8	2.42	8.1
1982	3.75	8.6	7.77	16.1
1983	3.91	10.5	4.22	8.8
1984	3.40	5.8	2.42	8.8
1985	2.52	7.7	2.92	8.5
1986	1.96	3.6	1.95	5.1
1987	1.68	3.0	2.98	3.4
1988	3.13	3.3	5.90	6.6
1989	2.26	2.5	4.65	4.6
1990	2.36	3.1	2.99	4.9
1991	2.39	2.9	1.25	2.8
1992	2.39	8.7	1.27	2.1

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

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

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

encompassed by the NEFSC autumn and spring offshore surveys: 1964-1967, 1968-1972, 1973-1976, 1977-1981, 1982-1984, 1985-1987, and 1988-1990 (Table D13). Total mortality was calculated from survey catch per tow at age data (Table D11) for fully recruited age groups (age 3+) by the $\log_e$ ratio of the pooled age 3+/age 4+ indices in the autumn surveys, and the pooled age 4+/age 5+ indices in the spring surveys. For example, the 1982-1984 values were derived from:

Autumn: ln (Σ age 3+ for 1981-83/Σ age 4+ for 1982-84)

Spring: ln (Σ age 4+ for 1982-84/Σ age 5+ for 1983-85)

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

The pooled estimates indicate that total mortality was relatively low (Z = 0.40) between 1964 and 1976 but significantly increased afterward to 0.75 to 0.78 during 1982-1987. Total mortality increased further to 0.94 during the 1988-1990. Except for the 1988-1990 period, values of Z derived from the spring surveys are slightly lower than those calculated from the autumn data. Rather than selecting one survey series over the other, total mortality was calculated by taking a geometric mean of the spring and autumn estimates in each time period.

ASSESSMENT METHODOLOGY

Virtual Population Analysis

The ADAPT (Gavaris 1988, Conser and Powers 1990) calibration method was used to derive estimates of terminal F values in 1991. Several trial formulations were evaluated. Bottom trawl survey indices for ages 2 to 6 were used for the spring and autumn NEFSC surveys, while ages 3 to 6 were used for the U.S. commercial CPUE data. The second calibration included additional indices for ages 2 to 4 from Massachusetts spring and ages 2 and 3 from Massachusetts autumn surveys. Virtual population analyses were performed in each case employing an 8+ group.

The inclusion of Massachusetts indices resulted in an increase in the coefficients of variation (CV) of the estimated stock sizes and Qs, although most of the variability was attributed to

Table D11. Standardized [for both door and gear changes] stratified mean number per tow at age and standardized stratified mean weight (kg) per tow of Atlantic cod in NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine, 1963-1992. [a,b,c]

Year	Age Group 0	1	2	3	4	5	6	7	8	9	10+	Totals 0+	1+	2+	3+	4+	5+	Standardized Mean wt (kg/tow)
										Spring [c,d,e]								
1968	0.128	0.613	1.234	1.407	0.846	0.538	0.207	0.129	0.111	0.059	0.165	5.438	5.310	4.697	3.463	2.056	1.211	17.92
1969	0.000	0.000	0.036	0.307	0.880	0.807	0.633	0.256	0.144	0.089	0.101	3.253	3.253	3.253	3.217	2.909	2.030	13.20
1970	0.000	0.159	0.123	0.055	0.094	0.273	0.466	0.615	0.075	0.059	0.287	2.206	2.206	2.047	1.923	1.869	1.775	11.06
1971	0.000	0.025	0.142	0.109	0.292	0.048	0.083	0.300	0.206	0.154	0.072	1.431	1.431	1.406	1.264	1.154	0.863	6.98
1972	0.000	0.353	0.153	0.519	0.197	0.200	0.036	0.106	0.101	0.229	0.164	2.058	2.058	1.705	1.552	1.033	0.836	8.04
1973	0.000	0.034	4.249	0.906	0.619	0.349	0.195	0.095	0.223	0.251	0.612	7.535	7.535	7.500	3.251	2.345	1.725	18.79
1974	0.000	0.476	0.056	1.359	0.329	0.222	0.114	0.048	0.048	0.020	0.232	2.905	2.905	2.429	2.373	1.014	0.685	7.44
1975	0.006	0.094	0.699	0.106	1.065	0.259	0.111	0.005	0.005	0.019	0.144	2.512	2.505	2.412	1.713	1.607	0.541	6.03
1976	0.000	0.042	0.304	1.048	0.153	0.897	0.086	0.108	0.066	0.000	0.073	2.777	2.777	2.735	2.430	1.382	1.229	7.55
1977	0.000	0.025	0.298	0.521	1.994	0.109	0.791	0.006	0.101	0.000	0.037	3.883	3.883	3.858	3.560	3.039	1.045	8.54
1978	0.000	0.034	0.105	0.285	0.348	0.766	0.075	0.320	0.008	0.106	0.008	2.055	2.055	2.020	1.916	1.630	1.282	7.70
1979	0.044	0.535	1.630	0.212	0.499	0.401	0.685	0.059	0.142	0.012	0.053	4.273	4.229	3.694	2.064	1.852	1.353	9.49
1980	0.070	0.070	0.440	0.343	0.123	0.418	0.239	0.303	0.000	0.129	0.014	2.149	2.079	2.009	1.569	1.226	1.103	6.18
1981	0.000	1.014	0.662	0.986	1.216	0.328	0.287	0.110	0.155	0.106	0.000	4.864	4.864	3.850	3.188	2.202	0.986	10.79
1982	0.015	0.336	1.019	0.516	0.694	0.864	0.117	0.108	0.000	0.042	0.039	3.751	3.737	3.400	2.381	1.865	1.171	8.62
1983	0.012	0.626	0.978	0.833	0.641	0.357	0.181	0.092	0.000	0.090	0.101	3.912	3.900	3.274	2.296	1.463	0.822	10.50
1984	0.000	0.151	1.033	1.147	0.741	0.190	0.053	0.058	0.030	0.000	0.000	3.402	3.402	3.251	2.218	1.072	0.331	5.83
1985	0.000	0.028	0.238	0.622	0.665	0.677	0.095	0.114	0.052	0.000	0.026	2.517	2.517	2.489	2.251	1.629	0.964	7.65
1986	0.000	0.417	0.330	0.647	0.387	0.074	0.046	0.027	0.011	0.000	0.018	1.957	1.957	1.540	1.210	0.563	0.176	3.60
1987	0.000	0.049	0.638	0.486	0.300	0.128	0.011	0.045	0.011	0.000	0.014	1.682	1.682	1.633	0.995	0.509	0.209	3.01
1988	0.029	0.663	1.053	0.633	0.355	0.217	0.087	0.063	0.000	0.027	0.000	3.127	3.098	2.435	1.382	0.749	0.394	3.30
1989	0.000	0.023	0.649	0.790	0.632	0.090	0.077	0.000	0.000	0.000	0.000	2.261	2.261	2.238	1.589	0.799	0.167	2.53
1990	0.000	0.000	0.190	1.327	0.627	0.167	0.032	0.018	0.000	0.000	0.000	2.362	2.362	2.362	2.172	0.845	0.217	3.08
1991	0.000	0.043	0.209	0.355	1.477	0.268	0.024	0.018	0.000	0.000	0.000	2.394	2.394	2.351	2.142	1.787	0.310	2.89
1992	0.000	0.050	0.250	0.220	0.260	1.320	0.210	0.070	0.000	0.010	0.000	2.390	2.390	2.340	2.090	1.870	1.610	8.66
										Autumn [d,e]								
1963	0.050	0.649	1.349	1.253	0.849	0.579	0.537	0.300	0.183	0.095	0.075	5.917	5.867	5.218	3.869	2.616	1.767	17.95
1964	0.000	0.092	0.122	0.471	0.856	0.853	0.783	0.373	0.237	0.114	0.101	4.003	4.003	3.911	3.789	3.318	2.462	22.79
1965	0.002	0.850	0.880	0.824	0.750	0.496	0.374	0.170	0.080	0.044	0.025	4.494	4.493	3.643	2.763	1.939	1.189	12.00
1966	0.170	0.204	0.640	0.697	0.718	0.558	0.441	0.192	0.078	0.048	0.036	3.783	3.613	3.409	2.769	2.072	1.354	12.91
1967	0.012	0.129	0.215	0.574	0.671	0.384	0.268	0.162	0.070	0.041	0.034	2.562	2.549	2.420	2.204	1.630	0.959	9.23
1968	0.012	0.036	0.179	0.719	1.256	0.973	0.627	0.261	0.156	0.072	0.095	4.387	4.374	4.338	4.159	3.440	2.184	19.44
1969	0.016	0.059	0.123	0.354	0.630	0.552	0.466	0.220	0.145	0.129	0.062	2.758	2.742	2.683	2.560	2.206	1.576	15.37
1970	0.743	0.941	0.265	0.551	0.329	0.488	0.423	0.789	0.131	0.094	0.147	4.900	4.157	3.217	2.952	2.401	2.072	16.43
1971	1.346	0.178	0.239	0.211	0.597	0.460	0.434	0.254	0.318	0.200	0.128	4.365	3.019	2.841	2.602	2.391	1.794	16.52
1972	0.031	5.579	1.217	1.526	0.234	0.094	0.172	0.039	0.159	0.242	0.016	9.307	9.276	3.697	2.480	0.955	0.721	12.96
1973	0.636	0.328	2.173	0.139	0.507	0.212	0.078	0.028	0.051	0.168	0.136	4.457	3.820	3.493	1.320	1.181	0.674	8.73
1974	0.282	1.123	0.189	1.744	0.292	0.359	0.078	0.012	0.012	0.042	0.198	4.332	4.050	2.927	2.738	0.994	0.702	8.97
1975	0.047	0.147	3.067	0.134	2.356	0.254	0.109	0.017	0.003	0.003	0.012	6.150	6.103	5.956	2.889	2.755	0.399	8.62
1976	0.000	0.243	0.209	0.632	0.100	0.768	0.058	0.095	0.000	0.016	0.031	2.151	2.151	1.908	1.699	1.067	0.967	6.74
1977	0.000	0.022	0.359	0.550	1.155	0.152	0.593	0.038	0.097	0.022	0.096	3.083	3.083	3.061	2.703	2.153	0.998	10.22
1978	0.249	1.369	0.371	1.118	0.656	1.430	0.112	0.325	0.009	0.060	0.051	5.749	5.500	4.131	3.760	2.642	1.987	12.89
1979	0.005	0.368	0.594	0.162	0.836	0.392	0.782	0.051	0.215	0.000	0.083	3.488	3.483	3.115	2.521	2.359	1.523	17.54
1980	0.027	1.264	2.602	1.754	0.497	0.232	0.335	0.207	0.030	0.018	0.071	7.037	7.010	5.745	3.144	1.390	0.893	14.21
1981	0.012	0.619	0.382	0.549	0.474	0.089	0.119	0.037	0.108	0.000	0.028	2.418	2.406	1.786	1.404	0.855	0.381	8.05
1982	0.000	0.700	3.142	2.473	1.167	0.248	0.000	0.039	0.000	0.000	0.000	7.769	7.769	7.068	3.927	1.454	0.287	16.07
1983	0.045	1.660	0.977	0.852	0.139	0.264	0.197	0.000	0.000	0.000	0.090	4.223	4.178	2.518	1.541	0.690	0.551	8.81
1984	0.044	0.384	0.421	0.565	0.399	0.220	0.204	0.089	0.000	0.031	0.066	2.423	2.379	1.995	1.574	1.009	0.610	8.81
1985	0.266	0.378	0.910	0.763	0.209	0.218	0.074	0.000	0.034	0.021	0.049	2.922	2.656	2.278	1.368	0.605	0.396	8.49
1986	0.000	0.301	0.490	0.654	0.333	0.086	0.042	0.000	0.000	0.024	0.021	1.951	1.951	1.650	1.160	0.506	0.173	5.10
1987	0.138	0.599	1.324	0.600	0.257	0.061	0.000	0.000	0.000	0.000	0.000	2.979	2.841	2.242	0.918	0.318	0.061	3.41
1988	0.000	1.951	2.245	0.960	0.528	0.110	0.076	0.033	0.000	0.000	0.000	5.903	5.903	3.952	1.707	0.747	0.219	6.61
1989	0.000	0.416	2.391	1.356	0.294	0.174	0.014	0.000	0.000	0.009	0.000	4.653	4.653	4.238	1.847	0.491	0.197	4.58
1990	0.006	0.029	0.367	1.643	0.623	0.278	0.028	0.010	0.000	0.000	0.000	2.985	2.978	2.949	2.583	0.939	0.317	4.91
1991	0.008	0.142	0.142	0.221	0.632	0.079	0.000	0.024	0.000	0.000	0.000	1.248	1.240	1.098	0.956	0.735	0.103	2.78
1992												1.277						2.13[a]

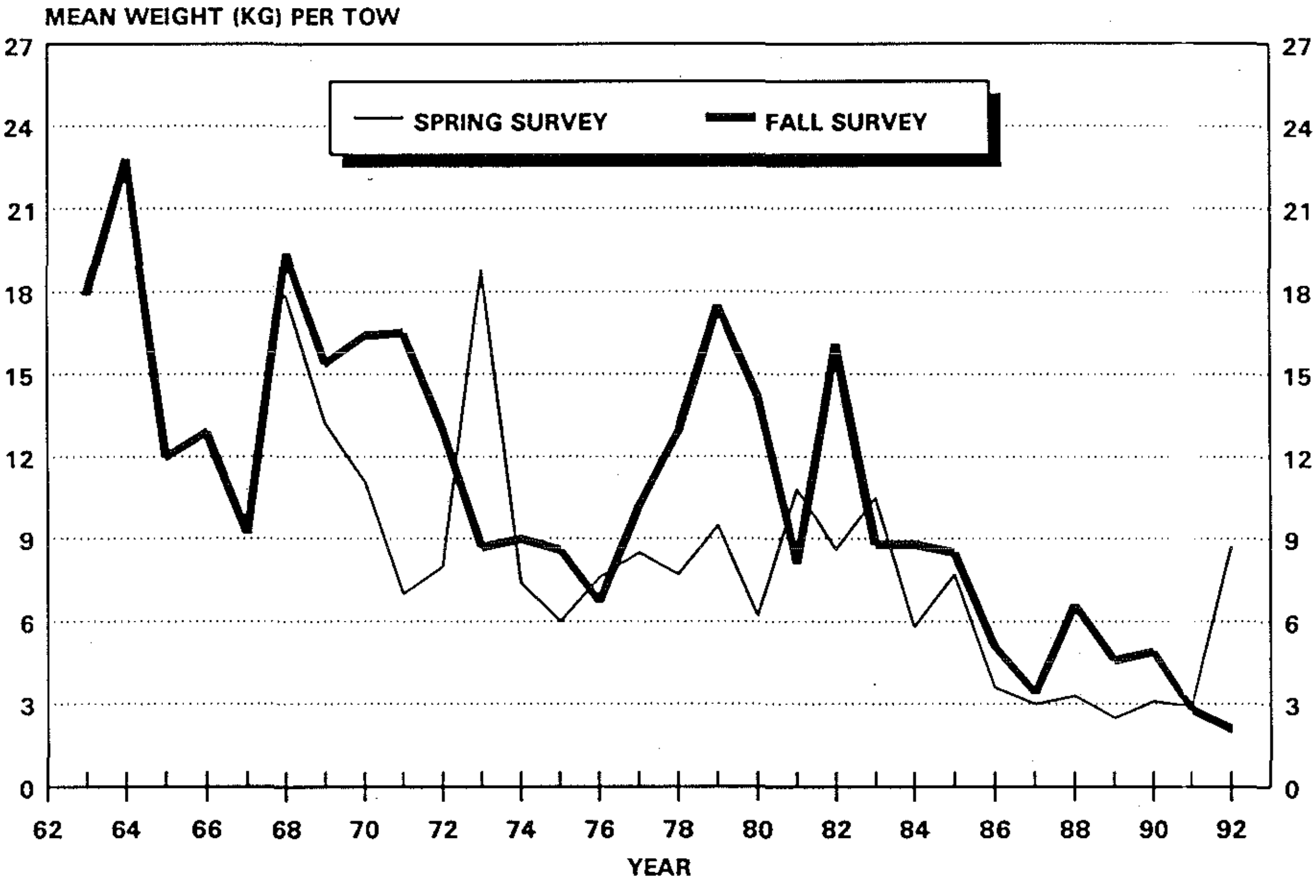
[a]Spring and autumn: Strata 26-30 and 36-40.
[b] Catch per tow at age values for 1963-1969 obtained by applying combined 1970-1981 age-length keys to stratified mean catch per tow at length distributions from each survey.
[c] Spring surveys during 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. No adjustments have been made to the catch per tow data for these differences.
[d] During 1963-1984, BMV oval doors were used in the spring and autumn surveys; since 1985, Portuguese polyvalent doors have been used in both surveys. Adjustments have been made to the 1963-1984 catch per tow data to standardize these data to polyvalent door equivalents. Conversion coefficients of 1.56 (numbers) and 1.62 (weight) were used in this standardization (NEFC 1991).
[e] In the Gulf of Maine, spring surveys during 1980-1982 and 1989-1991 and autumn surveys during 1977-1978, 1980, and 1989-1991 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data to standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

Table D12. Standardized mean catch per tow in numbers and weight (kg) of Atlantic cod in State of Massachusetts inshore spring and autumn bottom trawl surveys in territorial waters in the Gulf of Maine (Massachusetts Regions 4-5), 1978-1990

Year	Age Group											Totals				Stratified Mean Wt (kg)
	0	1	2	3	4	5	6	7	8	9	10+	0+	1+	2+	3+	
Gulf of Maine Area (Massachusetts Regions 4-5)[1]																
Spring																
1978	21.965	12.784	4.162	4.572	0.872	1.028	0.000	0.000	0.023	0.000	0.000	45.406	23.441	10.657	6.495	12.16
1979	56.393	36.630	2.581	1.533	4.659	1.995	0.183	0.000	0.000	0.000	0.069	104.043	47.650	11.020	8.439	20.53
1980	8.156	50.311	12.679	0.971	0.745	0.737	0.080	0.214	0.000	0.025	0.000	73.918	65.762	15.451	2.772	17.71
1981	19.753	24.794	23.884	3.122	1.279	0.041	0.146	0.022	0.022	0.000	0.000	73.063	53.310	28.516	4.632	21.79
1982	1.489	16.235	7.060	3.418	1.147	0.232	0.011	0.057	0.045	0.000	0.000	29.694	28.205	11.970	4.910	13.42
1983	0.453	27.703	18.572	5.331	0.501	1.221	0.142	0.022	0.000	0.000	0.000	53.945	53.492	25.789	7.217	19.77
1984	0.206	2.896	5.408	2.271	0.865	0.138	0.162	0.000	0.000	0.000	0.000	11.946	11.740	8.844	3.436	8.63
1985	0.793	2.711	3.822	2.794	0.692	0.000	0.000	0.000	0.000	0.000	0.000	10.812	10.019	7.308	3.486	6.42
1986	0.957	19.960	3.222	0.887	0.426	0.090	0.019	0.000	0.000	0.000	0.000	25.561	24.604	4.644	1.422	7.77
1987	0.659	8.590	6.997	2.268	0.257	0.147	0.048	0.000	0.000	0.087	0.000	19.053	18.394	9.804	2.807	9.59
1988	1.595	11.841	11.356	2.511	1.370	0.000	0.039	0.000	0.000	0.000	0.000	28.712	27.117	15.276	3.920	9.66
1989	0.157	20.679	25.260	6.580	0.458	0.106	0.124	0.000	0.000	0.000	0.000	53.364	53.207	32.528	7.268	18.26
1990	4.10	6.33	6.89	17.77	2.64	0.18	0.05	0.02	0.000	0.000	0.000	37.980	33.88	27.55	20.66	19.51
1991	0.32	5.88	3.56	2.54	5.03	0.36	0.000	0.000	0.000	0.000	0.000	17.69	17.37	11.49	7.93	11.37
1992												19.888				10.11
Autumn																
1978	151.533	2.082	0.000	0.120	0.140	0.318	0.000	0.080	0.000	0.000	0.000	154.273	2.740	0.658	0.658	3.02
1979	4.933	3.430	0.042	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	8.431	3.498	0.068	0.026	0.99
1980	5.680	8.834	0.052	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	14.616	8.936	0.102	0.050	1.57
1981	2.018	5.652	7.290	0.729	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15.689	13.671	8.019	0.729	6.65
1982	4.667	2.346	1.005	0.060	0.050	0.000	0.000	0.000	0.000	0.000	0.000	8.128	3.461	1.115	0.110	1.35
1983	1.308	0.651	0.100	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.072	0.764	0.113	0.013	0.18
1984	12.296	0.344	0.022	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.675	0.379	0.035	0.013	0.18
1985	2.832	0.419	0.018	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.279	0.447	0.028	0.010	0.09
1986	2.478	1.150	0.833	0.000	0.067	0.000	0.000	0.000	0.000	0.000	0.000	4.528	2.050	0.900	0.067	0.55
1987	389.584	2.386	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	391.990	2.406	0.020	0.000	0.45
1988	4.571	20.490	0.679	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	25.740	21.169	0.679	0.000	1.57
1989	2.971	2.700	0.350	0.210	0.185	0.000	0.000	0.000	0.000	0.000	0.000	6.416	3.445	0.745	0.395	1.27
1990	9.37	9.13	1.74	0.31	0.06	0.03	0.000	0.000	0.000	0.000	0.000	20.638	11.27	2.14	0.40	1.56
1991	4.65	4.20	0.81	0.03	0.05	0.01						9.75	5.10	0.90	0.09	0.80

[1] Massachusetts sampling strata 25-36.

Figure D4. Standardized stratified mean catch per tow (kg) of Atlantic cod in the NEFSC spring and autumn research vessel bottom trawl surveys in the Gulf of Maine, 1963-1992.



the age 3 autumn index. Thus, the final calibration was performed using all of the indices described above with the exception of the Massachusetts autumn age 3 index. All indices were given equal weight. Stock sizes corresponding to the 1986 to 1990 year classes were estimated for ages 2 to 6 in 1992 to generate fishing mortalities at ages 2 to 5 in 1991. A flat-topped partial recruitment pattern was employed with full F on ages 4 and older as indicated from a separable VPA. Thus, F for ages 6 and older in the terminal year was set equal to the unweighted mean F of ages 4 and 5. In years prior to the terminal year, F on the oldest true age was determined from estimates of Z for ages 4 to 7. F for the plus group was set equal to F on the oldest true age.

Yield and Spawning Stock Biomass per Recruit

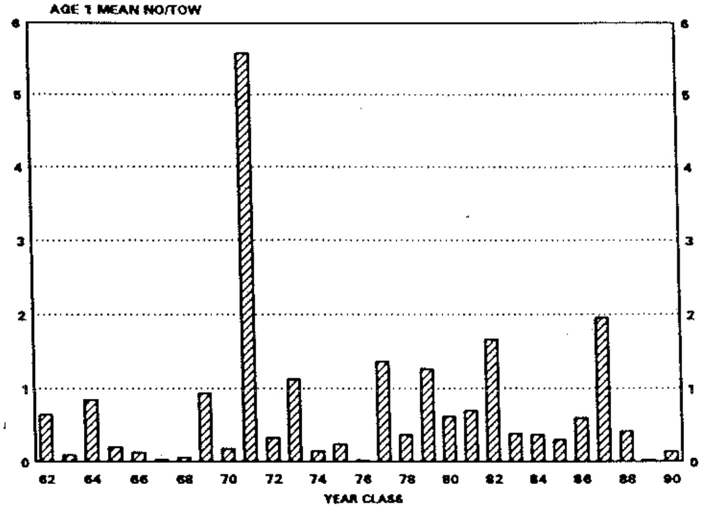
Yield-per-recruit, total stock biomass per recruit, and spawning stock biomass per recruit analyses were performed using the Thompson and Bell (1934) method. To obtain the exploitation pattern for these analyses, geometric mean F at age was first computed over the period 1986-1990 from the final converged VPA results. A smoothed exploitation pattern was then obtained by dividing the F at age by the mean unweighted F for ages 4 to 7. Mean weights at age for application to yield per recruit were computed as the arithmetic average of catch mean weights at age (Table D4) over the 1989-1991 period. Mean weights at age for application to SSB per recruit were computed as the arithmetic average of stock mean weights at age (Table D5) over the 1989-1991 period. The maturation ogive was taken from O'Brien *et al.* (in press).

Projections for 1993 and 1994

Catches and stock sizes were projected through 1993 at various levels of F and recruitment assuming a status quo F in 1992. The exploitation pattern, mean weights and maturation rates were as described above for the yield and SSB per recruit analyses. Survivors at ages 2 to 8+, taken from the final calibrated VPA, were

GULF OF MAINE COD

USA FALL SURVEY: YEAR CLASS STRENGTH AT AGE 1



GULF OF MAINE COD

USA FALL SURVEY: YEAR CLASS STRENGTH AT AGE 2

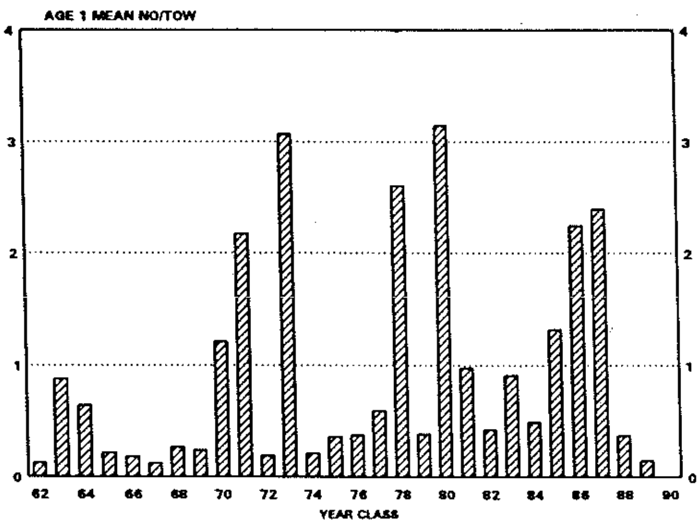


Figure D5. Relative year class strength of Gulf of Maine cod at age 1 and age 2 based on standardized catch per tow (number) indices from NEFSC autumn research vessel bottom trawl surveys, 1963-1991.

Table D13. Estimates of instantaneous total mortality (Z) and fishing mortality (F)[1] for Gulf of Maine Atlantic cod for eight time periods, 1964-1990, derived from NEFSC offshore spring and autumn bottom trawl survey data[2]

	Gulf of Maine					
Time Period	Spring		Autumn		Geometric Mean	
	Z	F	Z	F	Z	F
1964-67	-	-	0.39	0.19	0.39	0.19
1968-72	0.37[3]	0.17	0.43[6]	0.23	0.40	0.20
1973-76	0.35[4]	0.15	0.45	0.25	0.40	0.20
1977-81	0.52	0.32	0.57[7]	0.37	0.54	0.34
1982-84	0.73	0.53	0.78	0.58	0.75	0.55
1985-87	0.58[5]	0.38	1.05	0.85	0.78	0.58
1988-90	1.24	1.04	0.72	0.61	0.94	0.74

[1] **Instantaneous natural mortality (M) assumed to be 0.20.**
[2] **Estimates derived from:**
Gulf of Maine spring:
ln (Σ age 4+ for year i to j / Σ age 5+ for years i+1 to j+1).
Gulf of Maine autumn:
ln (Σ age 3+ for years i-1 to j-1 / Σ age 4+ for years i to j).
[3] **Excludes spring 1972-1973 data (4+/5+) since these gave large negative Z value.**
[4] **Excludes spring 1973-1974 data (4+/5+) since these gave unreasonably high Z value.**
[5] **Excludes spring 1985-1986 data (4+/5+) since these gave unreasonably high Z value.**
[6] **Excludes autumn 1967-1968 data (3+/4+) since these gave large negative Z value.**
[7] **Excludes autumn 1976-1977 data (3+/4+) since these gave large negative Z value.**

used to start the projections in 1992. Age 2 recruitment for the 1991 and 1992 year classes in 1993 and 1994 were taken as the geometric mean of the 1980-1988 year classes as estimated by the VPA (6.1 million). Projections are provided over a range of recruitment levels including low and high observations in addition to the geometric mean. The range of F includes F_{max}, $F_{20\%msp}$, 90% of F_{SQ}, and F_{SQ}.

ASSESSMENT RESULTS

Virtual Population Analysis

Results from the final VPA calibration show very low correlations (< 0.10) among estimates of slopes (Q) and moderately low correlations (< 0.20) between stock sizes and Qs. All parameter estimates were significant in both analyses. Coefficients of variation (CV) for 1992 stock size estimates ranged from 27% (ages 3 and 4) to 50% (age 6), and CVs for Qs were either 18% or 19% on all indices.

Average (ages 4 to 7, unweighted) fishing mortality in 1991 was estimated at 1.14 (Table D14, Figure D6), a 14% increase over 1990. The 14% increase in mean fully recruited F is consistent with the 17% increase in standardized fishing effort indicated by the general linear model

Table D14. Stock size, fishing mortality, and spawning stock biomass obtained from VPA calibrated with NEFSC and Massachusetts spring and autumn survey indices and U.S. commercial CPUE at age indices for Gulf of Maine cod

Stock Numbers (Jan 1) in millions - GMCOD92

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	6080.809	5632.941	7753.562	4810.749	7288.093	9809.079	19943.296	3966.289	2670.369	4537.261	0.000
2	9122.486	4978.544	4611.861	6348.078	3938.707	5966.985	8030.993	16328.189	3247.322	2186.312	3714.794
3	4358.791	6220.184	3292.498	3372.315	4829.098	3148.735	4689.909	6430.447	13063.460	2473.191	1478.737
4	2672.279	2091.076	2959.954	1573.671	1453.528	1995.663	2039.588	2534.092	3832.447	7596.389	1179.759
5	1477.367	1153.648	754.711	1066.149	391.719	454.415	630.446	807.563	759.106	1270.158	2454.368
6	179.711	636.804	367.241	222.491	302.842	94.503	121.404	148.802	254.905	232.423	269.901
7	210.952	84.701	139.529	125.133	66.341	87.789	17.653	60.489	48.537	66.639	60.900
8	318.271	191.317	115.035	91.152	93.490	47.319	40.567	35.636	127.218	60.531	33.321
1+	**24420.665**	**20989.216**	**19994.390**	**17609.739**	**18363.818**	**21604.488**	**35513.857**	**30311.507**	**24003.363**	**18422.903**	**9191.781**

Fishing Mortality - GMCOD92

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.1829	0.2135	0.1130	0.0735	0.0239	0.0408	0.0223	0.0231	0.0723	0.1910
3	0.5345	0.5426	0.5382	0.6416	0.6837	0.2343	0.4156	0.3175	0.3421	0.5402
4	0.6400	0.8191	0.8211	1.1906	0.9627	0.9523	0.7265	1.0054	0.9044	0.9298
5	0.6416	0.9447	1.0214	1.0586	1.2219	1.1199	1.2438	0.9531	0.9836	1.3488
6	0.5522	1.3182	0.8766	1.0101	1.0383	1.4777	0.4967	0.9203	1.1416	1.1393
7	0.6477	0.9500	0.8822	1.1676	1.0490	1.0273	0.8288	1.0202	0.9540	1.1393
8	0.6477	0.9500	0.8822	1.1676	1.0490	1.0273	0.8288	1.0202	0.9540	1.1393
4-7	**0.6204**	**1.0080**	**0.9004**	**1.1067**	**1.0680**	**1.1443**	**0.8239**	**0.9748**	**0.9959**	**1.1393**

SSB At the Start of the Spawning Season - males & females (mt)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	279.268	259.256	342.256	208.742	315.150	431.623	884.910	189.900	124.471	211.490
2	4128.022	2378.125	2235.356	3229.377	2055.311	3115.612	4133.605	8333.216	1523.338	1032.841
3	4419.886	6395.164	3409.523	3502.206	5326.099	3645.748	5587.333	7435.895	14562.007	2379.669
4	5272.487	3437.366	5093.878	2609.312	2596.884	3882.623	3391.217	4721.398	6146.460	12453.578
5	5478.277	3080.370	1857.316	3013.166	1119.350	1370.345	2040.952	2040.127	2226.525	3006.943
6	1150.792	2636.628	1448.734	819.632	1282.375	401.124	618.035	619.344	1107.789	1038.018
7	1421.929	437.469	810.522	680.069	350.667	525.090	122.428	390.847	289.574	457.653
8	3554.754	1810.129	1215.290	890.438	913.095	498.430	416.568	495.246	1559.278	648.767
Tot	**25705.416**	**20434.507**	**16412.875**	**14952.941**	**13958.932**	**13870.594**	**17195.049**	**24225.974**	**27539.442**	**21228.961**

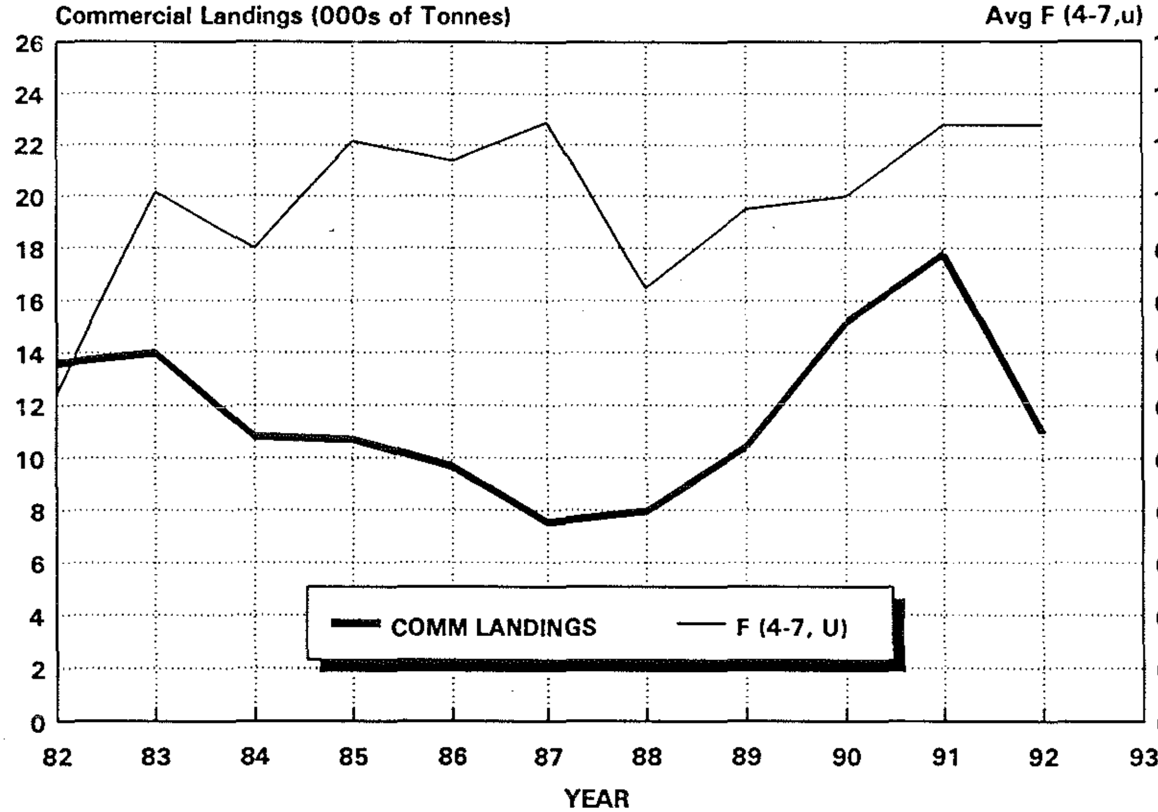


Figure D6. Trends in total commercial landings and fishing mortality for Gulf of Maine cod, 1982-1992.

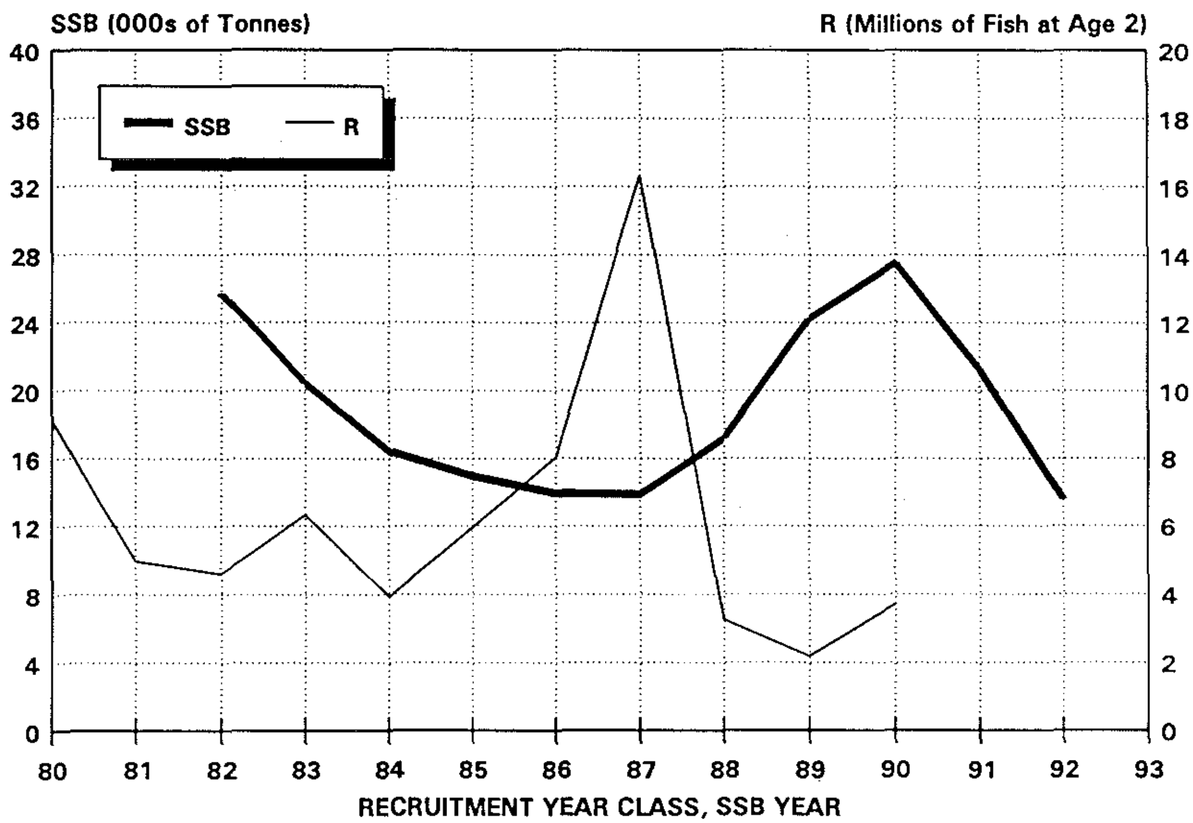


Figure D7. Trends in spawning stock biomass and recruitment for Gulf of Maine cod, 1980-1992.

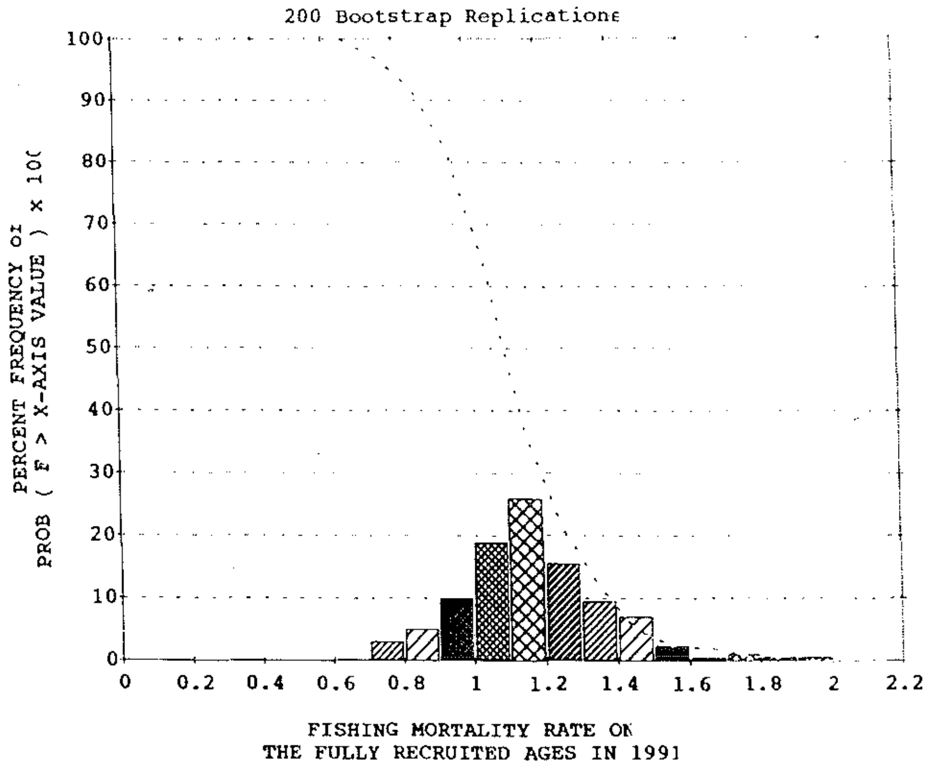


Figure D8. Precision of the estimates of the instantaneous rate of fishing mortality (F) on the fully recruited ages (Ages 4+) in 1991 for Gulf of Maine cod. The vertical bars display both the range of the estimator and the probability of individual values within that range. The dashed line gives the probability that F is greater than any selected value on the X axis. The precision estimates were derived from 200 bootstrap replications.

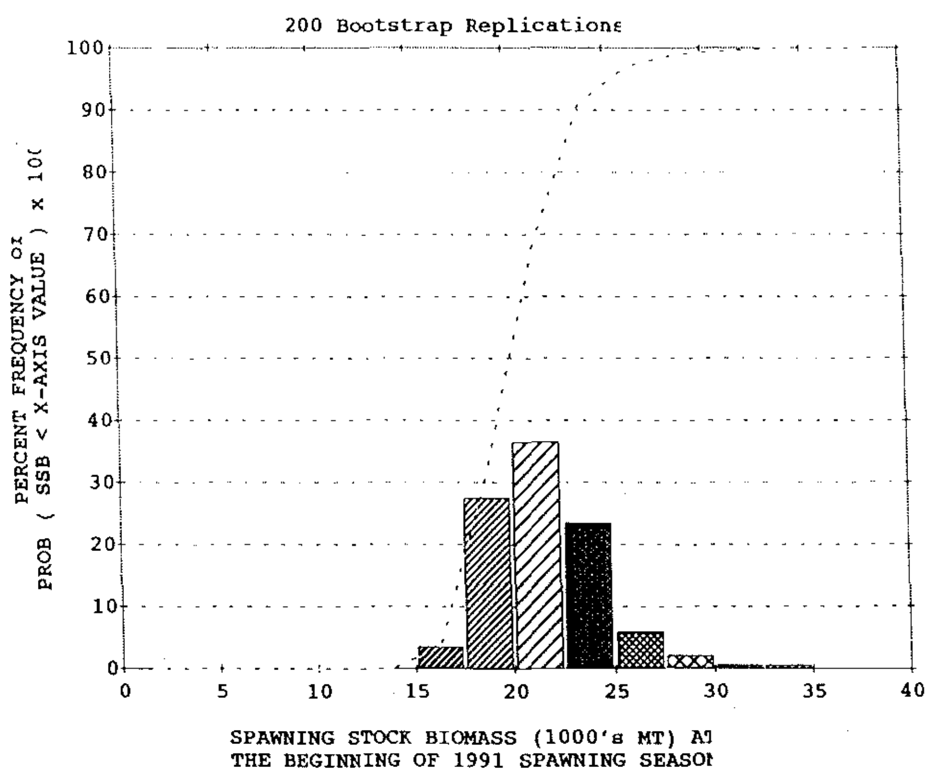


Figure D9. Precision of the estimates of spawning stock biomass at the beginning of the 1991 spawning season for Gulf of Maine cod. The vertical bars display both the range of the estimator and the probability of individual values within that range. The dashed line gives the probability that SSB is less than any selected value on the X axis. The precision estimates were derived from 200 bootstrap replications.

Table D15. Precision and bias estimates of the age-specific instantaneous fishing mortality rates (F) in 1991 for Gulf of Maine cod. ADAPT estimate is from the final consensus assessment run. Standard errors, coefficients of variation (C.V.) and bias estimates are derived from 200 bootstrap replications. Ages 4+ represent the fully-recruited portion of the stock.

AGE	ADAPT ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	CV FOR ADAPT SOLN
2	1.910E-1	1.963E-1	5.013E-2	0.26
3	5.402E-1	5.408E-1	1.137E-1	0.21
4	9.298E-1	9.583E-1	2.107E-1	0.23
5	1.349E0	1.369E0	3.359E-1	0.25
6	1.139E0	1.164E0	1.973E-1	0.17
7	1.139E0	1.164E0	1.973E-1	0.17
8+	1.139E0	1.164E0	1.973E-1	0.17
4+	1.139E0	1.164E0	1.973E-1	0.17

AGE	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	ADAPT EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
2	5.306E-3	3.545E-3	2.78	1.857E-1	0.27
3	6.115E-4	8.039E-3	0.11	5.396E-1	0.21
4	2.850E-2	1.490E-2	3.07	9.013E-1	0.23
5	1.990E-2	2.375E-2	1.48	1.329E0	0.25
6	2.420E-2	1.395E-2	2.12	1.115E0	0.18
7	2.420E-2	1.395E-2	2.12	1.115E0	0.18
8+	2.420E-2	1.395E-2	2.12	1.115E0	0.18
4+	2.420E-2	1.395E-2	2.12	1.115E0	0.18

(Table D9). Spawning stock biomass declined from a 1990 maximum of 27,500 tons to 21,200 tons in 1991. The 1987 year class (16.3 million) is the highest in the 1982 to 1990 series and almost twice the size of the above average 1980 and 1986 year classes. The unusually strong 1987 year class accounted for the high level of SSB observed in 1990 (Figure D7). Recent recruitment, however, has been poor as the 1988 to 1990 year classes (< 4 million) are estimated to be among the poorest in the series.

To evaluate the precision of the final estimates, a bootstrap procedure (Efron 1982) having 200 iterations was used to generate distributions of the 1991 fishing mortality rate and spawning stock biomass. This method accounts for random variation in the calibration data (survey and LPUE). Figures D8 and D9, respectively, show the distribution of these bootstrap estimates and a cumulative probability curve. The distribution of the estimates indicates the amount of uncertainty by visually depicting variability. The cumulative probability can be used to evaluate the risk of making a decision based on the estimated value. It expresses the probability (chance) that the fishing mortality rate was greater than a given level when measurement errors are considered. Regarding spawning stock biomass, the cumulative plot indicates the probability that it was less than a given level. The precision and bias of the age-specific fishing mortality rates are presented in Table D15. Precision increases for 4+ aggregated ages compared to fishing mortality estimates on individual ages.

The fully recruited fishing mortality for ages 4+ was reasonably well estimated (CV = 0.17). The distribution of 200 iterations of the above bootstrap method is presented in Figure D8. The mean bootstrap estimate of F (1.164) was slightly higher than the point estimate (1.139) from the VPA and ranged from 0.7 to 2.0. $F_{20\%}$ is much lower than the lowest bootstrap estimate and F_{1991} is almost certainly above the overfishing definition mortality rate. Fishing mortality in 1990 (1.00) falls within the lower range of these bootstrap estimates for 1991. Therefore given the amount of precision associated with the 1991 estimate, the probability that the true F_{1991} is greater than F_{1990} is about 80%.

Although the abundance estimates of individual ages in 1992 had wider variances (CV = 0.27 to 0.50), the estimate of 1991 spawning stock biomass was robust (C.V. = 0.13). Two hundred bootstrap replications gave the distri-

Table D16. Yield and spawning stock biomass per recruit estimates and input data for Gulf of Maine cod

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992

GULF OF MAINE COD: Run Date: 15-12-1992; Time: 09:38:34.01

Proportion of F before spawning: .1670
Proportion of M before spawning: .1670
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 10
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> B:\ASSES\GMCODYPR.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Stock
1	.0001	1.0000	.0600	.000	.814
2	.0347	1.0000	.5000	1.149	1.016
3	.3828	1.0000	.8400	1.679	1.417
4	1.0000	1.0000	.9600	2.592	2.148
5	1.0000	1.0000	1.0000	4.088	3.233
6	1.0000	1.0000	1.0000	6.609	5.345
7	1.0000	1.0000	1.0000	9.881	7.912
8	1.0000	1.0000	1.0000	12.006	10.943
9	1.0000	1.0000	1.0000	15.123	13.248
10	1.0000	1.0000	1.0000	18.000	18.000

Summary of Yield per Recruit Analysis for: Cod, Gulf of Maine -1992 ASSMT AVE WTS, FPAT AND MAT VECTORS

Slope of the Yield/Recruit Curve at F=0.00: --> 28.6006
F level at slope=1/10 of the above slope (F0.1): ---> .151
Yield/Recruit corresponding to F0.1: ---> 1.7125
F level to produce Maximum Yield/Recruit (Fmax): ---> .254
Yield/Recruit corresponding to Fmax: ---> 1.8282
F level at 20 % of Max Spawning Potential (F20): ---> .356
SSB/Recruit corresponding to F20: -----> 5.7994

Listing of Yield per Recruit Results for: Cod, Gulf of Maine -1992 ASSMT AVE WTS, FPAT AND MAT VECTORS

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	31.3639	3.9054	28.9988	100.00
	.060	.13884	1.13027	4.8254	21.5648	3.2131	19.3375	66.68
	.120	.22602	1.59604	4.3923	16.0053	2.7789	13.8848	47.88
F0.1	.151	.25961	1.71253	4.2259	14.0326	2.6119	11.9580	41.24
	.180	.28602	1.77670	4.0951	12.5612	2.4807	10.5244	36.29
	.240	.32995	1.82684	3.8782	10.2930	2.2627	8.3222	28.70
Fmax	.254	.33833	1.82817	3.8369	9.8880	2.2211	7.9302	27.35
	.300	.36358	1.81619	3.7126	8.7285	2.0961	6.8103	23.48
F20%	.356	.38850	1.78139	3.5904	7.6782	1.9729	5.7994	20.00
	.360	.39022	1.77816	3.5819	7.6091	1.9644	5.7330	19.77
	.420	.41190	1.72929	3.4760	6.7832	1.8575	4.9412	17.04
	.480	.42993	1.67780	3.3882	6.1578	1.7687	4.3437	14.98
	.540	.44519	1.62774	3.3142	5.6735	1.6938	3.8822	13.39
	.600	.45830	1.58094	3.2509	5.2908	1.6296	3.5185	12.13
	.660	.46970	1.53812	3.1960	4.9831	1.5738	3.2266	11.13
	.720	.47974	1.49937	3.1479	4.7316	1.5248	2.9885	10.31
	.780	.48866	1.46454	3.1053	4.5232	1.4814	2.7914	9.63
	.840	.49664	1.43331	3.0674	4.3482	1.4426	2.6260	9.06
	.900	.50385	1.40533	3.0332	4.1995	1.4077	2.4856	8.57
	.960	.51039	1.38024	3.0023	4.0718	1.3760	2.3650	8.16
	1.020	.51637	1.35772	2.9742	3.9611	1.3471	2.2605	7.80
	1.080	.52187	1.33746	2.9485	3.8642	1.3207	2.1690	7.48
	1.140	.52694	1.31918	2.9248	3.7787	1.2963	2.0883	7.20
	1.200	.53164	1.30264	2.9029	3.7028	1.2737	2.0166	6.95

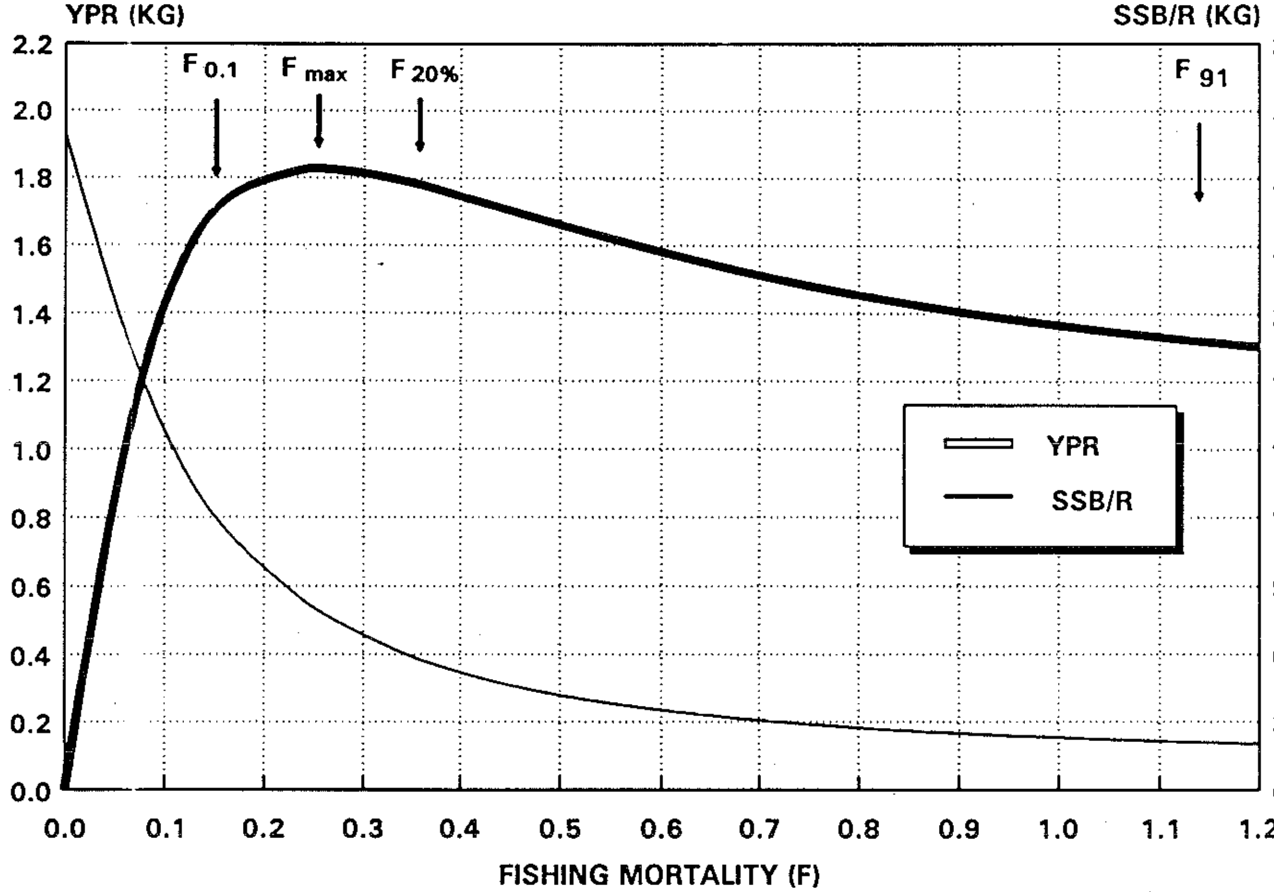


Figure D10. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for Gulf of Maine cod.

bution presented in Figure D9. The bootstrap mean (21,650 t) was slightly higher than the VPA point estimate (21,230) and ranged from 15,000 t to 35,000 t. Current spawning stock biomass is the lowest observed in the series.

Yield and Spawning Stock Biomass per Recruit

A smooth exploitation pattern was computed from the geometric mean Fs obtained from the 1986 to 1990 Fs at age from the VPA. The final exploitation pattern is as follows:

Age 1 0.0001, Age 2 0.0347,
Age 3 0.3828, Age 4+ 1.000

This pattern is similar to that obtained from the separable VPA and to that presented in the 1991 Gulf of Maine cod assessment, and was used in yield and SSB per recruit calculations.

Input data and results of the yield and SSB per recruit calculations are listed in Table D16 and are illustrated in Figure D10. The yield per recruit analyses indicate that $F_{0.1}$ = 0.15, F_{max} = 0.25, and $F_{20\%}$ = 0.36.

Projections for 1993 and 1994

Input and output from the projections are given in Table D17 and are illustrated in Figure D11. The assumption of status quo F in 1992 of 1.14 resulted in a catch of approximately 11,000 t in 1992. Preliminary catch statistics indicate that 1992 Gulf of Maine cod landings will be considerably lower than 1991, possibly in the range of 11,000 to 12,000 t. Thus the assumption of status quo F may underestimate the actual fishing mortality. For 1993, continued fishing at F = 1.14 will result in a projected catch of about 7,000 t and will lead to further reductions in SSB from 21,200 t in 1991 to about 11,700 t in 1993 and 13,000 t in 1994 if average recruitment conditions prevails.

Table D17. Stock biomass and catch projections, starting conditions and input data for Gulf of Maine cod

The NEFC/PDB Catch and Stock Size Prediction Program - PDBPRED
GULF OF MAINE COD: Run Date: 22-11-1992; Time: 15:48:24.07

Input for Projections:

Number of Years: 3; Initial Year: 1992; Final Year: 1994
Number of Ages : 7; Age at Recruitment: 2; Last Age: 8
Natural Mortality is assumed Constant over time at: .200
Proportion of F before spawning: .1670
Proportion of M before spawning: .1670
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file
===>B:\ASSES\GMCODPRD.DAT

Year-specific Input data for Projection # 1

	Year	Recruits at Age 2	Reference F	Natural Mortality	Target Catch
Low					
	1992	3715.	1.140	.200	N/A
	1993	3247.	1.140	.200	N/A
	1994	3247.	1.140	.200	N/A
Ave					
	1992	3715.	1.140	.200	N/A
	1993	6188.	1.140	.200	N/A
	1994	6188.	1.140	.200	N/A
High					
	1992	3715.	1.140	.200	N/A
	1993	16328.	1.140	.200	N/A
	1994	16328.	1.140	.200	N/A

Age-specific Input data for Projection # 1

Age	Stock Size in 1992	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
2	3715.	.0330	1.0000	.5000	1.149	1.016
3	1479.	.3796	1.0000	.8400	1.679	1.417
4	1180.	1.0000	1.0000	.9600	2.592	2.148
5	2454.	1.0000	1.0000	1.0000	4.088	3.233
6	270.	1.0000	1.0000	1.0000	6.609	5.345
7	61.	1.0000	1.0000	1.0000	9.881	7.912
8+	33.	1.0000	1.0000	1.0000	15.006	14.000

Projections for 1993 and 1994 under various recruitment and F levels assuming:
F92=F91=1.14

1993-1994 Recruitment Level	1992 F	1992 Landings	1992 SSB	1993 F	1993 Landings	1993 SSB	1994 SSB
Low = 3247	1.14	10907	13595	F_{max}=0.25	2197	11361	14988
	1.14	10970	13595	$F_{20\%}$=0.36	2985	11224	13996
	1.14	10970	13595	90% F_{SQ}=1.03	6670	10411	9607
	1.14	10970	13595	F_{SQ}=1.14	7111	10285	9113
Ave = 6188	1.14	10970	13595	F_{max}=0.25	2223	12804	19136
	1.14	10970	13595	$F_{20\%}$=0.36	3021	12666	18115
	1.14	10970	13595	90% F_{SQ}=1.03	6755	11852	13573
	1.14	10970	13595	F_{SQ}=1.14	7224	11720	13032
High = 16328	1.14	10970	13595	F_{max}=0.25	2311	17778	34437
	1.14	10970	13595	$F_{20\%}$=0.36	3146	17638	32319
	1.14	10970	13595	90% F_{SQ}=1.03	7125	16801	27161
	1.14	10970	13595	F_{SQ}=1.14	7615	16671	26546

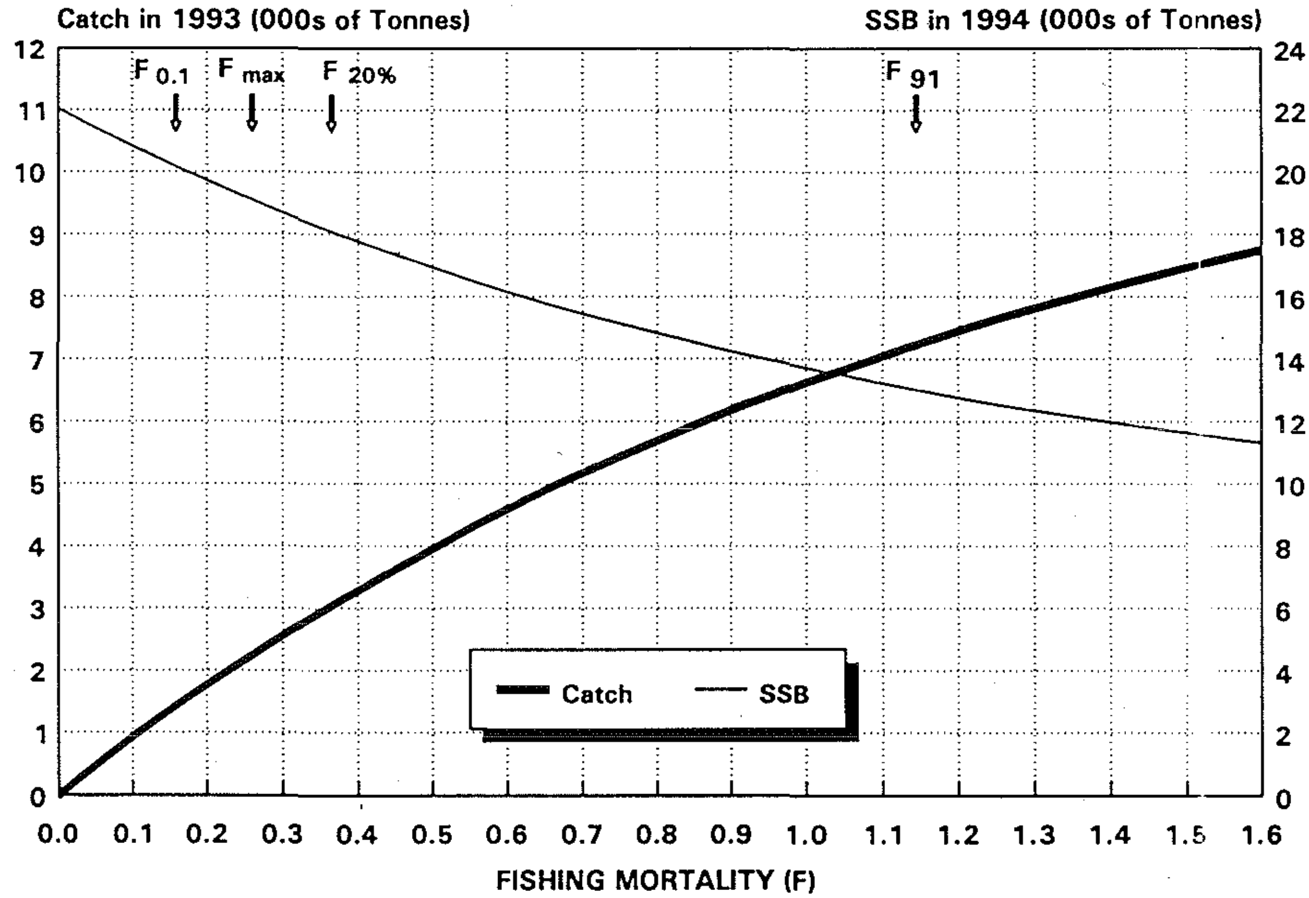


Figure D11. Predicted catches in 1993 and spawning stock biomasses in 1994 of Gulf of Maine cod over a range of fishing mortalities in 1993 from F-0 to F-1.6.

SOURCES OF UNDERTAINTY

This assessment updated the previous assessment conducted during SAW12. Because the recommended improvements will take considerable time, some of the same sources of uncertainty identified in the last assessment remain. The omission of commercial fishery discards and recreational catch estimates from the catch at age matrix continue to introduce uncertainty into the results. Commercial fishery discard mortality may be a significant component of total mortality in certain years, but estimates were not available for this assessment. Omission of commercial discards and recreational catch results in an underestimation of the total fishery removals from the stock.

In this assessment, the tuned VPA suggested that recruitment in 1990, 1991, and 1992 were among the lowest observed in the time series. Another model (RCT3) gave somewhat higher estimates, but these were not used in the projections. Survey methods that yield more certain estimates of recruiting year class strength are necessary to predict future landings at a given fishing mortality rate with acceptable precision.

The VPA utilized tuning indices derived from effort standardized on otter trawl LPUE. Although a large proportion of landings come from otter trawl effort, it can lead to divergent trends in F and effort which are difficult to explain. Inconsistencies of this type may occur because of changes in effort that are not captured by the standardization procedure (*e.g.* changes in technology and shifts to other fishing methods), or because the standardization procedure itself is based on assumptions that may not be very robust. However, the F_{1991} was consistent with the observed increase in standardized effort between 1990 and 1991.

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GULF OF MAINE COD RESEARCH RECOMMENDATIONS

1. Discards and recreational catches contribute to significant mortality of cod. Recreational landings have contributed to 10 to 30% of total landings. The procedures to calculate catch at age for these two sources are undetermined, but inclusion of these sources of removal would be useful in improving the assessment. The size or age composition of recreational catches is necessary to add these catches to the catch at age matrix.
2. The current projection methods do not include all sources of uncertainty within the assessment. Future projection methods could include these sources by using a Monte Carlo approach for all input parameters, including current fishing mortality, natural mortality, starting stock conditions, as well as recruitment.
3. Other survey methods that would improve recruitment estimates should be evaluated, *e.g.* fixed rather than random sampling stations.
4. Fully recruited fishing mortality appeared to be well estimated in regard to measurement error. However, the VPA suggested that F on age 2 more than doubled from 1990 to 1991. A retrospective analysis should be attempted to reveal underlying biases in terminal year estimates.

Terms of reference for future assessments:

1. The present effort standardization uses the catch per effort for interviewed otter trawl trips to standardize effort for all commercial gears. This standardization procedure may not be effective in capturing changes in effort patterns for other gears. Due to this level of aggregation in the commercial tuning indices, similar problems are expected in future assessments. Standardization of effort for individual gears and ages should be conducted separately to calculate commercial catch per effort for VPA tuning. A better understanding of meaningful units of fixed gear fishing effort is needed, *e.g.* sink gill nets.
2. Studies should be undertaken to understand the possible changing relationship between effort and fishing mortality.
3. This assessment utilized tuning indices that were adjusted for changes of trawl doors and vessels used for the survey. The former change was made in 1985. It was noted that several indices exhibited an abrupt change in the sign of the residuals in 1986. The effect of the survey adjustments on these indices should be investigated for this stock.

E. GEORGES BANK COD ASSESSMENT

INTRODUCTION

Atlantic cod (*Gadus morhua*) in the Georges Bank area have been commercially exploited since the 17th Century. Reliable landings statistics are available since 1893. Historically, the Georges Bank fishery (NAFO Division 5Z and Subarea 6) can be separated into five periods: (Figure E1):

(1) 1893-1914, when high landings (> 40,000 t) in 1895 and 1906-1907 were followed by about 10 years of sharply-reduced landings
(2) 1915-1940, when annual landings fluctuated between 20,000 and 30,000 t, and when cod was generally taken as a bycatch in the Georges Bank haddock fishery
(3) 1940-1960, when landings declined, reaching a record low of 8,100 tons in 1953. Declines in this period reflect a reduction in fishing activity during World War II and redirection of remaining fleet effort toward the more abundant haddock resource
(4) 1960-1976, when Canadian and distant-water fleet fisheries for Georges Bank cod developed. Large increases in fishing effort for cod during this period resulted in a fivefold increase in annual landings between 1960 and 1966 (11,000 to 53,000 t) but landings sharply declined afterward reaching only 20,000 t in 1976
(5) 1977 onward, after the implementation of extended fisheries jurisdiction by both the United States and Canada. Total landings of Georges Bank cod doubled between 1977 and 1982 (27,000 to 57,000 t), declined to 26,000 t in 1986, increased to 42,500 t in 1990 and were 37,600 t in 1991 (Table E1). Since October 1984, when the International Court of Justice delimited a maritime boundary between the United States and Canada in the Gulf of Maine/Georges Bank region, fishing activity by each country has been restricted to its own waters on Georges Bank.

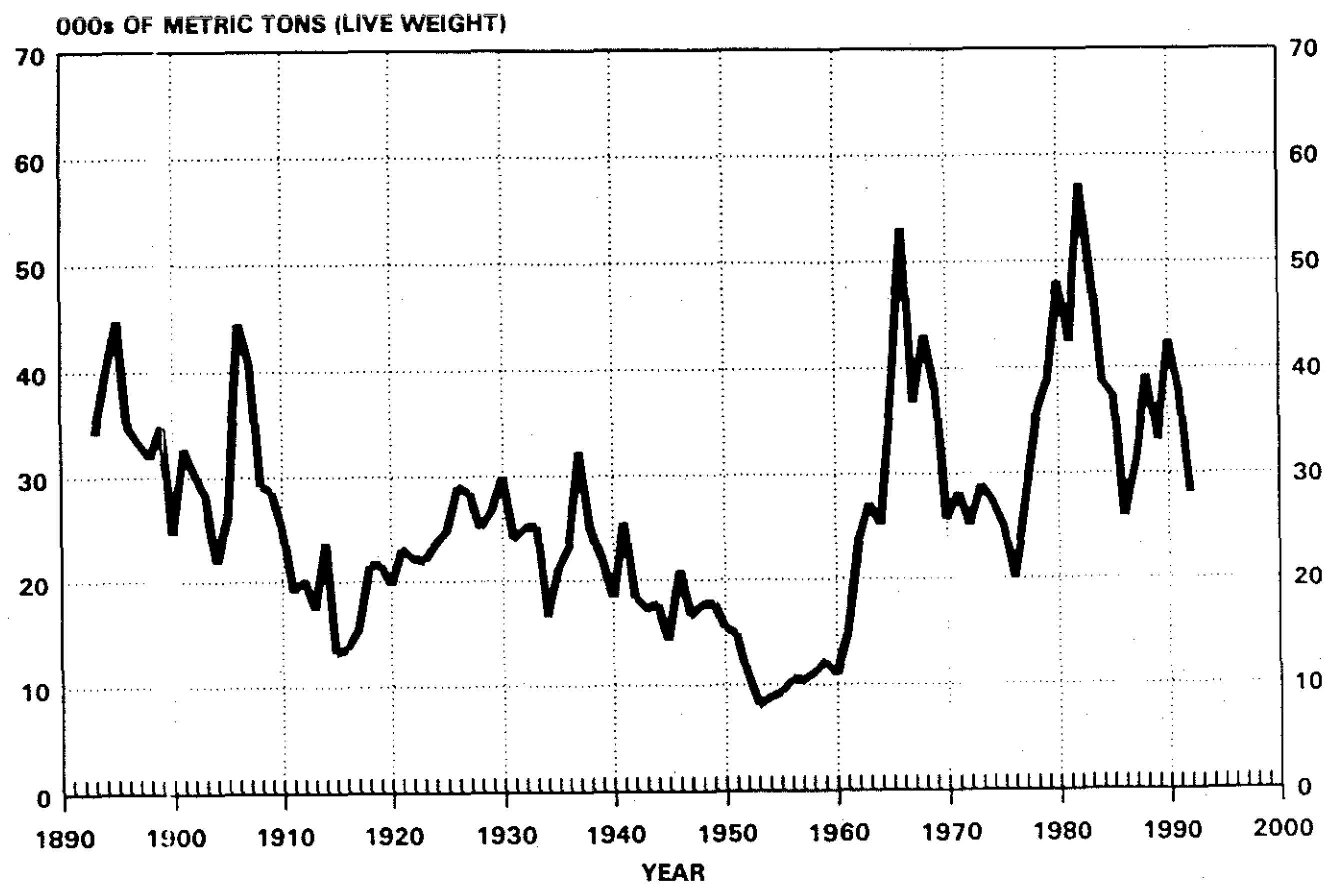


Figure E1. Total commercial landings of Georges Bank cod, 1893-1992.

Table E1. Commercial landings (mt) of Atlantic cod from Georges Bank and South (Division 5Z and Subarea 6), 1960-1992

Year	Country						Total
	USA	**Canada**	**USSR**	**Spain**	**Poland**	**Other**	
1960	10834	19	-	-	-	-	10853
1961	14453	223	55	-	-	-	14731
1962	15637	2404	5302	-	143	-	23486
1963	14139	7832	5217	-	-	1	27189
1964	12325	7108	5428	18	48	238	25165
1965	11410	10598	14415	59	1851	-	38333
1966	11990	15601	16830	8375	269	69	53134
1967	13157	8232	511	14730	-	122	36752
1968	15279	9127	1459	14622	2611	38	43136
1969	16782	5997	646	13597	798	119	37939
1970	14899	2583	364	6874	784	148	25652
1971	16178	2979	1270	7460	256	36	28179
1972	13406	2545	1878	6704	271	255	25059
1973	16202	3220	2977	5980	430	114	28923
1974	18377	1374	476	6370	566	168	27331
1975	16017	1847	2403	4044	481	216	25008
1976	14906	2328	933	1633	90	36	19926
1977	21138	6173	54	2	-	-	27367
1978	26579	8778	-	-	-	-	35357
1979	32645	5978	-	-	-	-	38623
1980	40053	8063	-	-	-	-	48116
1981	33849	8499	-	-	-	-	42348
1982	39333	17824	-	-	-	-	57157
1983	36756	12130	-	-	-	-	48886
1984	32915	5763	-	-	-	-	38678
1985	26828	10443	-	-	-	-	37271
1986	17490	8411	-	-	-	-	25901
1987	19035	11845	-	-	-	-	30880
1988	26310	12932	-	-	-	-	39242
1989	25097	8001	-	-	-	-	33098
1990	28193	14310	-	-	-	-	42503
1991[1]	24175	13455	-	-	-	-	37630
1992[2]	15700	12400	-	-	-	-	28100

[1]**Provisional**
[2]**Predicted**

This report presents an updated and revised analytical assessment of the Georges Bank cod stock (NAFO Division 5Z and Statistical Area 6) for the period 1978 to 1991 based on analysis of commercial landings and effort data and research vessel survey data through 1991. Specific analytic details regarding the assessment are presented in Serchuk *et al.* (1993). Previous analytical assessments of this stock were conducted by the United States in 1986 (Serchuk and Wigley 1986; NEFC 1986), in 1988 (Serchuk 1988, unpublished; NEFC 1989), in 1990 (Serchuk and Wigley 1990, unpublished ; NEFSC 1990), and in 1991 (Serchuk et al. 1991, unpublished; NEFSC 1992). Analytical assessments of the component of the Georges Bank cod stock in Canadian waters (Unit Areas 5Zj and 5Zm) have been conducted by CAFSAC [Canadian Atlantic Fisheries Scientific Advisory Committee] in 1990 (Hunt 1990), 1991 (Hunt *et al.* 1991), and 1992 (Hunt and Buzeta 1992).

RECREATIONAL FISHERY CATCHES

Estimated recreational cod catches [from both the Georges Bank and Gulf of Maine cod stocks combined, and including fish reported caught and subsequently released alive] during 1960 to 1989 ranged between 3,450 t (1986) and 16,300 t (1970) (Table E2). The highest estimates were derived prior to 1979 but must be considered tentative due to methodological weaknesses and differences in survey procedures in these years (United States Department of Commerce 1979, p. 21). Between 1981 and 1985, annual recre-

Table E2. Estimated number (1,000) and weight (mt, live) of Atlantic cod caught by marine recreational fishermen in 1960, 1965, 1970, 1974, and 1979-1991[1]

Year	All Regions		Georges Bank Stock	
	Number of Cod (000s)	Weight of Cod (mt)	Number of Cod (ooos)	Weight of Cod (mt)
1960	4791	14016	Not Estimated	
1965	5032	13565	Not Estimated	
1970	3844	16292	Not Estimated	
1974	2901	12368	Not Estimated	
1979	3091	4026	393	580
1980	2440	7331	186	471
1981	4845	9712	1605	4677
1982	3250	8244	1453	5296
1983	3747	7542	1693	4920
1984	2562	5080	832	2406
1985	3674	7664	1998	4635
1986	1548	3510	331	1092
1987	2063	3779	467	1168
1988	2966	7327	1494	4284
1989	2463	6119	538	1875
1990	2635	5144	690	1696
1991	1854	3727	444	1255

[1] **From 1979-1991 Marine Recreational Fishery Statistics Survey expanded catch estimates.**

ational cod landings exhibited little variability; apart from 1984, annual catches varied between 8,000 and 9,000 t, and averaged 8,500 t per year. Recreational cod catches declined in 1986 and 1987 to less than 4,000 t, increased to more than 6,000 t in 1988 and 1989, but declined to 5,000 t in 1990, and were only 3,700 t in 1991.

Preliminary estimates of recreational catches of cod by stock unit have recently been derived using landing site information (from intercept surveys) to allocate catches between the Gulf of Maine and Georges Bank stocks (Recreational Fisheries Statistics Working Group, unpublished). Between 1981 and 1985, estimated catches from the Georges Bank stock (Div 5Z and Area 6) ranged between 2,400 t and 5,300 t, and averaged 4,400 t per year (Table E2). Since 1986, however, recreational catches of Georges Bank cod have averaged just 1,900 t per year, and accounted (apart from 1988) for only a third of the total U.S. recreational cod landings.

Recreational catches have not been included in any of the assessment analyses since a number of problems still remain in estimating the quantity and size/age composition of the recreational catch, by stock (Recreational Fisheries Statistics Working Group, unpublished). Among these are:

(1) lack of recreational catch estimates in January and February when some party boats in Massachusetts, Rhode Island, and New York land cod
(2) inability to properly categorize catches of long-range trips (*e.g.*, to Georges Bank) that are being made in increasing numbers by party boats, from Maine to New York
(3) catch estimates for the Georges Bank stock are imprecise [*i.e.*, relatively large CVs], and
(4) length frequency sampling intensity, particularly for the Georges Bank stock, is low and is probably insufficient to accurately characterize the size composition of the catch. Moreover, length frequency sampling is opportunistic and thus samples are not distributed in proportion to the catch, by time, fishing mode, or state of landing.

COMMERCIAL FISHERY LANDINGS

Total commercial landings in 1991 were 37,600 t, 11% lower than in 1990 (Table E1). The United States and Canada, sole participants in the fishery since 1978, accounted for 64% and 36%, respectively, of the 1991 total. The 1991 U.S. landings (24,200 mt) were 14% less than in 1990, and the fourth lowest U.S. total since 1977. Canadian 1991 landings totaled 13,500 mt, 6% lower than in 1990, but still the fourth highest Canadian landings ever.

As in the past, otter trawl landings accounted for most (68%) of the 1991 landings. The otter trawl fishery accounted for 80% of the 1991 U.S. landings (Table E3) and 50% of the Canadian landings (Hunt and Buzeta 1992). During 1978-1991, 85% of the U.S. landings and 61% of the Canadian landings were attributable to otter trawl gear.

CATCH COMPOSITION

Sampling Intensity

United States length frequency sampling averaged one sample per 320 t landed over the 14-year period but, since 1982, has improved to one sample per 280 t landed. Sampling intensity in 1991 (1 sample per 275 t) was greater than in

Table E3. Distribution of U.S. commercial landings (mt, live) of Atlantic cod from Georges Bank (Area 5Ze), by gear type, 1965-1992. The percentage of total U.S. commercial landings of Atlantic cod from Georges Bank by gear type is also presented for each year. Data only reflect Georges Bank cod landings that could be identified by gear type.

	Landings (mt, live)						**Percentage of Annual Landings**					
Year	**Otter Trawl**	**Sink Gill Net**	**Line Trawl**	**Handline**	**Other Gear**	**Total**	**Otter Trawl**	**Sink Gill Net**	**Line Trawl**	**Handline**	**Other Gear**	**Total**
1965	10251	0	582	505	9	11347	90.3	-	5.1	4.5	0.1	100.0
1966	10206	0	787	757	19	11769	86.7	-	6.7	6.4	0.2	100.0
1967	10915	0	894	704	9	12522	87.2	-	7.1	5.6	0.1	100.0
1968	12084	0	936	524	<1	13544	89.2	-	6.9	3.9	-	100.0
1969	13194	0	1371	387	<1	14952	88.2	-	9.2	2.6	-	100.0
1970	11270	0	1676	404	<1	13350	84.4	-	12.6	3.0	-	100.0
1971	12436	0	2334	230	2	15002	82.9	-	15.6	1.5	-	100.0
1972	10179	0	2071	217	10	12477	81.6	-	16.6	1.7	0.1	100.0
1973	12431	3	2185	206	21	14846	83.7	-	14.7	1.4	0.2	100.0
1974	14078	3	2548	11	9	16649	84.6	-	15.3	0.1	-	100.0
1975	12069	0	2435	84	4	14592	82.7	-	16.7	0.6	-	100.0
1976	12257	4	1519	153	5	13938	88.0	-	10.9	1.1	-	100.0
1977	18529	30	912	83	22	19576	94.7	0.2	4.7	0.4	0.1	100.0
1978	20862	81	1569	1180	59	23751	87.8	0.3	6.6	5.0	0.3	100.0
1979	26562	620	2707	860	159	30908	85.9	2.0	8.8	2.8	0.5	100.0
1980	32479	4491	1102	0	273	38345	84.7	11.7	2.9	-	0.7	100.0
1981	27694	3515	120	584	197	32110	86.2	10.9	0.4	1.8	0.6	100.0
1982	33371	2935	385	624	210	37525	88.9	7.8	1.0	1.7	0.6	100.0
1983	30981	1812	831	441	81	34146	90.7	5.3	2.4	1.3	0.3	100.0
1984	26161	2573	366	753	197	30050	87.1	8.6	1.2	2.5	0.6	100.0
1985	21444	2482	436	284	163	24809	86.4	10.0	1.8	1.1	0.7	100.0
1986	13576	1679	692	305	95	16347	83.0	10.3	4.2	1.9	0.6	100.0
1987	13711	1522	1636	222	71	17162	79.9	8.9	9.5	1.3	0.4	100.0
1988	20296	1864	1950	232	116	24458	83.0	7.6	8.0	0.9	0.5	100.0
1989	17946	3150	1583	119	91	22889	78.4	13.8	6.9	0.5	0.4	100.0
1990	21707[1]	2316	1252	395	133	25803	84.1	9.0	4.9	1.5	0.5	100.0
1991	17892[2]	2171	1919	286	180	22448	79.7	9.7	8.5	1.3	0.8	100.0
1992*						15700						

* Predicted
[1] Includes 849 tons taken by pair-trawl (Note: 1990 was the first year that pair-trawl landings exceeded a few tons)
[2] Includes 1068 tons taken by pair-trawl

preceding years (1989 = 1 sample per 380 t; 1990 = 1 sample per 340 t). Virtually all of the U.S. samples have been taken from otter trawl landings, but sampling is proportionally stratified by market category (scrod, market, and large). Comparison of length frequency samples taken from otter trawl landings with those obtained from fixed gears (a few samples from longlines and gill nets) revealed no obvious differences in size composition of fish, within a market category, by gear.

Canadian sampling intensity has historically been much lower than that in the U.S. fishery. Prior to 1985, Canadian sampling coverage averaged about one sample per 1000 t landed (Hunt and Buzeta 1992). Sampling intensity has markedly improved since 1985 and has averaged one sample per 325 t landed during the 1986-1991 period. Sampling intensity in 1991 was 1 sample per 299 t. Canadian samples were primarily from otter trawl landings (Hunt 1988, 1990). Canadian sampling is not done by market category but representative samples of the landings are taken.

Age Composition

Age composition of U.S. landings during 1978-1991 was estimated, by market category, from monthly length frequency and age samples, pooled by calendar quarter. Quarterly mean weights, by market category, were obtained from applying the U.S. cod length-weight equation ($\ln Weight_{(kg,live)} = -11.7231 + 3.0521 \ln Length_{(cm)}$) to the quarterly market category sample length frequencies. Mean weight values were then divided into quarterly market category landings to derive estimated numbers landed by quarter, by market category. Quarterly age/length keys were then

Table E4. Landings at age (thousands of fish, mt) and mean weight (kg) and mean length (cm) at age of total commercial landings of Atlantic cod from the Georges Bank and South cod stock (NAFO Division 5Z and Statistical Area 6), 1978-1991

Year	Age 1	2	3	4	5	6	7	8	9	10+	Total	% of Total Landings USA	Canada
						Total Commercial Landings in Numbers (000's) at Age							
1978	2	393	7748	2303	830	131	345	47	40	15	11854	73.7	26.3
1979	34	1989	900	4870	1212	458	77	253	4	48	9845	81.2	18.8
1980	89	3777	5828	500	2308	1076	445	87	167	10	14287	80.9	19.1
1981	27	3205	4221	2464	235	1406	417	123	130	62	12290	84.1	15.9
1982	331	9138	3824	2787	2000	281	673	213	71	83	19401	74.1	25.9
1983	108	4286	8063	2456	1055	776	95	235	100	65	17239	72.2	27.8
1984	81	1307	3423	3336	840	516	458	44	171	121	10297	89.0	11.0
1985	134	6426	2443	1368	1885	412	218	203	21	97	13207	68.4	31.6
1986	156	1326	4573	797	480	627	87	72	47	29	8194	71.7	28.3
1987	26	7473	1406	2121	279	252	270	63	38	24	11952	64.2	35.8
1988	10	1577	8022	1012	1497	244	161	197	50	47	12817	71.6	28.4
1989	-	2088	2922	4155	331	541	82	43	50	18	10230	81.1	18.9
1990	7	4942	5042	1882	2264	229	245	36	17	38	14702	74.3	25.7
1991	52	1525	3243	3281	1458	1088	126	70	23	23	10889	67.7	32.3
						Total Commercial Landings in Weight (Tons) at Age							
1978	1	515	18890	7990	3597	757	2549	395	465	198	35357	75.2	24.8
1979	30	2970	1936	20504	5923	3288	711	2611	44	606	38623	84.5	15.5
1980	75	5516	14382	1833	13036	7184	3735	793	1408	154	48116	83.2	16.8
1981	24	4789	9953	8416	1224	10156	3575	1212	1848	1151	42348	79.9	20.1
1982	253	12812	10187	10681	10705	1827	6303	2110	891	1388	57157	68.8	31.2
1983	105	6387	19167	8126	4891	4963	763	2418	1120	946	48886	75.2	24.8
1984	85	2137	8389	12074	4271	3401	4078	447	1938	1858	38678	85.1	14.9
1985	121	9111	5095	5319	9588	2644	1765	2073	246	1309	37271	72.0	28.0
1986	145	1955	11189	2917	2692	4505	776	717	596	409	25901	67.5	32.5
1987	19	11071	3509	8882	1619	1945	2416	633	426	360	30880	61.6	38.4
1988	8	2399	18923	3552	8085	1618	1412	1960	566	719	39242	67.0	33.0
1989	-	3375	6633	15673	1783	3625	669	455	588	298	33098	75.8	24.2
1990	5	7709	12412	6629	11075	1448	2069	382	222	552	42503	66.3	33.7
1991	59	2481	8265	11221	6955	6411	933	736	223	346	37630	64.2	35.8
						Total Commercial Landings Mean Weight (kg) at Age							
1978	0.707	1.310	2.461	3.469	4.336	5.787	7.374	8.492	11.785	13.200	2.983		
1979	0.889	1.494	2.149	4.211	4.888	7.178	9.183	10.313	11.699	12.625	3.923		
1980	0.836	1.460	2.468	3.668	5.647	6.676	8.390	9.089	8.432	15.400	3.368		
1981	0.882	1.495	2.358	3.415	5.213	7.222	8.565	9.888	14.170	18.565	3.446		
1982	0.765	1.402	2.664	3.834	5.352	6.511	9.363	9.897	12.503	16.723	2.946		
1983	0.971	1.490	2.377	3.309	4.637	6.393	7.964	10.286	11.227	14.554	2.836		
1984	1.053	1.635	2.451	3.619	5.083	6.582	8.909	10.104	11.303	15.356	3.756		
1985	0.907	1.418	2.086	3.887	5.087	6.412	8.097	10.236	11.418	13.494	2.822		
1986	0.929	1.475	2.447	3.660	5.603	7.191	8.915	9.955	12.687	14.104	3.161		
1987	0.726	1.481	2.495	4.187	5.810	7.726	8.949	10.013	11.414	15.000	2.584		
1988	0.786	1.520	2.359	3.511	5.401	6.647	8.776	9.987	11.143	15.298	3.062		
1989	-	1.617	2.269	3.772	5.396	6.694	8.222	10.718	11.665	17.111	3.235		
1990	0.831	1.560	2.462	3.522	4.892	6.333	8.456	10.648	12.580	14.526	2.891		
1991	1.114	1.627	2.548	3.420	4.769	5.891	7.410	10.520	9.686	15.373	3.456		
						Total Commercial Landings Mean Length (cm) at Age							
1978	39.5	50.0	60.8	67.9	72.7	80.4	80.2	93.1	103.4	106.5	64.1		
1979	44.7	52.2	57.7	73.2	76.8	87.5	95.3	99.5	103.4	106.4	69.6		
1980	43.8	51.8	61.2	69.7	80.9	86.0	92.4	93.8	92.4	114.6	65.6		
1981	44.4	52.2	60.2	68.4	78.2	88.0	93.5	97.5	110.3	119.5	65.6		
1982	42.2	51.2	62.4	70.5	79.1	84.3	96.0	97.4	105.8	115.0	61.9		
1983	45.5	52.3	60.4	67.0	75.3	84.4	90.7	99.1	101.9	111.4	62.4		
1984	47.2	54.0	61.5	69.8	77.8	85.5	94.4	98.6	102.3	112.8	68.6		
1985	44.9	51.1	57.5	71.4	78.0	84.3	91.3	98.8	102.3	108.2	61.1		
1986	45.0	51.9	61.1	69.2	80.7	87.7	94.4	98.0	105.9	108.4	64.3		
1987	40.7	51.8	61.2	73.0	81.8	90.1	94.5	98.2	102.5	111.2	59.7		
1988	40.8	52.8	60.4	68.5	79.5	85.3	93.6	97.7	101.5	111.2	64.1		
1989	-	53.8	60.0	70.4	79.2	85.2	91.7	100.3	103.2	113.3	65.7		
1990	41.7	53.5	61.0	68.7	76.6	83.2	92.1	100.2	106.0	110.8	62.9		
1991	47.7	53.6	62.2	67.7	75.8	80.9	87.8	99.4	95.9	113.9	67.0		

Table E5. Mean weight at age (kg) at the beginning of the year (January 1) for Georges Bank and South cod stock (NAFO Division 5Z and Subarea 6), 1978-1992. Values derived from catch mean weight at age data (mid-year) using procedures described by Rivard (1980).

	Year														
Age	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
1	0.486	0.694	0.625	0.700	0.548	0.748	0.907	0.711	0.736	0.502	0.548	0.583	0.594	1.067	0.659
2	1.023	1.028	1.139	1.118	1.112	1.068	1.260	1.222	1.157	1.173	1.050	1.127	1.123	1.163	1.163
3	1.881	1.678	1.920	1.855	1.996	1.826	1.911	1.847	1.863	1.918	1.869	1.857	1.995	1.994	2.277
4	2.922	3.219	2.808	2.903	3.007	2.969	2.933	3.087	2.763	3.201	2.960	2.983	2.827	2.902	3.256
5	3.370	4.118	4.876	4.373	4.275	4.216	4.101	4.291	4.667	4.611	4.755	4.353	4.296	4.098	4.031
6	4.594	5.579	5.712	6.386	5.826	5.849	5.525	5.709	6.048	6.579	6.214	6.013	5.846	5.368	5.549
7	6.235	7.290	7.760	7.562	8.223	7.201	7.547	7.300	7.561	8.022	8.234	7.393	7.524	6.850	6.465
8	7.235	8.721	9.136	9.108	9.207	9.814	8.970	9.549	8.978	9.448	9.454	9.699	9.357	9.432	8.015
9	10.004	9.967	9.325	11.349	11.119	10.541	10.783	10.741	11.396	10.660	10.563	10.793	11.612	10.156	11.734
10+	13.200	12.625	15.400	18.565	16.723	14.554	15.356	13.494	14.104	15.000	15.298	17.111	14.526	15.373	15.373

applied to the quarterly market category numbers at length distributions to provide numbers at age. These values were summed over market categories and quarters to attain the annual U.S. landings at age matrix. Derivation of catch by quarter, rather than by month, was performed since not all months had at least two length frequency samples per market category (*i.e.*, minimum desired for monthly catch estimates).

For many of the length frequency samples, sample weights were also available. These were converted (x 1.17) to live weights and compared to the calculated weights from the length-weight equation. In most cases, the differences were small (<5%) implying that use of the length-weight equation to derive landings numbers imparted little, if any, bias to the catch calculations.

Canadian landings at age data for 1978 to 1991 were taken from Hunt and Buzeta (1992) and combined with the U.S. data to produce an overall landings at age matrix for the 1978 to 1991 period. The proportions of landings derived from the United States and Canada are indicated in Table E4.

Commercial landings in 1991 were dominated by the 1987 and 1988 year classes. Together, these two cohorts accounted for 60% of the landings by number and 52% by weight. The 1988 year class was much more dominant in the U.S. fishery than in the Canadian fishery; the 1988 cohort accounted for 37% of the U.S. landings in number, but only 15% of the Canadian landings. The 1987 year class dominated the 1991 Canadian landings (35% by number; 32% by weight), with the 1985 and 1986 cohorts being the next most important in terms of weight and numbers, respectively.

Mean Weights at Age

Mean weights at-age in the landings for ages 1 to 10+ during 1978 to 1991 are given in Table E4 and, based on landings patterns, are considered mid-year values. Although no consistent trends in size or weight at age are evident over the 14-year time series, mean weights in 1990 and 1991 for age groups 2 and 3 were among the highest on record, while mean weights for age groups 4 to 6 in 1990-1991 were near the lowest on record. Both the United States and Canadian landings exhibited these patterns, although the changes are more pronounced in the Canadian data.

Mean weights at age for calculating stock biomass at the beginning of the year are provided in Table E5. These values were derived from the catch mean weights at age data (Table E4) using the procedures described by Rivard (1980).

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial Catch Rates

United States commercial LPUE indices (landings per unit effort, expressed in metric tons landed per day fished) were calculated, by tonnage class (Class 2 = 5 to 50 GRT; Class 3 = 51 to 150 GRT; Class 4 = 151 to 500 GRT), from otter trawl trips landing cod from Georges Bank (Subdivision 5Ze). Indices were derived based on all trips landing cod, and for directed trips in which cod comprised 50% or more of the total trip catch

Table E6. U.S. commercial landings (L)[1], days fished (DF), and landings per day fished (L/DF), by vessel tonnage class (Class 2 = 2 to 50 GRT; Class 3 = 51 to 150 GRT; Class 4 = 151-500 GRT), of Atlantic cod for otter trawl trips catching cod from Georges Bank (NAFO Division 5Ze), 1965-1991. Data are also provided for otter trawl trips in which cod composed 50% or more of the total trip catch by weight ('directed trips').

	Class 2			Class 3			Class 4			Totals	
Year	L	DF	L/DF	L	DF	L/DF	L	DF	L/DF	L	L/DF[3]
					ALL TRIPS						
1965	487	1661	0.29	5201	9719	0.54	4351	4175	1.04	10039	0.74
1966	386	1555	0.25	4754	10505	0.45	4731	4510	1.05	9871	0.73
1967	437	1069	0.41	5292	8570	0.62	4519	3789	1.19	10248	0.86
1968	321	570	0.56	6861	8534	0.80	4903	3397	1.44	12085	1.05
1969	433	500	0.87	7942	7953	1.00	4819	2783	1.73	13194	1.26
1970	508	535	0.95	6729	8296	0.81	4033	2218	1.82	11270	1.18
1971	563	681	0.83	7652	8808	0.87	4215	2195	1.92	12430	1.22
1972	524	721	0.73	6382	9257	0.69	3274	1766	1.85	10180	1.07
1973	322	550	0.59	7814	8668	0.90	4295	1701	2.52	12431	1.45
1974	585	617	0.95	8222	9438	0.87	5266	2097	2.51	14073	1.49
1975	509	534	0.95	7029	8684	0.81	4527	2085	2.17	12065	1.33
1976	421	474	0.89	7861	7791	1.01	3969	1469	2.70	12251	1.55
1977	850	607	1.40	13250	9492	1.40	4423	1472	3.00	18523	1.78
1978	1165	715	1.63	14853	9411	1.58	4829	1551	3.11	20847	1.94
1979	956	658	1.45	18377	9924	1.85	7116	2507	2.84	26449	2.10
1980	1062	882	1.20	21331	10961	1.95	10053	3726	2.70	32446	2.16
1981	1184	845	1.40	17025	10615	1.60	9404	3797	2.48	27613	1.89
1982	1406	695	2.02	20468	10717	1.91	11450	4296	2.67	33324	2.18
1983	835	429	1.95	17112	10694	1.60	13011	5116	2.54	30958	2.00
1984	375	427	0.88	14883	13605	1.09	10899	5746	1.90	26157	1.42
1985	370	453	0.82	12852	13629	0.94	8215	5501	1.49	21437	1.15
1986	150	233	0.64	8014	10442	0.77	5411	4354	1.24	13575	0.96
1987	108	220	0.49	8505	12067	0.70	5090	4770	1.07	13703	0.84
1988	100	233	0.43	12808	13791	0.93	7345	5799	1.27	20253	1.05
1989	144	320	0.45	10104	13151	0.77	7631	5274	1.45	17879	1.06
1990	141	260	0.54	11586	13567	0.85	9891	5552	1.78	21618	1.27
1991	89	239	0.37	9067	12843	0.71	8716	5472	1.59	17872	1.14
					50% Trips						
1965	18	8	2.25	353	86	4.10	819	159	5.15	1190	4.79
1966	7	<1	-	370	88	4.20	991	199	4.98	1368	4.74
1967	33	17	1.94	874	238	3.67	1464	318	4.60	2371	4.22
1968	16	3	5.33	1665	464	3.59	1442	328	4.40	3123	3.97
1969	73	9	8.11	2612	773	3.38	1475	359	4.11	4160	3.72
1970	164	25	6.56	1695	534	3.17	1739	388	4.48	3598	3.96
1971	117	15	7.80	2232	721	3.10	2163	494	4.38	4512	3.84
1972	152	54	2.81	2137	716	2.98	1879	445	4.22	4168	3.53
1973	52	16	3.25	3242	820	3.95	3010	486	6.19	6304	5.01
1974	259	119	2.18	3707	1115	3.32	3899	703	5.55	7865	4.39
1975	246	85	2.89	2678	842	3.18	3128	585	5.35	6052	4.29
1976	159	66	2.41	3665	1089	3.37	2664	464	5.74	6488	4.32
1977	502	120	4.18	6595	1342	4.91	2899	373	7.77	9996	5.70
1978	846	215	3.93	6554	1644	3.99	2427	330	7.35	9827	4.81
1979	612	168	3.64	9714	2558	3.80	4270	840	5.08	14596	4.17
1980	644	196	3.29	11727	2909	4.03	5616	1067	5.26	17987	4.39
1981	766	153	5.01	9414	2591	3.63	4312	953	4.52	14492	3.97
1982	1046	212	4.93	14724	3631	4.06	7791	1521	5.12	23561	4.45
1983	566	130	4.35	11884	3033	3.92	8795	1872	4.70	21245	4.25
1984	140	55	2.55	9156	3454	2.65	6620	1918	3.45	15916	2.98
1985	184	65	2.83	8725	4346	2.01	6053	2330	2.60	14962	2.26
1986	58	18	3.22	5258	2969	1.77	3755	1406	2.67	9071	2.15
1987	36	18	2.00	5743	3874	1.48	3354	1781	1.88	9133	1.63
1988	37	22	1.68	9974	6457	1.54	5527	2731	2.02	15538	1.71
1989	66	56	1.18	7864	6023	1.31	6200	3083	2.01	14130	1.62
1990	61	16	3.81	8490	4965	1.71	8151	3204	2.54	16702	2.12
1991	27	12	2.25	6110	4358	1.40	6647	2633	2.52	12784	1.98

[1] **Metric tons, live weight.**

[2] **Days fished with trawl on bottom; derived by dividing hours fished with trawl on bottom by 24.**

[3] **Total L/DF was derived by weighting individual tonnage class L/DF values by the percentage of total landings for by each vessel class and summing over the three vessel class categories.**

Table E7. Percentage, within vessel tonnage class[1], of Atlantic cod otter trawl landings (L)[2], vessel trips (T), and effort (DF)[3] from Georges Bank (NAFO Division 5Ze) accounted for by otter-trawl trips in which cod composed 50% or more of the total trip catch by weight ('directed trips'), 1965-1991.

Year	Class2			Class3			Class4			Totals		
	L	T	DF	L	T	DF	L	T	DF	L	T	DF
1965	3.7	1.0	0.5	6.8	1.9	0.9	18.8	5.3	3.8	11.9	2.4	1.6
1966	1.8	0.1	<0.1	7.8	1.4	0.8	20.9	6.5	4.4	13.9	2.2	1.7
1967	7.6	1.3	1.6	16.5	4.0	2.8	32.4	11.5	8.4	23.1	4.9	4.3
1968	5.0	1.0	0.5	24.3	5.9	5.4	29.4	12.3	9.7	25.8	6.5	6.4
1969	16.9	5.2	1.8	32.9	10.0	9.7	30.6	13.8	12.9	31.5	10.3	10.2
1970	32.3	10.4	4.7	25.2	7.3	6.4	43.1	19.5	17.5	31.9	9.7	8.6
1971	20.8	6.9	2.2	29.2	8.3	8.2	51.3	24.2	22.5	36.3	10.3	10.5
1972	29.0	8.8	7.5	33.5	9.7	7.7	57.4	25.2	25.2	40.9	11.5	10.3
1973	16.1	3.4	2.9	41.5	10.7	9.5	70.1	31.4	28.6	50.7	12.9	12.1
1974	44.3	11.1	19.3	45.1	13.9	11.8	74.0	37.8	33.5	55.9	17.3	15.9
1975	48.3	10.6	15.9	38.1	12.3	9.7	69.1	32.8	28.1	50.2	15.7	13.4
1976	37.8	11.1	13.9	46.6	16.9	14.0	67.1	35.1	31.6	53.0	19.1	16.6
1977	59.1	15.5	19.8	49.8	18.9	14.1	65.5	29.2	25.3	54.0	19.8	15.9
1978	72.6	22.0	30.1	44.1	22.6	17.5	50.3	28.1	21.3	47.1	23.2	18.7
1979	64.0	21.0	25.5	52.9	28.0	25.8	60.0	35.4	33.5	55.2	28.7	27.2
1980	60.6	21.1	22.2	55.0	26.9	26.5	55.9	34.5	28.6	55.4	27.7	26.8
1981	64.7	21.1	18.1	55.3	26.0	24.4	45.9	27.3	25.1	52.5	25.6	24.2
1982	74.4	23.9	30.5	71.9	34.1	33.9	68.0	38.8	35.4	70.7	33.7	34.1
1983	67.8	19.5	30.3	69.4	29.1	28.4	67.6	38.9	36.6	68.6	30.6	31.0
1984	37.3	7.0	12.9	61.5	25.9	25.4	60.7	35.2	33.4	60.8	26.4	27.4
1985	49.7	8.7	14.3	67.9	29.8	31.9	73.7	41.9	42.4	69.8	30.9	34.4
1986	38.7	7.9	7.7	65.6	27.6	28.4	69.4	32.5	32.3	66.8	27.2	29.2
1987	33.3	3.5	8.2	67.5	29.1	32.1	65.9	36.3	37.3	66.6	29.1	33.3
1988	37.0	5.4	9.9	77.9	43.3	46.8	75.2	45.9	47.1	76.7	41.8	46.5
1989	45.8	8.7	17.5	77.8	43.0	45.8	81.2	56.8	58.5	79.0	44.2	48.9
1990	43.3	8.5	6.2	73.3	37.2	36.6	82.4	56.0	57.7	77.3	40.8	42.2
1991	30.3	7.9	5.0	67.4	34.8	33.9	76.3	52.7	48.1	71.5	38.8	37.7

[1] **Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT.**
[2] **Metric tons, live weight.**
[3] **Effort expressed as days fished with trawl on bottom; derived by dividing hours fished with trawl on bottom by 24.**

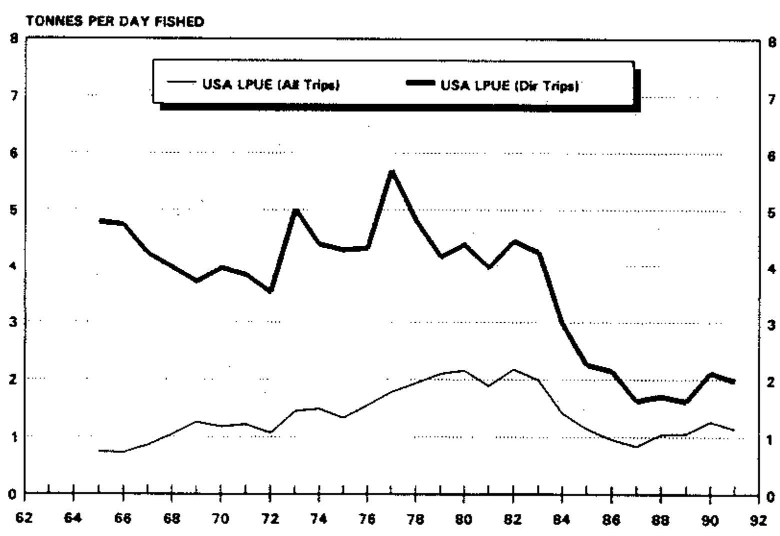


Figure E2. Trends in U.S. commercial LPUE (landings per day fished) of Georges Bank cod, 1965-1991. Data are based on all otter trawl trips in which cod were caught (All Trips) and on otter trawl trips in which cod composed 50% or more of the trip catch by weight (Directed Trips).

by weight (Table E6). Directed trips have accounted for more than 50% (and as high as 79%) of U.S. Georges Bank otter trawl landings of cod since 1973 (Table E7). In 1991, directed trips accounted for 72% of the U.S. landings. In the past four years (1988 to 1991), the U.S. fishery for cod has become highly directed (*i.e.*, nearly 75% of the U.S. otter trawl landings of cod are taken in "directed trips").

Since 1970, both total and directed U.S. LPUE indices have generally exhibited similar trends (Table E6; Figure E2). LPUE values for Class 3 and 4 vessels (which account for more than 95% of the U.S. otter trawl landings of Georges Bank cod) generally increased during the early 1970s, leveled off during the mid-1970s, and then sharply increased attaining peak levels in the late 1970s. Subsequently, LPUE indices trended downward until 1988 when both total and directed indices increased. In 1990, LPUE values again increased, but both LPUE indices declined slightly in 1991. Taken at face value, the 1990 to 1991 LPUE indices suggest that the exploitable stock biomass of cod during the past two years was higher than during 1987 to 1989. Canadian LPUE indices are not considered to be reliable indicators of stock abundance (Hunt 1990), and have not be used in any of recent Canadian assessments of the Georges Bank cod stock (Hunt and Buzeta 1992).

In terms of calculated effort (total landings/total U.S. LPUE index), both total and U.S. fishing effort peaked at record-high levels in 1988, declined in 1989, and have since stabilized at a level about 10% less than the 1988 peak (Table E8).

Fishing effort was standardized by applying a five-factor (year, month, tonnage class, area, and depth) general linear model (GLM) to log LPUE data derived for all otter trawl trips taking cod from 1978 through 1991 (Table E9). The model accounted for just over 30% of the total sum of squares, although all five factors were highly significant. Retransformed log year coefficients were multiplied by the 1978 base year LPUE (from Table E6) and divided into the annual U.S. landings (from Table E8) to derive effort values. However, the model may not account for all changes in catchability due to increases in technology. Both series of U.S. effort estimates (Table E8 and Table E9) show the same trends over time with peak U.S. effort occurring in 1985 followed by a decline in 1986 and 1987. Although effort in both series increased in 1988, the GLM standardized series indicates that effort stabilized during 1989 to 1991 while the calculated series indicates that effort declined by about 5% per year during the 1989 to 1991 period (Figure E3).

Table E8. Total and U.S. commercial landings, U.S. landings per unit of effort indices (LPUE, all cod trips), and derived effort indices for Georges Bank cod, 1965-1991

Year	Total Landings (mt)	USA Landings (mt)	USA LPUE Index (All Cod Trips)	Total Calculated Days Fished	USA Calculated Days Fished
1965	38333	11410	0.745	51483	15324
1966	53134	11990	0.730	72811	16430
1967	36752	13157	0.862	42616	15256
1968	43136	15279	1.053	40954	14506
1969	37939	16782	1.262	30054	13294
1970	25652	14899	1.178	21781	12650
1971	28179	16178	1.224	23018	13215
1972	25059	13406	1.065	23527	12586
1973	28923	16202	1.452	19924	11161
1974	27331	18377	1.487	18380	12358
1975	25008	16017	1.326	18857	12077
1976	19926	14906	1.553	12827	9596
1977	27367	21138	1.782	15357	11862
1978	35357	26579	1.937	18252	13720
1979	38623	32645	2.102	18375	15531
1980	48116	40053	2.158	22298	18562
1981	42348	33849	1.891	22393	17899
1982	57157	39333	2.176	26270	18078
1983	48886	36756	2.005	24388	18337
1984	38678	32915	1.424	27152	23106
1985	37271	26828	1.149	32446	23355
1986	25901	17490	0.956	27096	18386
1987	30880	19035	0.836	36947	22775
1988	39242	26310	1.051	37344	25037
1989	33098	25097	1.058	31294	23729
1990	42503	28193	1.273	33375	22138
1991	37630	24175	1.137	33082	21253

The two methods were used for computing fishing effort, so it is not surprising that each had slightly different results. The GLM method accounts for spatial and seasonal effects, as well as tonnage class differences. The "calculated effort" approach does not explicitly consider these factors and hence may be more sensitive to changes in fleet directivity. The increased directivity of the U.S. fishery to high levels during 1988 to 1991 probably inflates the "all cod trips" U.S. LPUE indices in the most recent years because a greater proportion of the total cod landings are currently represented by directed trips. Hence, the calculated U.S. effort values for 1988 to 1991 should probably be considered as underestimates.

Research Vessel Survey Indices

The methods used to conduct the fall and spring surveys are described by Azarovitz (1981).

Table E9. GLM for CPUE for Georges Bank cod modeled as a function of year, month, vessel tonnage class, fishing area, and depth effects, with no interactions.

GEORGES BANK COD EFFORT (DAYS) STANDARDIZATION 10:36 FRIDAY, OCTOBER 23, 1992 2
STANDARD - Year 78: MONTH 5: TC 33: AREA 521: DEPTH 3
(USING ALL UNSUMMED DATA - FROM PRE_GLM.SAS)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LCPE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	45	49957.83577372	1110.17412830	562.45	0.0	0.312117	19.6532
ERROR	55782	110103.17800285	1.97381195		ROOT MSE		LCPE MEAN
CORRECTED TOTAL	55827	160061.01377657			1.40492418		7.14857344

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE II SS	F VALUE	PR > F
YEAR	13	4753.28877099	185.24	0.0	13	7943.75989068	309.58	0.0
MONTH	11	846.54360028	38.99	0.0	11	3917.53334270	180.43	0.0
TC2	9	19681.46960262	1107.92	0.0	9	5311.02855096	298.97	0.0
AREA	8	20598.75046064	1304.50	0.0	8	24067.57642021	1524.18	0.0
DEPTH	4	4077.78333920	516.49	0.0	4	4077.78333920	516.49	0.0

SOURCE	DF	TYPE III SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
YEAR	13	7943.75989068	309.58	0.0	13	7943.75989068	309.58	0.0
MONTH	11	3917.53334270	180.43	0.0	11	3917.53334270	180.43	0.0
TC2	9	5311.02855096	298.97	0.0	9	5311.02855096	298.97	0.0
AREA	8	24067.57642021	1524.18	0.0	8	24067.57642021	1524.18	0.0
DEPTH	4	4077.78333920	516.49	0.0	4	4077.78333920	516.49	0.0

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE	Year	Re-transformed Year Coefficient	Standardized Effor (days)
INTERCEPT		8.47668849 B	230.65	0.0	0.03675098	78	1.00	13721.73
YEAR	79	-0.24666151 B	-7.03	0.0001	0.03510957	79	0.781888	21554.72
	80	-0.18381651 B	-5.43	0.0001	0.03386445	80	0.832563	24836.39
	81	-0.40052670 B	-11.75	0.0001	0.03408595	81	0.670354	26068.25
	82	-0.27825784 B	-8.38	0.0001	0.03320579	82	0.757518	26806.17
	83	-0.56183385 B	-16.92	0.0	0.03319935	83	0.570479	33262.81
	84	-0.68682862 B	-21.03	0.0	0.03265615	84	0.503437	33753.52
	85	-1.00859176 B	-30.85	0.0	0.03269802	85	0.364928	37953.48
	86	-1.26184553 B	-36.22	0.0	0.03484087	86	0.283302	31872.13
	87	-1.22838045 B	-36.73	0.0	0.03344061	87	0.29293	33547.42
	88	-0.96205248 B	-29.26	0.0	0.03287729	88	0.382315	35527.9
	89	-1.03306492 B	-30.56	0.0	0.03380827	89	0.35612	36382.81
	90	-0.91841279 B	-27.57	0.0	0.03331370	90	0.399375	36444.43
	91	-1.09679253 B	-32.06	0.0	0.03421058	91	0.334137	37351.89
	78	0.00000000 B	.	.	.			

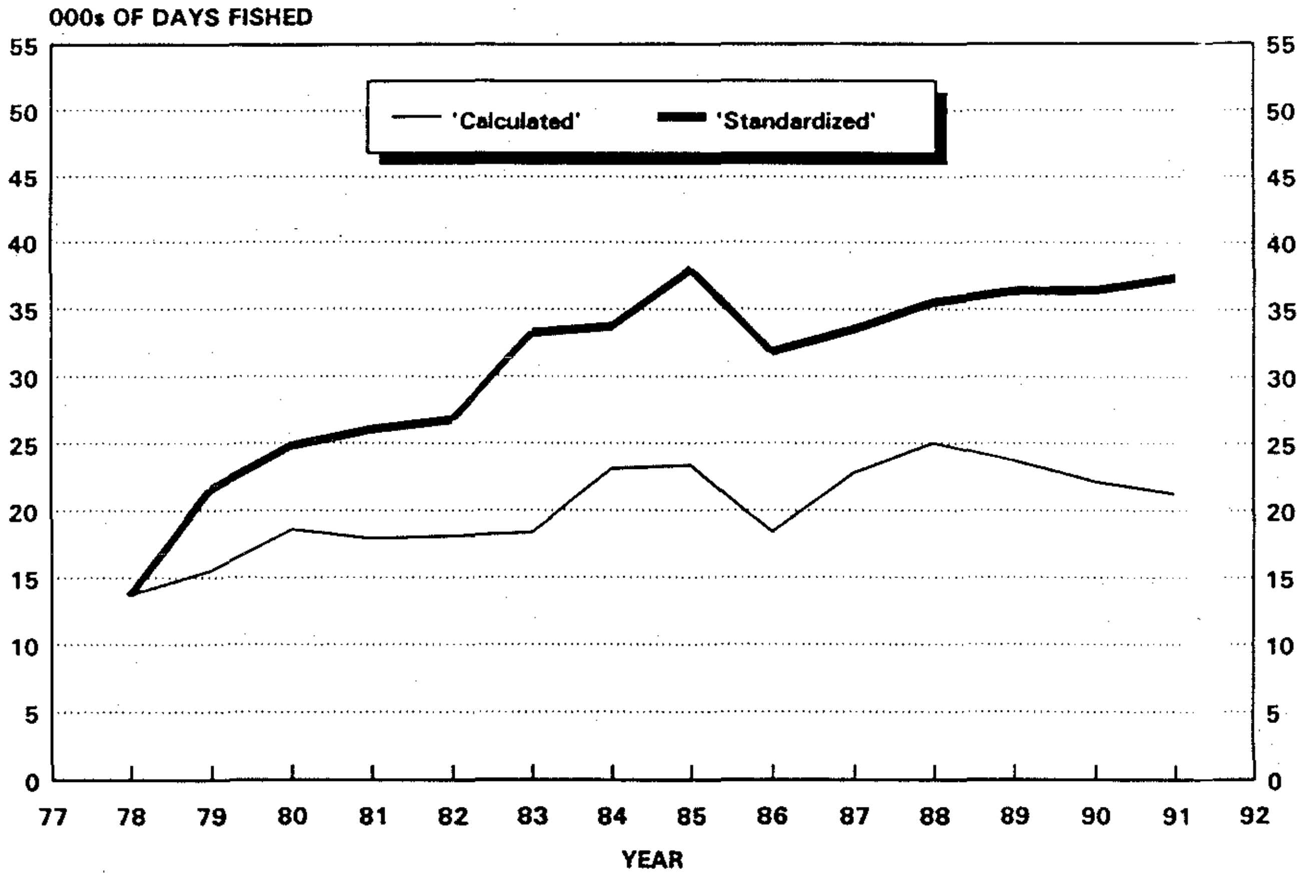


Figure E3. Trends in calculated and standardized U.S. fishing effort for Georges Bank cod, 1978-1991.

As in the previous assessment, adjustments were made to the NEFSC survey catch per tow data for cod to account for the fishing power differences between the two research vessels used in the survey time series (*R/V Albatross IV* and *R/V Delaware II*) and for the differences in catchability between the BMV and polyvalent doors. All of the survey data have now been standardized to *Albatross IV*, polyvalent door equivalents (Tables E10 and E11).

NEFSC spring and autumn offshore catch per tow indices for Georges Bank cod have exhibited similar trends, both in abundance and biomass, during the survey time series (Table E10). Survey biomass indices were relatively low and stable during 1963 to 1971, fluctuated at a generally higher level between 1972 and 1981, but have since declined to record-low levels (Figure E4). Large increases in the number per tow indices in 1967, 1972-1973, 1976, 1978, 1981, 1985, and 1988-1989 (Table E10) reflect above average recruitment of the 1966, 1971, 1975, 1977, 1978, 1980, 1983, 1985, 1987 and 1988 year classes at ages 1 and 2 (Table E11; Figure E5).

MORTALITY

Natural Mortality

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

Total Mortality Estimates

Pooled estimates of instantaneous total mortality (Z) were calculated for seven time periods encompassed by the NEFSC autumn and spring offshore surveys: 1964-1967, 1968-1972, 1973-1976, 1977-1981, 1982-1984, 1985-1987, and 1988-1991 (Table E12). Total mortality was calculated from survey catch per tow at age data for fully recruited age groups (age 3+) by the $\log_e$ ratio of the pooled age 3+/age 4+ indices in the autumn surveys, and the pooled age 4+/age 5+ indices in the spring surveys. For example, the

Table E10. Standardized mean catch per tow in numbers and weight (kg) for Atlantic cod in NEFSC offshore spring and autumn research vessel bottom trawl surveys on Georges Bank (strata 13-25), 1963-1992[a,b,c]

	Spring		Autumn	
Year[a,b,c]	No/Tow	Wt/Tow	No/Tow	Wt/Tow
1963	-	-	4.37	17.8
1964	-	-	2.98	11.6
1965	-	-	4.25	11.7
1966	-	-	4.81	8.1
1967	-	-	10.38	13.6
1968	4.72	12.6	3.30	8.6
1969	4.64	17.8	2.20	8.0
1970	4.34	15.6	5.07	12.5
1971	3.39	14.2	3.19	9.9
1972	8.97	19.0	13.09	23.0
1973	18.68[d]	39.7 [d]	12.28	30.8
1974	14.75	36.4	3.49	8.2
1975	6.89	26.0	6.41	14.1
1976	7.06	18.6	10.44	17.7
1977	6.30	15.4	5.45	12.5
1978	12.31	31.2	8.59	23.3
1979	5.16	16.9	5.95	16.5
1980	7.75	24.9	2.91	6.7
1981	10.44	26.1	9.04	19.0
1982	8.20[e]	15.4 [e]	3.71	6.9
1983	7.70	24.0	3.64	6.5
1984	4.08	15.4	4.75	10.3
1985	6.94	21.5	2.43	3.5
1986	5.04	16.7	3.12	4.7
1987	3.26	10.3	2.33	4.4
1988	5.86	13.5	3.11	5.8
1989	4.80	10.8	4.78	4.6
1990	4.74	11.6	3.62[f]	7.1 [f]
1991	4.39	9.0	0.96	1.4
1992	2.67	7.5	1.87	3.0

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

[b] Spring surveys during 1981-1982 and 1989-1991 and autumn surveys during 1977-1981 and 1989-1991 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data to standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

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

[d] Excludes unusually high catch of 1894 cod (2558 kg) at Station 230 (Strata tow 20-4).

[e] Excludes unusually high catch of 1032 cod (4096 kg) at Station 323 (Strata tow 16-7).

[f] Excludes unusually high catch of 111 cod (504 kg) at Station 205 (Strata tow 23-4).

1982-1984 values were derived from:

Autumn:
ln (Σage 3+ for 1981-83/Σage 4+ for 1982-84)

Spring:
ln (Σage 4+ for 1982-84 /Σage 5+ for 1983-85)

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

The pooled estimates indicate that total mortality was high (0.73) during 1964 to 1967, declined significantly during 1968 to 1972 (0.34), increased to between 0.56 and 0.63 during 1973 to 1981, and peaked at record-high levels (0.68 to 1.10) during 1982 to 1987. Total mortality estimates for the most recent, 1988 to 1991, period (0.86) are lower than those for 1985 to 1987, but higher than in all other time periods. Values of Z derived from the spring surveys are generally lower than those calculated from the autumn data. Rather than selecting one survey series over the other, total mortality was calculated by taking a geometric mean of the spring and autumn estimates in each time period.

METHODOLOGY

Virtual Population Analysis

The ADAPT (Gavaris 1988, Conser and Powers 1990) calibration method was used to derive estimates of terminal F values in 1991. Several calibration formulations were evaluated. Age-disaggregated analyses were performed in each case.

The final ADAPT calibration was performed with the NEFSC spring and autumn abundance indices for ages 1 to 6 and U.S. commercial LPUE indices for ages 3 to 6. Due to the inordinate effect of high residuals in the converged period of the VPA on the stock size estimates in the terminal year, linear time-tapered downweighting was applied with zero weight given to all years prior to 1982. In addition, all indices were weighted according to the inverse of their variance. Stock sizes in 1992 were estimated for ages 1 to 6, providing estimates of F in 1991 for ages 1 to 5 (Table E13). F on ages 6 to 9 in 1991 were taken as the mean of F on ages 4 and 5 (the only fully recruited ages that were estimated directly) (Table E14). F for age 10+ in each year was taken as the

Table E11. Standardized stratified mean catch per tow at age (numbers) of Atlantic cod in NEFSC offshore spring and autumn bottom trawl surveys on Georges Bank, 1963-1992[a,b,c]

Year	Age Group 0	1	2	3	4	5	6	7	8	9	10+	Totals 0+	1+	2+	3+	4+	5+
Spring																	
1968	0.513	0.136	1.615	0.825	0.665	0.385	0.246	0.140	0.083	0.056	0.058	4.722	4.209	4.073	2.459	1.633	0.969
1969	0.000	0.123	0.546	1.780	0.888	0.451	0.326	0.215	0.128	0.072	0.112	4.641	4.641	4.518	3.972	2.192	1.304
1970	0.000	0.381	0.814	0.480	1.295	0.162	0.655	0.275	0.061	0.136	0.083	4.341	4.341	3.961	3.147	2.666	1.371
1971	0.000	0.207	0.819	0.502	0.223	0.585	0.142	0.351	0.304	0.080	0.175	3.388	3.388	3.181	2.362	1.860	1.636
1972	0.056	2.902	1.833	2.641	0.510	0.119	0.324	0.122	0.220	0.115	0.125	8.967	8.911	6.009	4.176	1.535	1.025
1973[d]	0.056	0.521	11.644	2.189	2.540	0.426	0.314	0.354	0.050	0.203	0.388	18.684	18.628	18.107	6.463	4.274	1.735
1974	0.000	0.446	4.557	5.972	0.761	2.003	0.440	0.101	0.257	0.034	0.175	14.747	14.747	14.301	9.744	3.772	3.011
1975	0.000	0.064	0.378	2.042	3.092	0.261	0.686	0.129	0.094	0.108	0.039	6.892	6.892	6.828	6.451	4.409	1.317
1976	0.111	1.301	1.922	0.944	0.691	1.572	0.164	0.262	0.036	0.000	0.055	7.057	6.947	5.646	3.724	2.780	2.089
1977	0.000	0.028	3.527	1.080	0.523	0.279	0.727	0.051	0.066	0.000	0.020	6.301	6.301	6.273	2.746	1.666	1.143
1978	3.312	0.376	0.187	5.530	0.969	0.778	0.144	0.713	0.051	0.142	0.109	12.312	9.000	8.624	8.436	2.906	1.938
1979	0.109	0.435	1.359	0.298	1.913	0.541	0.234	0.087	0.145	0.012	0.022	5.156	5.047	4.611	3.253	2.955	1.042
1980	0.105	0.039	2.265	2.688	0.209	1.482	0.597	0.192	0.031	0.030	0.111	7.749	7.644	7.605	5.340	2.652	2.443
1981	0.301	2.303	1.916	2.779	1.667	0.100	0.870	0.269	0.144	0.000	0.085	10.435	10.134	7.831	5.914	3.135	1.468
1982[e]	0.148	0.488	3.395	1.406	1.295	1.039	0.016	0.298	0.064	0.016	0.035	8.200	8.053	7.564	4.169	2.763	1.468
1983	0.081	0.329	1.967	3.048	0.766	0.697	0.431	0.055	0.192	0.000	0.136	7.702	7.621	7.291	5.324	2.276	1.510
1984	0.000	0.402	0.462	0.797	1.161	0.446	0.424	0.223	0.000	0.156	0.008	4.079	4.079	3.677	3.215	2.418	1.257
1985	0.244	0.098	2.633	0.757	1.058	1.328	0.270	0.203	0.172	0.025	0.150	6.938	6.694	6.596	3.963	3.206	2.148
1986	0.092	0.871	0.423	1.824	0.360	0.545	0.633	0.063	0.119	0.095	0.015	5.040	4.948	4.077	3.654	1.830	1.470
1987	0.000	0.034	1.612	0.403	0.752	0.060	0.179	0.147	0.016	0.027	0.025	3.255	3.255	3.221	1.609	1.206	0.454
1988	0.180	0.700	0.684	3.115	0.413	0.645	0.045	0.020	0.052	0.000	0.007	5.861	5.681	4.981	4.297	1.182	0.769
1989	0.000	0.380	1.334	0.743	1.532	0.228	0.344	0.051	0.040	0.081	0.067	4.798	4.798	4.418	3.084	2.342	0.810
1990	0.041	0.194	0.926	1.707	0.653	0.896	0.125	0.139	0.013	0.016	0.027	4.736	4.695	4.501	3.575	1.868	1.215
1991	0.195	1.068	0.511	0.807	0.883	0.464	0.336	0.039	0.041	0.000	0.045	4.389	4.194	3.126	2.615	1.808	0.925
1992	0.000	0.123	1.255	0.470	0.163	0.270	0.144	0.161	0.020	0.037	0.028	2.671	2.671	2.548	1.293	0.823	0.660
Autumn																	
1963	0.019	0.719	0.778	0.920	0.897	0.354	0.326	0.175	0.103	0.014	0.069	4.374	4.356	3.636	2.858	1.938	1.041
1964	0.009	0.640	0.699	0.588	0.538	0.145	0.136	0.062	0.050	0.030	0.083	2.980	2.970	2.331	1.632	1.044	0.505
1965	0.173	1.299	0.998	0.707	0.484	0.167	0.179	0.112	0.081	0.023	0.023	4.248	4.075	2.775	1.777	1.070	0.587
1966	1.025	1.693	1.000	0.515	0.264	0.100	0.095	0.062	0.039	0.002	0.017	4.811	3.786	2.094	1.094	0.579	0.315
1967	0.072	7.596	1.334	0.523	0.406	0.133	0.133	0.055	0.051	0.012	0.070	10.383	10.312	2.716	1.382	0.860	0.454
1968	0.070	0.314	1.611	0.783	0.271	0.073	0.067	0.027	0.023	0.008	0.048	3.296	3.226	2.913	1.301	0.518	0.246
1969	0.000	0.343	0.622	0.626	0.331	0.094	0.061	0.019	0.023	0.022	0.059	2.200	2.200	1.856	1.234	0.608	0.278
1970	0.413	1.688	1.353	0.524	0.694	0.153	0.000	0.033	0.055	0.055	0.098	5.065	4.652	2.964	1.611	1.087	0.393
1971	0.399	0.602	0.632	0.390	0.301	0.476	0.183	0.042	0.089	0.000	0.075	3.189	2.789	2.187	1.555	1.165	0.864
1972	0.947	7.443	1.295	1.771	0.399	0.243	0.571	0.109	0.204	0.022	0.083	13.087	12.140	4.697	3.402	1.632	1.232
1973	0.203	1.749	6.070	1.182	2.012	0.211	0.226	0.175	0.062	0.139	0.251	12.280	12.078	10.329	4.259	3.076	1.064
1974	0.462	0.409	0.654	1.521	0.164	0.114	0.103	0.000	0.069	0.000	0.000	3.494	3.033	2.624	1.970	0.449	0.285
1975	2.377	0.994	0.421	0.624	1.685	0.112	0.156	0.000	0.000	0.000	0.037	6.407	4.029	3.036	2.615	1.991	0.306
1976	0.000	6.148	2.072	0.763	0.278	0.739	0.055	0.270	0.039	0.053	0.020	10.436	10.436	4.288	2.217	1.454	1.176
1977	0.152	0.237	3.424	0.702	0.251	0.174	0.396	0.007	0.027	0.000	0.078	5.447	5.296	5.059	1.635	0.933	0.682
1978	0.396	1.855	0.255	4.180	0.964	0.335	0.165	0.344	0.051	0.030	0.014	8.587	8.192	6.337	6.082	1.902	0.938
1979	0.118	1.619	1.717	0.224	1.613	0.296	0.180	0.036	0.115	0.007	0.022	5.948	5.829	4.210	2.493	2.269	0.656
1980	0.280	0.818	0.564	0.774	0.076	0.251	0.053	0.067	0.025	0.000	0.000	2.908	2.629	1.810	1.246	0.472	0.396
1981	0.261	3.525	2.250	1.559	0.589	0.054	0.579	0.057	0.064	0.018	0.083	9.040	8.778	5.254	3.003	1.444	0.855
1982	0.320	0.875	2.094	0.220	0.069	0.097	0.000	0.016	0.000	0.000	0.022	3.711	3.391	2.516	0.423	0.203	0.134
1983	1.031	0.647	1.022	0.796	0.055	0.047	0.003	0.000	0.012	0.000	0.023	3.636	2.605	1.958	0.936	0.140	0.086
1984	0.186	2.496	0.101	0.886	0.870	0.017	0.062	0.039	0.006	0.039	0.044	4.747	4.561	2.065	1.964	1.078	0.207
1985	1.084	0.220	0.803	0.103	0.115	0.101	0.000	0.000	0.004	0.000	0.000	2.430	1.346	1.126	0.323	0.220	0.105
1986	0.096	2.280	0.153	0.382	0.010	0.061	0.090	0.016	0.000	0.008	0.028	3.124	3.028	0.748	0.595	0.213	0.203
1987	0.204	0.414	1.353	0.112	0.195	0.028	0.012	0.000	0.000	0.007	0.000	2.325	2.121	1.707	0.354	0.242	0.047
1988	0.549	0.903	0.433	0.909	0.091	0.178	0.000	0.011	0.039	0.000	0.000	3.113	2.564	1.661	1.228	0.319	0.228
1989	0.262	2.738	1.030	0.183	0.499	0.055	0.008	0.004	0.000	0.000	0.000	4.780	4.518	1.780	0.750	0.566	0.067
1990[f]	0.156	0.362	1.534	1.164	0.209	0.145	0.012	0.013	0.000	0.000	0.022	3.617	3.460	3.098	1.564	0.401	0.192
1991	0.040	0.415	0.168	0.277	0.028	0.029	0.000	0.000	0.000	0.000	0.000	0.957	0.917	0.502	0.334	0.057	0.029
1992												1.870					

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

[b] Spring surveys during 1981-1982 and 1989-1991 and autumn surveys during 1977-1981 and 1989-1991 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data to standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

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

[d] Excludes unusually high catch of 1894 cod (2558 kg) at Station 230 (Strata tow 20-4).

[e] Excludes unusually high catch of 1032 cod (4096 kg) at Station 323 (Strata tow 16-7).

[f] Excludes unusually high catch of 111 cod (504 kg) at Station 205 (Strata tow 23-4).

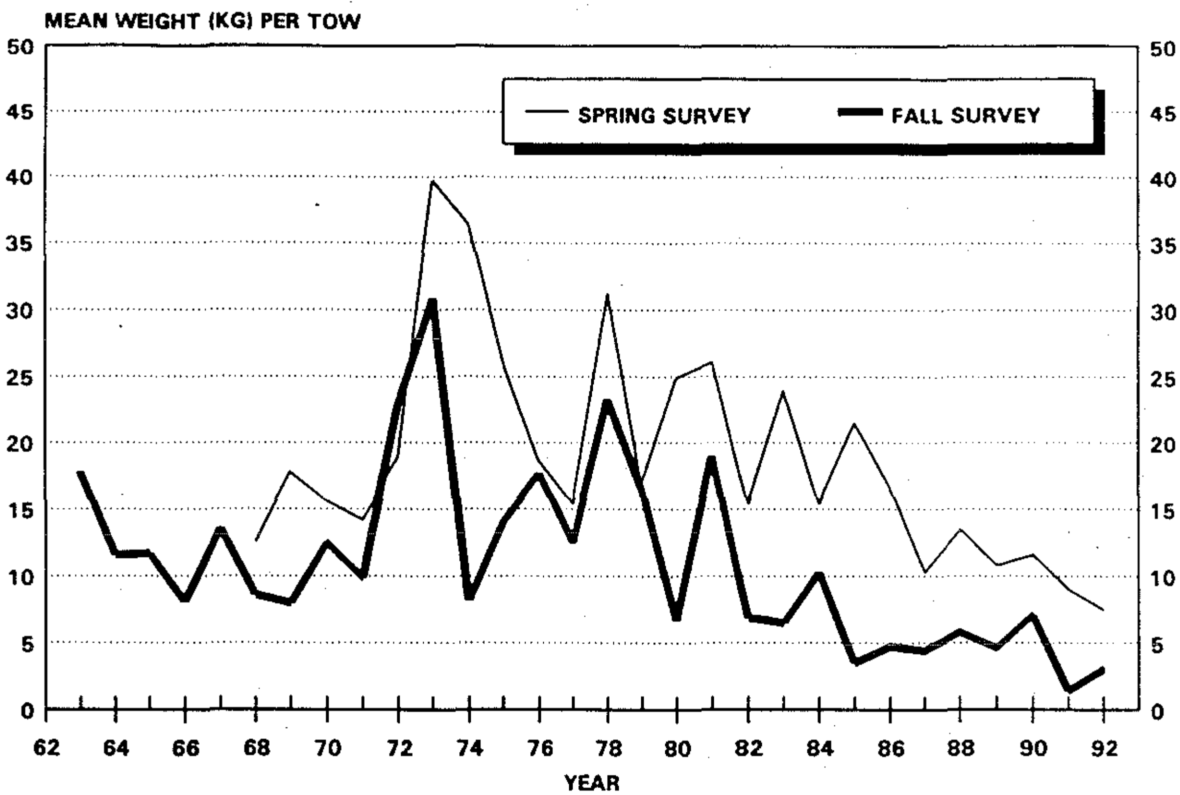


Figure E4. Standardized stratified mean catch per tow (kg) of Atlantic cod in the NEFSC spring and autumn research vessel bottom trawl surveys on Georges Bank, 1963-1992.

F estimated for the oldest true age (age 9). Spawning stock biomass was calculated at spawning time [March 1] by applying maturity ogives for 1978 to 1981, 1982 to 1985, and 1986 to 1991, derived from O'Brien (1990) (Table E13).

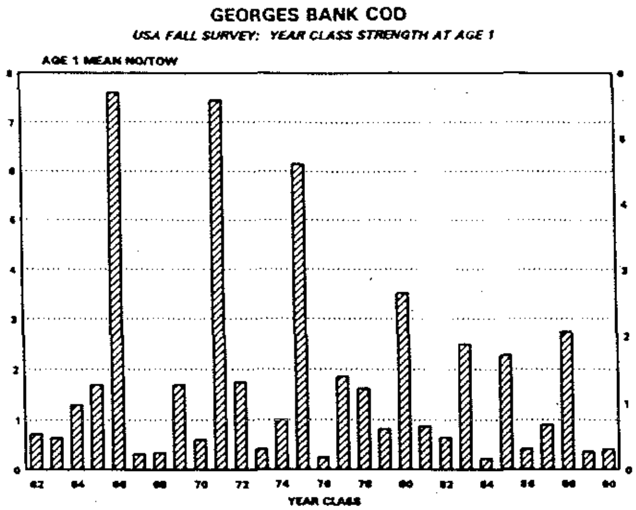
Yield and Spawning Stock Biomass per Recruit

Yield-per-recruit, total stock biomass per recruit, and spawning stock biomass per recruit analyses were performed using the Thompson and Bell (1934) method. To obtain the exploitation pattern for these analyses, geometric mean F at age was first computed over the period 1986 to 1990 from the final converged VPA results. A smoothed exploitation pattern was then obtained by dividing the F at age by the mean unweighted F for ages 4 to 8. Mean weights at age for application to yield per recruit were computed as the arithmetic average of landings mean weights at age (Table E4) over the 1989 to 1991 period. Mean weights at age for application to SSB per recruit were computed as the arithmetic average of stock mean weights at age over the period 1989 to 1991. The maturation ogive was taken from O'Brien *et al.* (in press).

Projections for 1993 and 1994

Because the 1992 catch could be estimated from preliminary landings, an estimate of F_{1992} was calculated by using those landings and the 1992 stock size for ages 2 to 10+ from the VPA. F_{1992} was derived by iterating the projection model until the accumulated catch over ages equalled the projected 1992 landings (approximately 28,100 t). The resulting F_{1992} (ages 4 to 8, unweighted) was 0.87.

Landings and stock sizes were projected through 1993 at various levels of F and recruitment assuming F_{1992} = 0.87. The exploitation pattern, mean weights and maturation rates were as described earlier for the yield and SSB per recruit analyses (Tables E15 and E16). Survivors



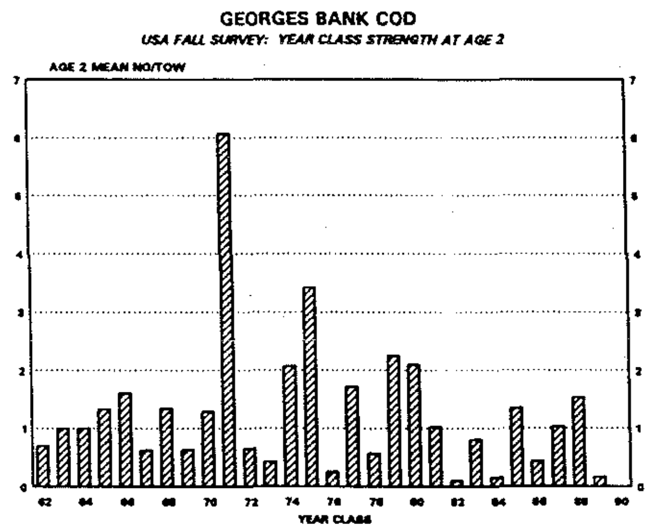


Figure E5. Relative year class strength of Georges Bank cod at age 1 and age 2 based on standardized catch per tow (number) indices from NEFSC autumn research vessel bottom trawl surveys, 1963-1991.

at ages 2 to 10+, taken from the final tuned VPA, were used to start the projections in 1992. Age 1 recruitment for the 1991 year class in 1992 was set at 10 million fish (*i.e.*, half the long-term mean) in light of imprecise survey-based predictors indicating below-average recruitment. Recruitment of the 1992 and 1993 year classes in 1993 and 1994 was taken as the geometric mean of the 1977 to 1988 year classes as estimated by the VPA (20.7 million).

Projections for 1993 and 1994 are provided over the range of observed recruitments (*e.g.*, low, mean, high) (Table E16). The F options used in the forecasts included: F_{max}, $F_{20\%}$, 90% of F_{SQ}, and F_{SQ}.

Table E12. Estimates of instantaneous total mortality (Z) and fishing mortality (F)[1] for Georges Bank cod sotck for seven time periods, 1964-1991, derived from NEFSC offshore spring and autumn bottom trawl survey data[2]

Time Period	Spring		Autumn		Geometric Mean	
	Z	F	Z	F	Z	F
1964-67	-	-	0.73	0.53	0.73	0.53
1968-72	0.34	0.14	0.35	0.15	0.34	0.14
1973-76	0.70	0.50	0.56	0.36	0.63	0.43
1977-81	0.47	0.27	0.67	0.47	0.56	0.36
1982-84	0.42	0.22	1.12	0.92	0.68	0.48
1985-87	0.84	0.64	1.45	1.25	1.10	0.90
1988-91	0.69	0.49	1.07	0.87	0.86	0.66

[1] Instantaneous natural mortality (M) assumed to be 0.20.
[2] Estimates derived from:
Georges Bank spring:
ln (Σage 4+ for year i to j/Σage 5+ for years i+1 to j+1).
Georges Bank autumn:
ln(Σ age 3+ for years i-1 to j-1/Σage 4+ for years i to j).

ASSESSMENT RESULTS

Virtual Population Analysis

Mean (ages 4 to 8, unweighted) fishing mortality in 1991 was estimated at 1.07 (Table E13, Figure E6), sharply higher than in 1989 (0.64) and 1990 (0.73). This 47% increase in F to a record-high level is inconsistent with 3% increase in standardized fishing effort indicated by the GLM (Table E9). However, it is possible that changes occurred within the fishery that were not captured by the standardization procedure and these may have contributed to the higher than expected F in 1991. Nonetheless, F_{1991} and the preliminary estimate of F_{1992} continue the trend of increasing F observed in recent years (Figure E6). At the same time F has trended upward, spawning stock biomass has generally decreased despite strong year classes in 1980, 1983, and 1985 (Figure E7). The 1985 cohort contributed to increases in SSB in 1987 and 1988, but due to recent below-average recruitment and high rates of exploitation, SSB declined from 68,400 t in 1990 to 54,700 t in 1991. In contrast to the 1991 assessment (NEFSC 1992), the strength of the 1990 year class is now estimated to be 18.3 million at age 1 in 1991 (vs 27.7 million).

Age 1 stock size in 1992 is poorly estimated (CV = 0.82). CVs on other ages ranged from 0.20 to 0.35. Correlations between estimated parameters were generally low (< 0.10), although some values as high as 0.25 to 0.34 between age 1 stock sizes and qs.

Estimates of Precision

To evaluate the precision of the final estimates, a bootstrap procedure (Efron 1982) having 200 iterations was used to generate distributions of the 1991 fishing mortality rate and spawning stock biomass. This method accounts for random variation in the calibration data (survey and LPUE). Figures E8 and E9, respectively, show the distribution of these bootstrap estimates and a cumulative probability curve. The distribution of the estimates indicates the amount of uncertainty by visually depicting variability. The cumulative probability can be used to evaluate the risk of making a decision based on the estimated value. It expresses the probability (chance) that the fishing mortality rate was greater than a given level when measurement errors are considered. Regarding spawning stock biomass, the cumulative plot indicates the probability that it was less than a given level. The precision and bias of the age-specific fishing mortality rates are presented in Table E14. Precision increases for 4+ aggregated ages compared to F estimates on individual ages.

The fully recruited fishing mortality for ages 4+ was reasonably well estimated (CV = 0.14). The distribution of 200 iterations of the aforementioned bootstrap method is presented in Figure E8. The mean bootstrap estimate of F (1.083) was slightly higher than the point estimate (1.072) from the VPA and ranged from 0.7 to 1.6. $F_{20\%}$ is much lower than the lowest bootstrap estimate and F_{1991} is almost certainly above the overfishing definition mortality rate. Fishing mortality for 1990 (0.73) and 1992 (0.87) fall within the lower range of these bootstrap estimates for 1991. Therefore, given the amount of precision associated with the 1991 estimate, the probability that the true F_{1991} is greater than fishing mortality in adjacent years is about 60%.

Although the abundance estimates of individual ages in 1992 had wider variances (CV = 0.20 to 0.82), the estimate of 1991 spawning stock biomass was robust (CV = 0.09). Two hundred bootstrap replications gave the distribution presented in Figure 9. The bootstrap mean (55,620 t) was slightly higher than the VPA point estimate (54,740) and ranged from 45,000 t to 72,500 t. Current spawning stock biomass is near the lowest observed in the time series (*i.e.*, near the record-low 1985 and 1986 SSBs).

Yield and Spawning Stock Biomass per Recruit

A smooth exploitation pattern was computed from the geometric mean Fs obtained from the 1986 to 1990 Fs at age from the VPA. The final exploitation pattern was as follows:

Age 1 0.0021, Age 2 0.3669,
Age 3 0.8145, Ages 4+ 1.00.

This pattern is similar to that obtained from the separable VPA and to that presented in the 1991 U.S. cod assessment, and was used in yield and SSB per recruit calculations.

Input data for the YPR and SSB/R analyses are listed in Table E15, and the results are presented in Table E15 and depicted in Figure E10. The results indicate that $F_{0.1}$ = 0.16, F_{max} = 0.29, and $F_{20\%}$ = 0.35. These values are nearly identical to those presented in the 1991 U.S. cod assessment (*i.e.*, $F_{0.1}$ = 0.16, F_{max} = 0.30, and $F_{20\%}$ = 0.36).

Projections for 1993 and 1994

Input values used in the projections are given in Table E16, and the results are presented in Table E16 and illustrated in Figure E11. Assuming average recruitment in 1993 and 1994, continued fishing at the 1992 level (F = 0.87) will result in projected landings of about 24,500 t in 1993, and will lead to further reductions in SSB to record-low levels (from 41,000 t in 1992 to about 37,500 t in 1993 and 1994). A rebuilding of SSB in 1994 to the below-average 1991 level (54,700 t) would require F in 1993 to be reduced to F_{max} (0.29).

If recruitment in 1993 and 1994 is below average and $F_{93} = F_{92}$, SSB in 1994 will be much lower than 37,000 t. Conversely, even if recruitment in <u>both</u> 1993 and 1994 is the highest on record (*i.e.*, 42.4 million fish at age 1), SSB in 1994 will only be rebuilt back to the low 1991 level unless F in 1993 in markedly lower than in 1992.

Table E13. Estimates of instantaneous fishing mortality (F), beginning stock sizes (millions of fish), and mean stock biomass (mt) for Georges Bank cod estimated from virtual population analysis (VPA) calibrated using the ADAPT procedure, 1978-1991

Fishing Mortality

Age	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0.0001	0.0016	0.0049	0.0007	0.0212	0.0125	0.0033	0.0176	0.0041	0.0018	0.0005	0.0000	0.0009	0.0031
2	0.1073	0.1019	0.2449	0.2439	0.3543	0.4131	0.2062	0.3846	0.2412	0.2730	0.1440	0.1376	0.4244	0.2856
3	0.4087	0.3811	0.4845	0.4761	0.5149	0.6129	0.6912	0.7396	0.5237	0.4359	0.5304	0.4314	0.5714	0.5512
4	0.3861	0.4903	0.3781	0.3885	0.6769	0.7514	0.5576	0.6659	0.5734	0.4941	0.6545	0.5844	0.5523	0.9481
5	0.3839	0.3609	0.4562	0.3062	0.6361	0.5931	0.6309	0.7239	0.5201	0.4020	0.8006	0.4608	0.7517	1.1961
6	0.1379	0.3789	0.6372	0.5624	0.7408	0.5470	0.6610	0.7481	0.5650	0.5752	0.7521	0.7799	0.6824	1.0721
7	0.3091	0.1122	0.7913	0.5479	0.5822	0.6037	0.7441	0.6605	0.3384	0.5099	0.9333	0.6168	1.0594	1.0721
8	1.4851	0.3922	0.1789	0.5229	0.6073	0.4109	0.6328	0.9113	0.4740	0.4403	0.8984	0.6998	0.6113	1.0721
9[1]	0.3606	0.4385	0.4897	0.4426	0.6623	0.6522	0.6007	0.7230	0.5459	0.4957	0.7684	0.6002	0.6720	1.0721
10+[2]	0.3606	0.4385	0.4897	0.4426	0.6623	0.6522	0.6007	0.7230	0.5459	0.4957	0.7684	0.6002	0.6720	1.0721
4+	0.3043[3]	0.3622	0.4886	0.4618	0.6508	0.5930	0.6379	0.7388	0.5028	0.4862	0.8012	0.6236	0.7215	1.0721

Stock Numbers (Jan 1) in thousands

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	27710.1	23507.3	20090.9	41376.4	17461.0	9589.3	27257.7	8499.0	42391.2	15905.3	21929.0
2	4267.7	22685.3	19215.4	16368.5	33851.7	13996.4	7753.3	22243.4	6837.2	34565.8	12998.7
3	25524.0	3138.5	16773.4	12314.7	10501.4	19447.0	7581.1	5165.3	12396.9	4398.0	21538.2
4	7946.0	13886.6	1755.2	8459.5	6263.1	5137.7	8626.2	3109.6	2018.4	6011.9	2328.6
5	2877.5	4421.8	6962.8	984.6	4696.5	2606.0	1984.3	4044.0	1308.1	931.4	3003.0
6	1124.2	1604.9	2523.6	3612.3	593.5	2035.5	1179.0	864.4	1605.3	636.7	510.1
7	1434.0	801.9	899.5	1092.5	1685.3	231.7	964.4	498.4	334.9	747.0	293.3
8	67.2	861.9	586.8	333.8	517.2	770.9	103.7	375.2	210.8	195.5	367.3
9	146.0	12.5	476.7	401.7	162.0	230.7	418.5	45.1	123.5	107.4	103.0
10+	54.3	148.1	28.3	189.9	187.0	148.1	292.7	205.5	75.4	67.2	95.5
1+	71150.8	71068.5	69312.6	85134.0	75918.8	54193.2	56160.8	45049.9	67301.7	63566.3	63166.7

	1989	1990	1991	1992
1	19289.3	8294.0	18309.1	3274.6
2	17944.9	15792.7	6784.2	14943.2
3	9215.5	12802.7	8458.3	4174.6
4	10375.4	4901.1	5919.8	3990.7
5	990.8	4735.1	2309.7	1878.0
6	1104.1	511.7	1828.2	571.8
7	196.9	414.4	211.7	512.3
8	94.4	87.0	117.6	59.3
9	122.4	38.4	38.6	33.0
10+	43.6	84.7	37.9	21.5
1+	59377.3	47661.9	44015.3	29458.8

[1] For all years prior to the terminal year of 1991, back-calculated stock sizes for ages 4-9 were used to estimate total mortality (Z) for age 9.
[2] F on age 10+ is assumed to be equivalent to F on age 9.
[3] Arithmetic average of ages 4-7 which removes the influence of the anomalously high F on age 8 in 1978.

SOURCES OF UNCERTAINTY

This assessment updated the previous assessment conducted during SAW13. Because the recommended improvements will take considerable time, some of the same sources of uncertainty identified in the last assessment remain. The omission of commercial fishery discards and recreational catch estimates from the catch at age matrix continue to introduce uncertainty into the results. Commercial fishery discard mortality may be a significant component of total mortality in certain years, but estimates were not available for this assessment. Omission of commercial discards and recreational catches results in an underestimation of the total fishery removals from the stock.

The relatively low precision (CV = 0.82) of VPA estimates of age 1 stock size makes predictions of landings and SSB difficult for a fishery that harvests a significant proportion (partial recruitment = 0.37) of age 2 fish. Survey methods that yield more precise indices of recruiting year class strength are necessary to predict future landings at a given fishing mortality rate with greater certainty.

The VPA utilized tuning indices based on standardized otter trawl LPUE. Although a large

Table E13.Continued

Spawning Stock Biomass (m) at the Beginning of the Spawning Season (March 1)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	912.4	1103.8	849.7	1959.5	1199.2	900.4	3108.3	757.8	6933.9	1774.8	2673.1
2	1410.0	7537.9	6911.1	5778.0	16130.9	6340.9	4290.9	11588.5	4702.3	23980.9	8252.2
3	33841.6	3728.1	22413.4	15922.7	15626.3	26041.7	10489.6	6851.1	18625.8	6905.4	32435.1
4	20217.4	38250.5	4296.1	21373.8	15782.5	12626.3	21629.8	8058.8	4804.5	16797.8	5857.4
5	8797.7	16582.8	30435.3	3957.1	17466.4	9627.2	7084.7	14874.6	5414.3	3884.9	12086.5
6	4881.5	8129.6	12538.0	20315.5	2955.8	10512.6	5642.6	4213.4	8546.7	3681.2	2704.9
7	8213.7	5548.9	5917.4	7293.0	12164.3	1459.0	6218.3	3152.2	2314.8	5323.5	1999.1
8	366.9	6809.3	5033.0	2695.3	4161.9	6832.5	809.7	2976.8	1691.4	1660.0	2891.1
9	1330.5	111.6	3962.5	4096.0	1560.2	2109.6	3948.5	415.3	1242.7	1019.8	926.2
10+	653.3	1681.0	388.0	3167.0	2708.9	1869.9	3933.2	2377.3	938.9	897.5	1243.0
1+	80625.0	89483.5	92744.6	86557.9	89756.5	78320.1	67155.7	55266.0	55215.3	65925.9	71068.5

	1989	1990	1991
1	2499.9	1095.6	4344.7
2	12238.9	10232.2	4656.1
3	14018.0	20440.9	13539.5
4	26612.8	11977.4	13901.8
5	3862.7	17356.3	7500.7
6	5638.2	2582.0	7939.0
7	1270.2	2527.5	1173.2
8	788.2	711.0	897.4
9	1156.6	385.5	317.5
10+	652.5	1064.5	471.5
1+	68737.8	68372.9	54741.3

The above SSB by age (a) and year (y) are calculated following the algorithm used int he NEFSC projection program, *i.e.*:
SSB(a,y) = W(a,y) X P(a,y) X (N(a,y) X exp[-Z(a,y)]

where Z(a,y) = 0.1667 X F(a,y)
N(a,y) = Jan 1 stock size estimates (males and females)
P(a,y) = proportion mature (generally females)
W(a,y) = weight at age at the beginning of the spawning season

The W(a,y) are assumed to be the same as the Jan 1 weights at age are calculated as geometric means in ADAPT from the mid-year weight at age estimates (from the catch) of the cohort in successive years.

Percent Mature

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	7	7	7	7	13	13	13	13	23	23	23	23	23	23
2	34	34	34	34	47	47	47	47	64	64	64	64	64	64
3	78	78	78	78	84	84	84	84	91	91	91	91	91	91
4	96	96	96	96	97	97	97	97	98	98	98	98	98	98
5	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	100	100	100	100	100	100	100	100	100
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100
10+	100	100	100	100	100	100	100	100	100	100	100	100	100	100

proportion of landings come from otter trawl effort, divergent patterns in F and effort where observed in 1991. Inconsistencies of this type may occur because of changes in effort that are not captured by the standardization procedure (*e.g.* changes in technology and shifts to other fishing methods), or because the standardization procedure itself is based on assumptions that may not be very robust.

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Table E14. Precision and bias estimates of the age-specific instantaneous fishing mortality rates (F) in 1991 for Georges Bank cod. ADAPT estimate is from the final consensus assessment run. Standard errors, coefficients of variation (C.V.) and bias estimates are derived from 200 bootstrap replications. Ages 4+ represent the fully-recruited portion of the stock.

AGE	ADAPT ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR ADAPT SOLN
1	3.144E-3	3.235E-3	1.029E-3	0.33
2	2.856E-1	2.869E-1	4.777E-2	0.17
3	5.512E-1	5.666E-1	1.213E-1	0.22
4	9.481E-1	9.675E-1	1.829E-1	0.19
5	1.196E0	1.199E0	2.355E-1	0.20
6	1.072E0	1.083E0	1.466E-1	0.14
7	1.072E0	1.083E0	1.466E-1	0.14
8	1.072E0	1.083E0	1.466E-1	0.14
9	1.072E0	1.083E0	1.466E-1	0.14
10+	1.072E0	1.083E0	1.466E-1	0.14
4+	1.072E0	1.083E0	1.466E-1	0.14

AGE	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	ADAPT EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1	9.102E-5	7.273E-5	2.90	3.053E-3	0.34
2	1.329E-3	3.378E-3	0.47	2.843E-1	0.17
3	1.546E-2	8.575E-3	2.80	5.357E-1	0.23
4	1.935E-2	1.294E-2	2.04	9.288E-1	0.20
5	3.049E-3	1.665E-2	0.25	1.193E0	0.20
6	1.120E-2	1.036E-2	1.04	1.061E0	0.14
7	1.120E-2	1.036E-2	1.04	1.061E0	0.14
8	1.120E-2	1.036E-2	1.04	1.061E0	0.14
9	1.120E-2	1.036E-2	1.04	1.061E0	0.14
10+	1.120E-2	1.036E-2	1.04	1.061E0	0.14
4+	1.120E-2	1.036E-2	1.04	1.061E0	0.14

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Table E15. Yield per recruit and spawning stock biomass per recruit analysis for Georges Bank cod

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
GEORGES BANK COD: Run Date: 9-12-1992; Time: 15:25:22.47

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 10
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> A:\CODGB92A.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights[1] Catch	Stock
1	.0021	1.0000	.2300	.973	.733
2	.3669	1.0000	.6400	1.601	1.138
3	.8145	1.0000	.9100	2.426	1.949
4	1.0000	1.0000	.9800	3.571	2.904
5	1.0000	1.0000	1.0000	5.019	4.249
6	1.0000	1.0000	1.0000	6.306	5.742
7	1.0000	1.0000	1.0000	8.029	7.256
8	1.0000	1.0000	1.0000	10.629	9.496
9	1.0000	1.0000	1.0000	11.310	10.854
10+	1.0000	1.0000	1.0000	15.670	15.670

[1]Mean of 1989-1991 catch and stock weights at age

Summary of Yield and SSB per Recruit Analysis for: GEORGES BANK COD

Slope of the Yield/Recruit Curve at F=0.00: --> 27.1476
F level at slope=1/10 of the above slope (F0.1): ---> .156
Yield/Recruit corresponding to F0.1: ---> 1.6470
F level to produce Maximum Yield/Recruit (Fmax): ---> .293
Yield/Recruit corresponding to Fmax: ---> 1.7815
F level at 20 % of Max Spawning Potential (F20): ---> .353
SSB/Recruit corresponding to F20: ----> 5.5206

Listing of Yield and SSB per Recruit Results for: GEORGES BANK COD

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	29.5940	4.2370	27.6088	100.00
	.070	.18277	1.17283	4.6068	19.0352	3.3279	17.2083	62.33
	.140	.29121	1.59602	4.0684	13.5735	2.7902	11.8613	42.96
$F_{0.1}$	.156	.31077	1.64697	3.9715	12.6732	2.6934	10.9833	39.78
	.210	.36336	1.74343	3.7113	10.4036	2.4337	8.7760	31.79
	.280	.41506	1.78065	3.4563	8.4114	2.1794	6.8477	24.80
F_{max}	.293	.42327	1.78147	3.4159	8.1185	2.1391	6.5651	23.78
	.350	.45408	1.77284	3.2645	7.0815	1.9882	5.5670	20.16
$F_{20\%}$	.353	.45559	1.77196	3.2571	7.0333	1.9808	5.5206	20.00
	.420	.48471	1.74735	3.1146	6.1499	1.8388	4.6740	16.93
	.490	.50947	1.71608	2.9939	5.4708	1.7185	4.0257	14.58
	.560	.52998	1.68416	2.8943	4.9588	1.6195	3.5390	12.82
	.630	.54729	1.65377	2.8106	4.5617	1.5362	3.1629	11.46
	.700	.56214	1.62568	2.7391	4.2461	1.4651	2.8650	10.38
	.770	.57505	1.60006	2.6773	3.9900	1.4036	2.6240	9.50
	.840	.58641	1.57682	2.6231	3.7783	1.3498	2.4254	8.78
	.910	.59649	1.55577	2.5751	3.6006	1.3022	2.2591	8.18
	.980	.60553	1.53668	2.5324	3.4493	1.2597	2.1181	7.67
	1.050	.61368	1.51932	2.4939	3.3189	1.2215	1.9968	7.23
	1.120	.62109	1.50351	2.4592	3.2055	1.1870	1.8916	6.85
	1.190	.62786	1.48905	2.4275	3.1058	1.1556	1.7993	6.52
	1.260	.63408	1.47579	2.3985	3.0174	1.1269	1.7177	6.22
	1.330	.63982	1.46359	2.3719	2.9385	1.1005	1.6451	5.96
	1.400	.64515	1.45235	2.3474	2.8677	1.0761	1.5800	5.72

Table E16. Stock and catch projections and input parameters for Georges Bank cod, 1992-1994

Input Parameters

Age	Stock Size in 1992	Fish Mortality Pattern	Proportion Mature	Average Weights Catch and Stock (kg)	
1	10000	0.0021	0.2300	0.973	0.733
2	14943	0.3669	0.6400	1.601	1.138
3	4175	0.8145	0.9100	2.426	1.949
4	3991	1.0000	0.9800	3.571	2.904
5	1878	1.0000	1.0000	5.019	4.249
6	572	1.0000	1.0000	6.306	5.742
7	512	1.0000	1.0000	8.029	7.256
8	59	1.0000	1.0000	10.629	9.496
9	33	1.0000	1.0000	11.310	10.854
10+	21	1.0000	1.0000	15.670	15.670

Forecasts

The forecasts for 1993 were performed assuming that total landings in 1992 would be 28,100 t. The fishing mortality needed to take the 1992 catch would be F(92) = 0.867.

Recruitment in 1993-94	1992			1993			1994
	F92	Landings	SSB	F93	Landings	SSB	SSB
MIN = 8300	0.867	28104	41066	F_{SQ} = 0.867	24465	35413	28822
	0.867	28104	41066	$F_{SQ-10\%}$ = 0.78	22702	35823	30685
	0.867	28104	41066	$F_{20\%}$ = 0.353	12048	37914	42488
	0.867	28104	41066	F_{max} = 0.293	10237	38218	44579
MEAN = 20661	0.867	28104	41066	F_{SQ} = 0.867	24485	37428	37584
	0.867	28104	41066	$F_{SQ-10\%}$ = 0.78	22720	37838	39484
	0.867	28104	41066	$F_{20\%}$ = 0.353	12056	39929	51474
	0.867	28104	41066	F_{max} = 0.293	10244	40233	53590
MAX = 42400	0.867	28104	41066	F_{SQ} = 0.867	24520	40972	52993
	0.867	28104	41066	$F_{SQ-10\%}$ = 0.78	22751	41382	54959
	0.867	28104	41066	$F_{20\%}$ = 0.353	12070	43473	67276
	0.867	28104	41066	F_{max} = 0.293	10255	43778	69439

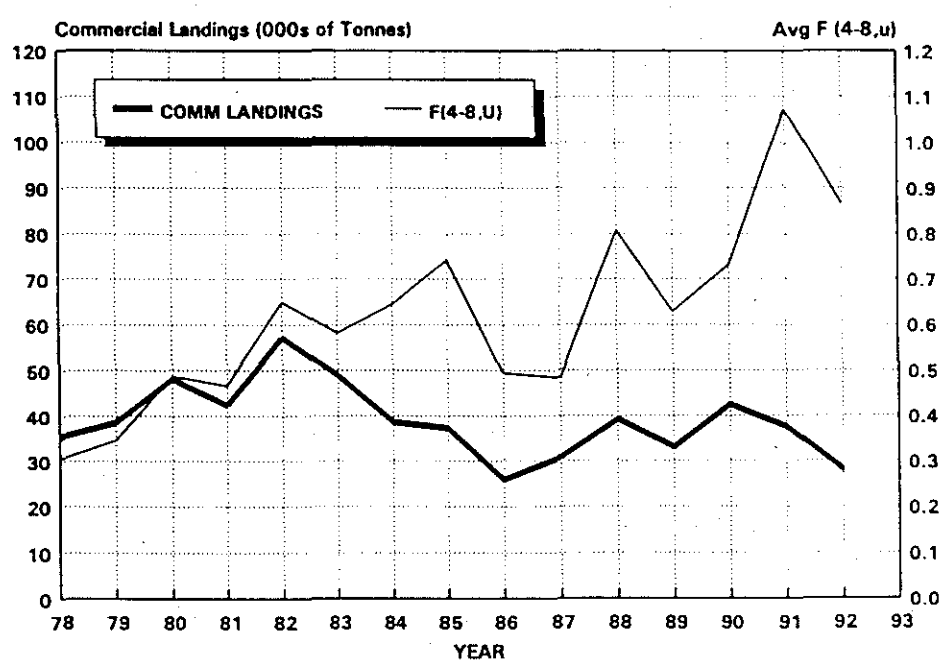

Figure E6. Trends in total commercial landings and fishing mortality for Georges Bank cod, 1978-1992.

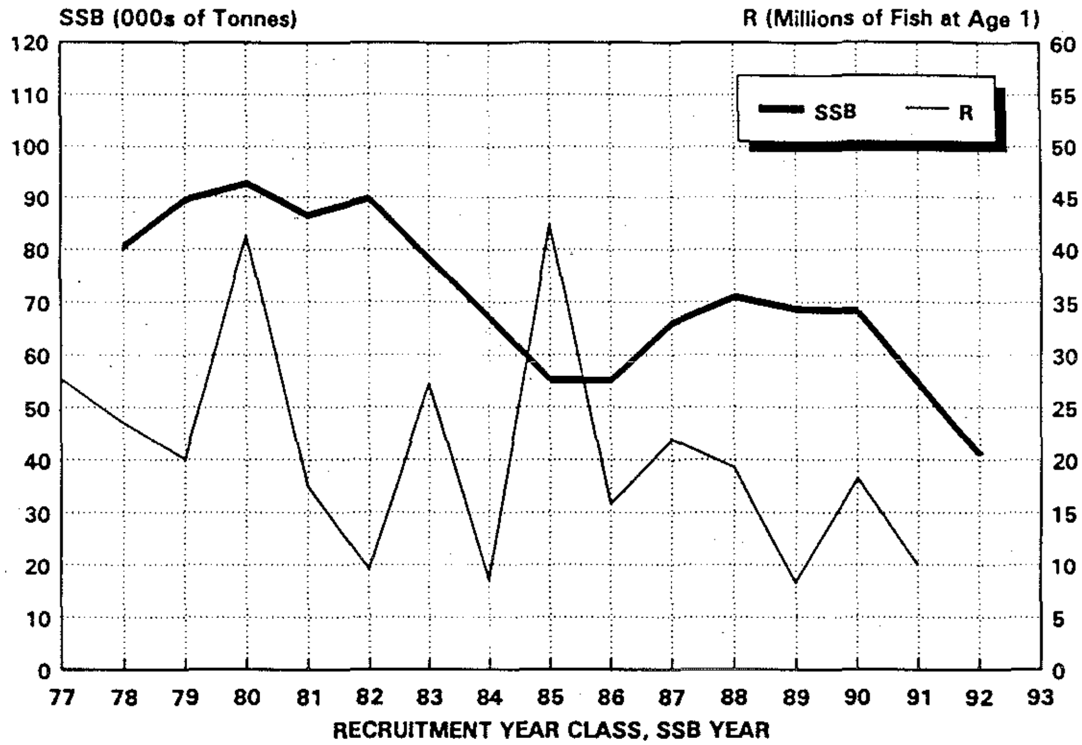

Figure E7. Trends in spawning stock biomass and recruitment for Georges Bank cod, 1977-1992.

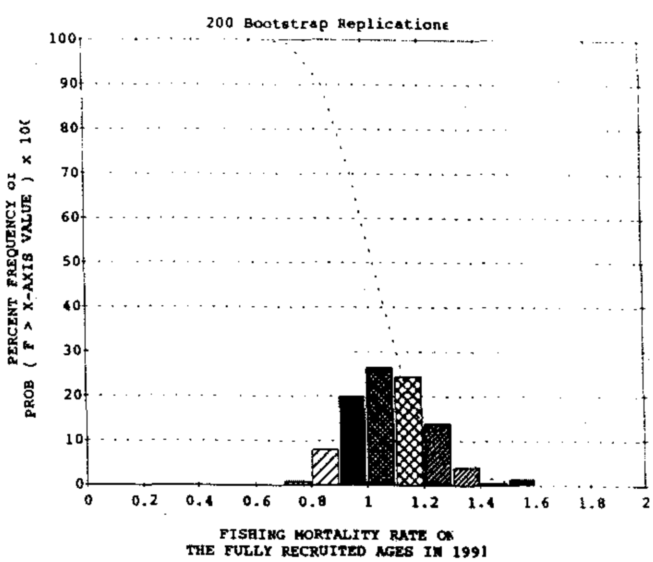

Figure E8. Precision of the estimates of the instantaneous rate of fishing mortality (F) on the fully recruited ages (Ages 4+) in 1991 for Georges Bank cod. The vertical bars display both the range of the estimator and the probability of individual values within that range. The dashed line gives the probability that F is greater than any selected value on the X axis. The precision estimates were derived from 200 bootstrap replications.

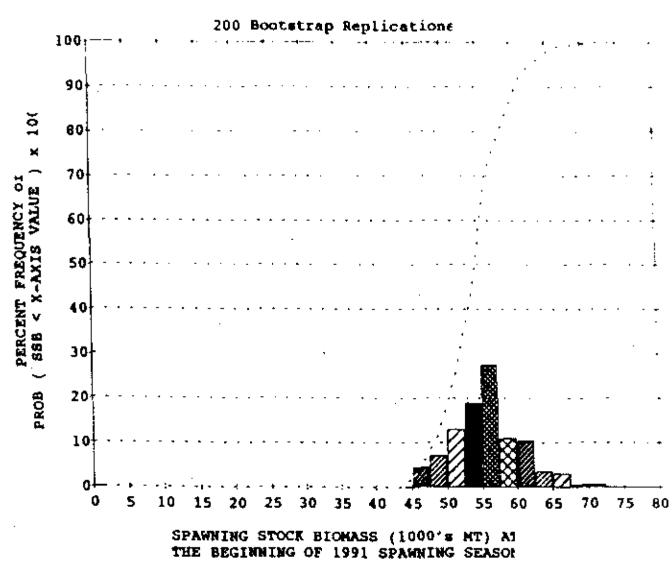

Figure E9. Precision of the estimates of spawning stock biomass at the beginning of the 1991 spawning season (March 1) for Georges Bank cod. The vertical bars display both the range of the estimator and the probability of individual values within that range. The dashed line gives the probability that SSBis less than any selected value on the X axis. The precision estimates were derived from 200 bootstrap replications.

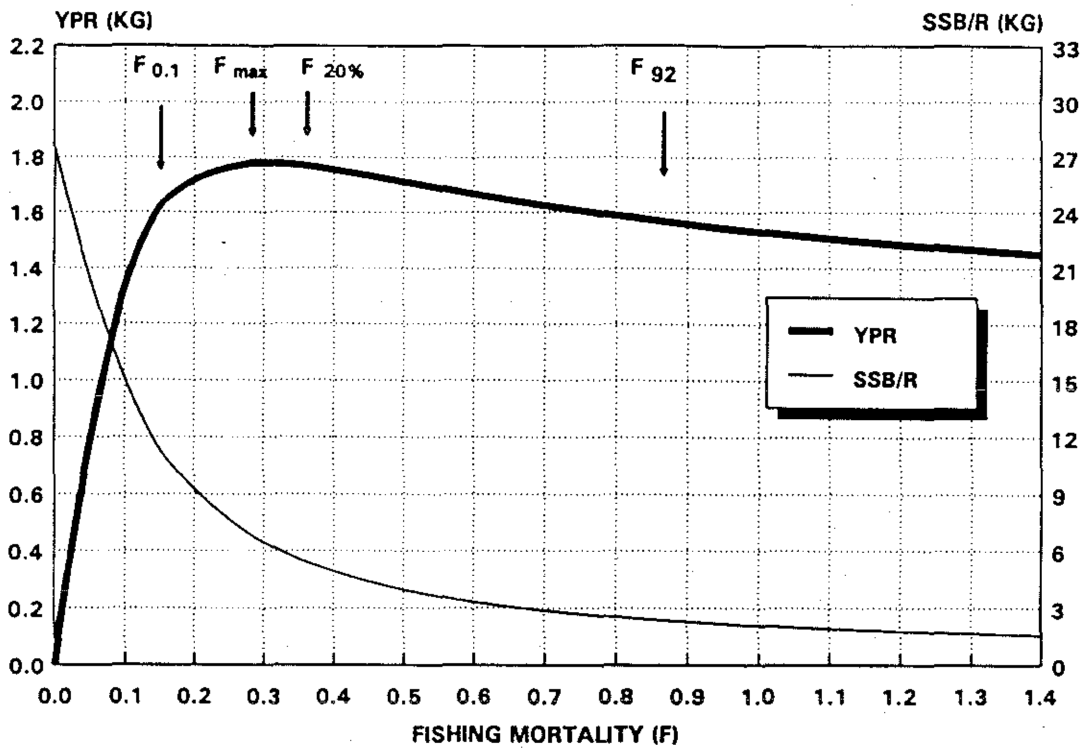

Figure E10. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for Georges Bank cod.

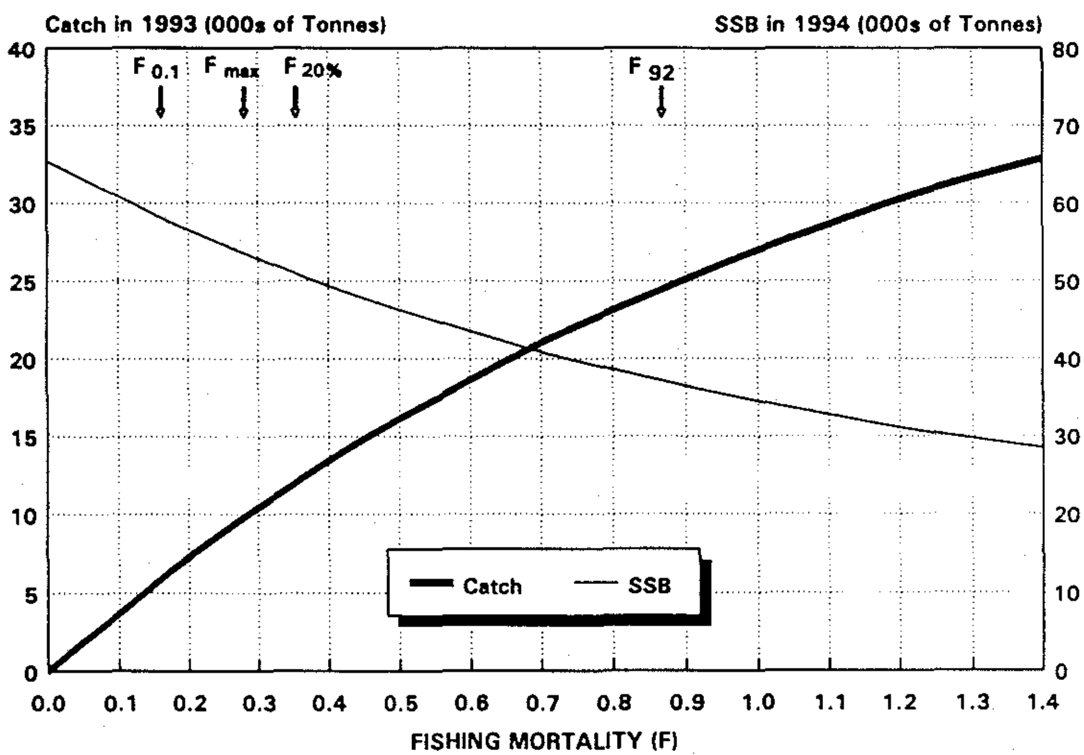

Figure E11. Predicted catches in 1993 and spawning stock biomasses in 1994 of Georges Bank cod over a range of fishing mortalities in 1993 from F=0 to F=1.4.

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GEORGES BANK COD RECOMMENDATIONS/RESEARCH NEEDS

RESEARCH RECOMMENDATIONS

1. Discards and recreational catches contribute to significant mortality of cod. Recreational landings have contributed to 5 to 10% of total landings. The procedures to calculate catch at age for these two sources are undetermined, but inclusion of these sources of removal would be useful in improving the assessment. The size or age composition of recreational catches is necessary to add these catches to the catch at age matrix.
2. The procedure for eliminating outliers in survey data and its influence on VPA tuning should be evaluated.
3. The current projection methods do not include all sources of uncertainty within the assessment. Future projection methods could include these sources by using a Monte Carlo approach for all input parameters, including current fishing mortality, natural mortality, starting stock conditions, as well as recruitment.
4. Other survey methods that would improve estimates of recruitment should be evaluated, *e.g.* fixed rather than random sampling stations.

TERMS OF REFERENCE FOR FUTURE ASSESSMENTS

1. Canadian survey data that began in 1986 may be useful in augmenting the current tuning indices. Future use of this additional data should be considered.
2. The present effort standardization uses the catch per effort for interviewed otter trawl trips to standardize effort for all commercial gears. This standardization procedure may not be effective in capturing changes in effort patterns for other gears. Due to this level of aggregation in the commercial tuning indices, similar problems are expected in future assessments. Standardization of effort for individual gears and ages should be conducted separately to calculate commercial catch per effort for VPA tuning. A better understanding of meaningful units of fixed gear fishing effort is needed, *e.g.* sink gill nets.
3. Studies should be undertaken to understand the possible changing relationship between effort and fishing mortality.

F. GEAR RESEARCH

INTRODUCTION

Management programs being proposed by the New England and Mid-Atlantic Fishery Management Councils include potential changes in regulated trawl mesh size and corresponding minimum fish lengths. These changes are proposed to address overfishing of New England groundfish and summer flounder. Regulated minimum trawl mesh sizes of 5.5 to 6 in. (140 to 152 mm) are either in force, or are being contemplated. There are, however, relatively few controlled mesh selection experiments with these mesh sizes, world-wide. As a result, the potential benefits accruing from mesh changes are to some degree uncertain. In addition, minimum fish lengths consistent with the goal of minimizing discarding of undersized fish resulting from the regulated mesh need to be computed.

The special topic for SAW 15 relating to gear studies was intended to bring together all relevant existing studies of mesh selection, particularly with respect to Atlantic cod and yellowtail flounder, and to recommend appropriate research directions for future mesh research. Three formal presentations were made to the SARC:
(1) an overview of existing mesh studies relevant to Atlantic cod and yellowtail flounder included research findings on the lengths at 50% selection (L-50%), as well as L-25 and L-75, when available. The experimental protocols of each study were reviewed, particularly since many factors other than cod-end mesh size have been shown to influence fish size selection.
(2) preliminary research results from mesh selection trials for yellowtail flounder, conducted by the University of Rhode Island in cooperation with the Northeast Regional Office of NMFS were reviewed;
(3) an overview of ongoing mesh selection experiments being conducted in Canada was presented. Based on these presentations and ensuing discussions, the SARC drew several conclusions regarding the utility of mesh studies conducted to date for providing management advice on mesh and minimum fish lengths, and recommended future research needs.

A REVIEW OF EXISTING MESH STUDIES FOR ATLANTIC COD AND YELLOWTAIL FLOUNDER

An overview of published mesh selectivity studies is given in Tables F1 to F4 and Figures F1-F3. These results include preliminary data resulting from ongoing yellowtail flounder studies being conducted by the University of Rhode Island (URI) and the NMFS Northeast Regional Office (NERO), which are described here. From each of the referenced studies, information regarding the L-50, L-25 and L-75 was extracted, as well as a description of the experimental protocol, including the mesh size being tested, its material, twine width, twine construction, method of estimating selection (covered cod-end, trouser trawl, alternate tow, *etc.*), numbers of tows observed, towing speed, and length selectivity characteristics. The selection range (SR) is defined as L-75 minus L25.

Some general conclusions regarding the selectivity of mesh can be drawn from these data:

- Several previous reviews have concluded that the selection factor (L-50• mesh size) increases with mesh size. Results reviewed herein indicate only a weak positive correlation. Differences among apparent selection factors among the studies are more related to differing experimental conditions other than mesh

- selection range generally increases with mesh size (Halliday and White 1989), but again the relationship is confounded with other experimental conditions of the various studies

- factors other than nominal mesh size can greatly influence selectivity, including:
  - Experimental design
    - Covered cod-ends retain smaller fish than observed in alternate tow experi ments
    - Twin-trawls are a very efficient design for detecting differences in length se lection
  - Trawl construction material
  - Tow duration
  - Rigging of experimental cod-ends
  - Mesh sizes in sections of the net other than the cod-end
  - Abundance of the experimental animal and associated bycatch in the net

RECENT SELECTION EXPERIMENTS FOR YELLOWTAIL FLOUNDER CONDUCTED BY URI/NERO

Preliminary results from recent selection experiments for yellowtail flounder were reviewed. These analyses are provisional, and additional work is currently being conducted. The objective of the project is to estimate L-50, L-25 and L-75 for 5.5 and 6 in. square and diamond mesh codends. To date, 31 experimental tows have been observed. The control net for these alternate tow experiments is a 4 in. (102 mm) mesh. Five tows per experimental mesh have been observed (4 meshes X 5 tows = 20, + 11 control tows). Each tow was 2 hours in duration.

Preliminary selection data for the experimental meshes are included in Figure F1 and Tables F1 and F2. Values of L-50 are generally consistent with the trends extrapolated from studies observing smaller experimental meshes. For diamond meshes, the selection ranges seem to be narrow, as compared with studies conducted in earlier years, when the yellowtail flounder population was more abundant, and composed of larger numbers of fish over the selection range. The conclusions from this research must be viewed as preliminary; several technical points were raised concerning the fitting of statistical models for estimating logistic selection curves from the data. In the absence of any other experimental data for these mesh sizes for yellowtail flounder, provisional values of L-50 from these results can be used by managers but information on the selection range (L-25, L-75) should be used with care, owing to the small amount of information regarding the shape of the tails of the selection ogives.

CANADIAN STUDIES OF MESH SELECTION

A number of studies of gear selection in the Canadian groundfishery have recently been completed, or are ongoing. These include the evaluation of 130, 140, and 155 mm mesh trawls and Scottish seines in the Gulf of St. Lawrence (Jalbert 1992, unpublished), and a biological and technological study of the effects of moving to higher trawl meshes for the Scotian shelf groundfish fishery (Halliday and White 1989).

Results of selection studies on Atlantic cod in the Gulf of St. Lawrence are included in Figure F2 and Table F3. Estimates of L-50 for 140 mm (5.5 in.) mesh are virtually identical to selection estimates currently being used by the New England Council to evaluate selectivity. Data from 155 mm trials, however, are thought to give an underestimate of L-50, owing to the lack of large cod in the Gulf. Therefore, selection characteristics for 155 mm mesh from Jalbert (1992) are not included in Figure F2. The L-50 for 152 mm (6 in.) mesh for Atlantic cod is best estimated by extrapolating the Smolowitz (1983) and Jalbert (1992, unpublished) studies. The other studies do not provide sufficient information to critically evaluate selection as a function of experimental conditions. Accordingly, the L-50 for 6 in. diamond mesh is provisionally estimated to be 52.4 cm (20.6 in.) fish length.

GEAR RESEARCH RECOMMENDATION/ RESEARCH NEEDS

Mesh selection data obtained from published and ongoing studies, provide a relatively clear picture of the general selectivity characteristics that can be anticipated for 5.5 and 6 in. cod-end mesh sizes for yellowtail flounder and Atlantic cod. Square mesh results in larger L-50s than diamond for the same mesh size for cod; and vice-versa for yellowtail flounder. No definitive conclusions can be drawn regarding the selection range of square *vs* diamond mesh. Furthermore, L-25 estimates cannot yet be definitively determined for yellowtail flounder or Atlantic cod, based on experimental results for 5.5 or 6 in. mesh. Mesh selection data plotted in Figures F1 to F3 are not necessarily comparable owing to the various experimental factors confounding cod-end mesh selection. These studies also vary greatly in quality and completeness of reporting on experimental conditions.

Several specific directions for future research were recommended by the SARC:

- Additional mesh selection trials are needed with 5.5 and 6 in. mesh to definitively set minimum fish sizes, consistent with L-25s for the "large mesh" species included in the Northeast Multispecies FMP
- Sea sampling data collected by the NEFSC contain a great deal of information on gear characteristics and catch and discard length frequencies. Although mesh sizes are not routinely measured by sea samplers, there may be great utility in comparing catch and discard size compositions in relation to nominal mesh size and other gear characteristics, particularly in light of the experimental tow data.
- Mesh studies to date have generally focused only on comparing size compositions from the experimental mesh to some control, with all other factors influencing selectivity held constant. A preferable experimental protocol would involve a factorial design, recognizing

Table F1. Yellowtail flounder mesh selectivity results for diamond mesh. Studies are cited in the references.

Study YR	Mesh (mm)	Mesh (Inches)	Experimental Method	L50 cm	L50 in	Selection Factor	Selection cm	Range (L25, L75) in
Smolowitz 1983	102	4.0	Covered cod end, 50mm	22	8.7	2.16	20-23	7.9-9.1
Lux 1968	129	5.1	Parallel tows	29.5	11.6	2.29	26.5-31.0	10.4-12.2
Smolowitz 1983	133	5.2	Covered cod end, 50mm	28.5	11.2	2.18	24.5-31.0	9.6-12.2
Smolowitz 1983	133	5.2	Uncovered - 102mm control	30.5	12.0	2.29	29.1-34	11.5-13.4
Carr 1991	140	5.5	Covered cod end	34	13.4	2.43	32-35	12.6-13.8
Harris 1992	140	5.5	Uncovered - 102mm control	34.7	13.7	2.6	33.5-36.2	13.2-14.3
Lux 1968	145	5.7	Parallel tows	34	13.4	2.34	27.5-36	10.8-14.2
Harris 1992	152	6.0	Uncovered - 102mm control	38.6	15.2	2.6	37.3-39.5	14.7-15.6
DeAlteris 1991	155	6.1	Trouser trawl - Square vs. diamond	32.3	12.7	2.08	-	-

Table F2. Yellowtail flounder mesh selectivity results for square mesh. Studies are cited in the references.

Study YR	Mesh (mm)	Mesh (Inches)	Experimental Method	L50 cm	L50 in	Selection Factor	Selection Range cm	(L25, L75) in
Carr 1991	140	5.5	Covered cod end	26.0	10.2	1.86	26-30	10.2-11.8
Harris 1992	140	5.5	Uncovered, 102 mm control	31.4	12.4	2.4	29.1-33.8	11.5-13.3
Harris 1992	152	6.0	Uncovered, 102 mm control	34.9	13.7	2.4	30.8-38.9	12.1-15.3
DeAlteris 1991	155	6.1	trouser trawl, square vs. diamond	31.0	12.2	2.00	-	-

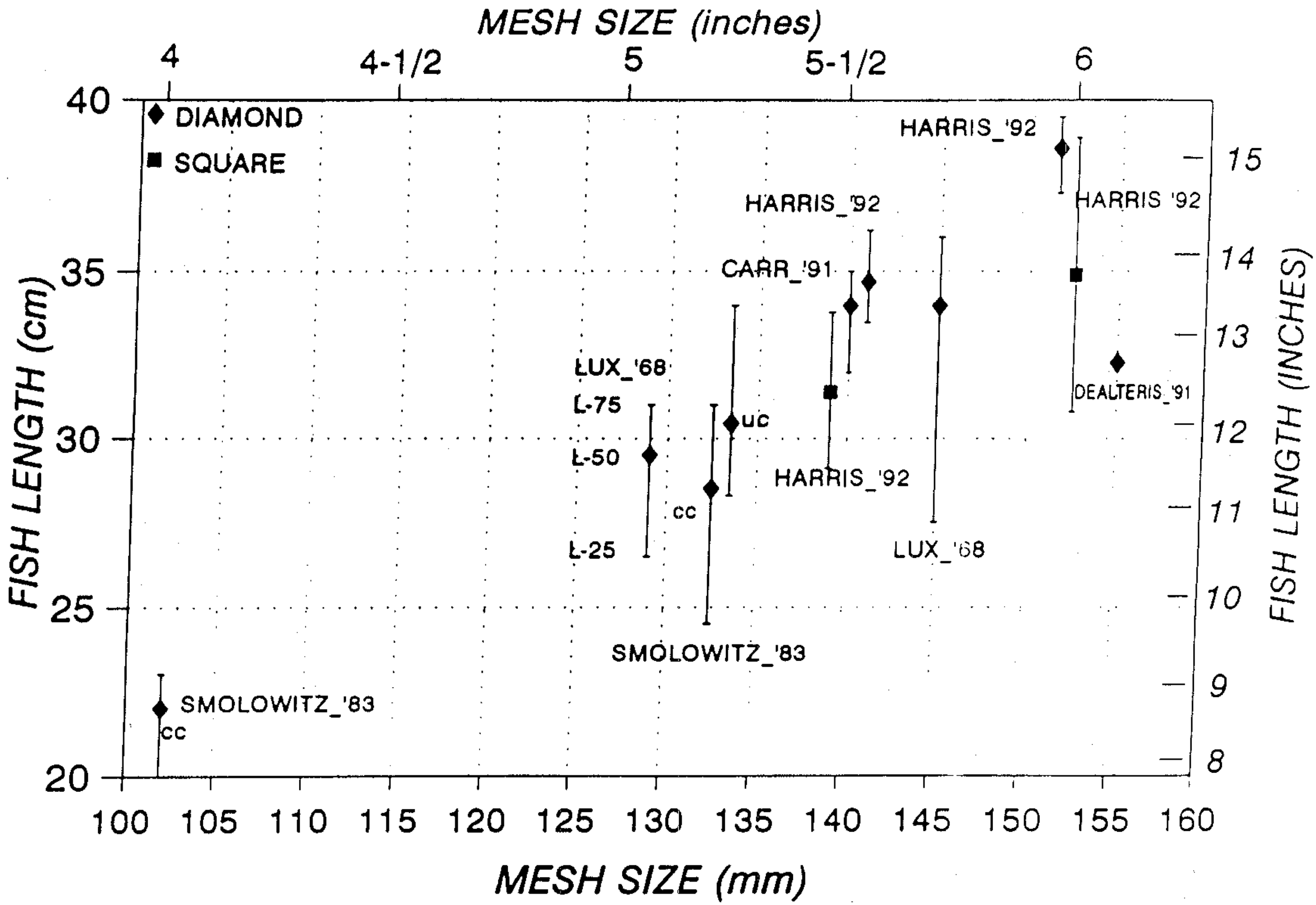


Figure F1. Relationships between experimental mesh sizes and selection characteristics for yellowtail flounder. Data plotted include lengths at 50%, 25% and 75% retention, for diamond-and square-mesh studies. Authors of the various studies are given in the references. For reference purposes, projected effective mesh selection assumed by the New England Fishery Management Council for 140 and 152 mm diamond (DIA) and square mesh (SQ) are plotted.

Table F3. Atlantic cod mesh selectivity results for diamond mesh. Studies are cited in the references.

Study YR	Mesh mm	Mesh (inches)	Experimental Method	L50 cm	L50 in	Selection Factor	Selection Range cm	(L25, L75) in
Clay 1979	90	3.5	Covered cod end, 20mm control	38.5	15.2	4.4	37-39	14.6-15.4
Smolowitz 1983	105	4.1	Covered cod end, 50mm control	33.	13.0	3.3	26.5-37.5	10.4-14.8
Cooper 1987	130	5.1	Trouser trawl	58.7	23.1	4.5	-	-
Isaksen 1988	120	4.7	Trouser trawl, 60mm control	49.2	19.4	3.6	-	-
Smolowitz 1983	135	5.3	Covered cod end, 50mm control	46.5	18.3	3.4	40.5-50.5	15.9-19.9
Smolowitz 1983	135	5.3	Uncovered cod end	52.1	20.5	3.9	45.9-56.5	18-22.2
Cooper 1988	135	5.3	Trouser trawl	52.0	20.5	3.8	-	-
Isaksen 1988	135	5.3	Trouser trawl, 60mm control	56.0	22.0	4.1	-	-
Cooper 1988	140	5.5	Trouser trawl	56.2	22.1	4.0	-	-
Jalbert 1992	140	5.5	Trouser trawl, 60mm control	48.4	19.1	3.5	42.80-54.19	16.9-21.3
Cooper 1988	155	6.1	Trouser trawl	61.3	24.1	3.9	-	-
Thorsteinsson 1988	155	6.1	-	48.0	18.9	3.1	39-55	15.4-21.7

Table F4. Atlantic cod mesh selectivity results for square mesh. Studies are cited in the references.

Study YR	Mesh (mm)	Mesh (inches)	Experimental Method	L50 cm	L50 in	Selection Factor	Selection Range cm	(L25,L75) in
Cooper 1987	130	5.1	Trouser trawl	59.7	23.5	4.6	-	-
Isaksen 1988	120	4.7	Trouser trawl, 60mm control	54.0	21.3	4.0	-	-
Isaksen 1988	135	5.3	Trouser trawl, 60mm control	60.2	23.7	4.5	-	-
Cooper 1988	140	5.5	Trouser trawl	61.4	24.2	4.4	-	-
Cooper 1988	155	6.1	Trouser trawl	65.0	25.6	4.2	-	-
Thorsteinsson 1988	155	6.1	-	59.2	23.3	3.9	53-65	20.9-25.6
Thorsteinsson 1988	155	6.1	-	58.5	22.9	4.0	52.8-61.6	20.8-24.3

Figure F2. Relationships between experimental mesh sizes and selection characteristics for Atlantic Cod using diamond mesh. Data plotted include lengths at 50%, 25% and 75% retention. Authors of the various studies are given in the references. For reference purposes, projected selection assumed by the New England Fishery Management Council for 140 and 152 mm diamond mesh are plotted.

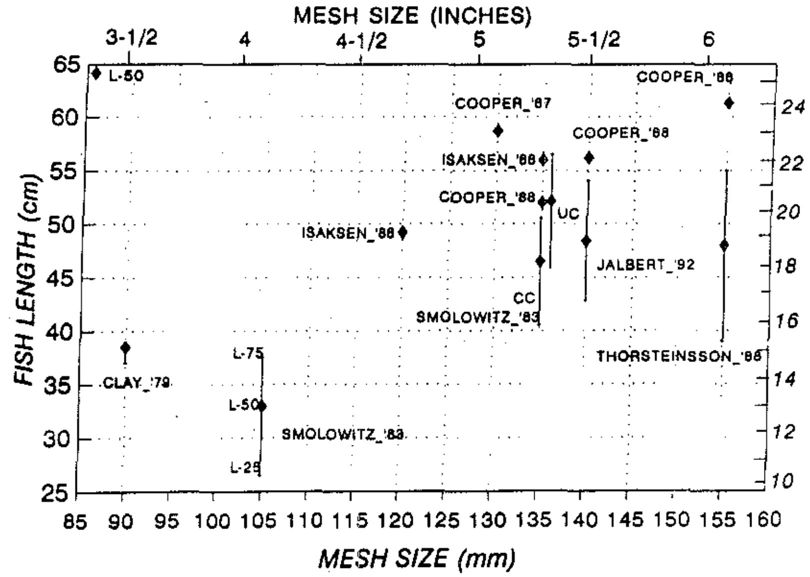
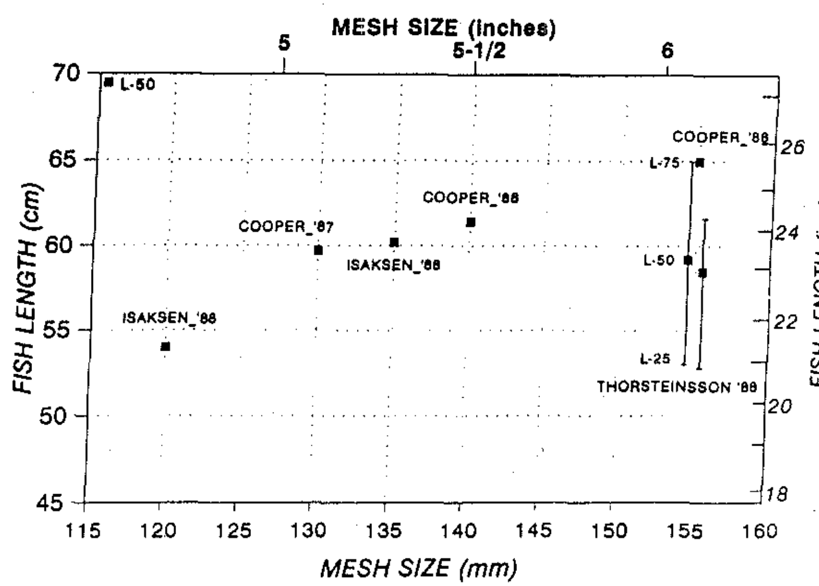


Figure F3. Relationships between experimental mesh sizes and selection characteristics for Atlantic Cod using square mesh. Data plotted include lengths at 50%, 25% and 75% retention. Authors of the various studies are given in the references.



that cod-end mesh selection is but one control variable available to managers to improve the selectivity of trawl gear.

- Several international and national groups are now attempting to develop standardized guidelines for conducting mesh experiments. Interpretation of historical studies is confounded by the extreme variability in protocols followed, and by experimental conditions. To the greatest extent practical, future mesh work should conform to the accepted guidelines.
- A critical problem faced in conducting mesh experiments for New England groundfish and summer flounder is that these stocks are generally at low levels of abundance, and that not all sizes of fish appropriate for the selection ranges of the experimental gear are available. Therefore, any experimental results obtained under these conditions must be considered provisional, pending adequate and representative sampling of the entire length span of the populations.
- Finally, one difficulty in interpreting historical selectivity data is that many reports contain only processed selection curves and their statistics, and not all experimental data, including length frequencies. The SARC strongly recommends that data reported in such studies should be as complete as possible, thereby allowing interpretation of the experimental conditions encountered.

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