Northeast Fisheries Science Center Reference Document 93-18

Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

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

This document was presented to and reviewed by the Stock Assessment Review Committee (SARC) of the 16th Northeast Regional Stock Assessment Workshop (16th SAW)

July 1993

Nine documents associated with the 16th Northeast Regional Stock Assessment Workshop (16th SAW) have been published as Northeast Fisheries Science Center reference documents. For copies of these documents, contact the NMFS/NEFSC, Information Services Unit, 166 Water St., Woods Hole, MA 02543-1097, (508)548-5123.

Reports Associated with the 16th Northeast Regional Stock Assessment Workshop (16th SAW)

CRD 93-13	Assessment of pollock, *Pollachius virens*, L., in Divisions 4VWX and Subareas 5 and 6, 1993 by R. K. Mayo and B. F. Figuerido
CRD 93-14	Assessment of summer flounder *(Paralichthys dentatus)*, 1993: Report of the Stock Assessment Workshop (SAW) Summer Flounder Working Group M. Terceiro, ed.
CRD 93-15	Analytical assessment of the Atlantic herring coastal stock complex by D. Stevenson, D. Libby, and K. Friedland
CRD 93-16	Report of the Workshop on Atlantic Herring Science and Assessment in the Gulf of Maine/Georges Bank Area NOAA/NMFS/NEFSC
CRD 93-17	Evaluation of available data for the development of overfishing definition for tilefish in the Middle Atlantic by G. Shepherd
CRD 93-18	Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessments NOAA/NMFS/NEFSC
CRD 93-19	Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW), The Plenary NOAA/NMFS/NEFSC
CRD 93-20	Calculating biological reference points for American lobsters by J. Idoine and M. Fogarty
CRD 93-21	Assessment of American lobster stock status off the Northeast United States, 1993 S. Murawski, ed.

TABLE OF CONTENTS

INTRODUCTION

The Stock Assessment Review Committee (SARC) of the 16th Northeast Regional Stock Assessment Workshop (16th SAW) met at the Northeast Fisheries Science Center (NEFSC) Woods Hole, Massachusetts during 21 - 25 June 1993. The SARC chairman was Dr. Vaughn Anthony (NEFSC). Members of the SARC were from a number of fisheries organizations and academia within the region, one agency from outside the region, and one from Canada (Table 1). Nearly 50 individuals participated in the meeting (Table 2).

The meeting was organized according to the SAW structure recommended by the SAW Steering Committee at a meeting in March 1993 and described in the Report of the 15th Northeast Regional Stock Assessment Workshop (15th SAW), The Plenary (pages 54-59).

Under the new SAW structure, SARC Subcommittees refined the analyses for the SARC to review, formulating many of the recommendations adopted by the SARC, and drafted summaries of assessments featured in this report. Subcommittee members who participated in the development of this documentation are presented in Table 3.

The SARC agenda (Table 4) included twelve species/stocks to review (four first priority; six second priority; and two third priority). Time, however, did not permit the evaluation of assessments for all 12 species/stocks. The SARC reviewed only assessments for pollock, summer flounder, herring, and lobster (first priority); and data possibilities for an overfishing definition as well as a surplus production model for tilefish (second priority). The geographic research area and statistical reporting areas pertaining to these species are presented in Figures 1 and 2.

This report, Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessments (NEFSC Reference Document 93-18), contains evaluations of presented analyses accompanied by a series of research recommendations developed through the SAW process. Specific recommendations are directed to the SAW Steering Committee and SARC Subcommittees.

In addition to the SARC report, publications resulting from this meeting include seven other documents in the NEFSC Reference Document series (Table 5). Some of the working papers on species/stocks that the SARC did not have time to review will undergo the usual NEFSC review process for inclusion in the NEFSC Reference Document series.

The first draft of the Advisory Report on Stock Status was produced by the SARC. Information was compiled according to the format approved by the SAW Steering Committee. The draft Advisory Report will be provided to the Steering Committee two weeks before the SAW Plenary Meeting scheduled for 29 July 1993, where the report will be reviewed in open session. The final version of the Advisory Report will be featured in the Plenary Report (NEFSC Reference Document 93-19).

The report of the Workshop on Atlantic Herring Science and Assessment in the Gulf of Maine/Georges Bank Area was presented for the SARC's information. The organization of the workshop was recommended at the 13th SAW SARC. The workshop focused on two main issues: (1) resource survey techniques in herring assessments and (2) stock identification. Work-

Table 1. Stock Assessment Review Committee (SARC) composition

Chair, NEFSC Chief Scientific Advisor:

Vaughn Anthony

Four ad hoc assessment members chosen by the Chair:

Ray Conser
Dan Hayes
Steve Murawski
Paul Rago

One person from NMFS Northeast Regional Office:

Pete Colosi

One person from each Regional Fishery Management Council:

Andy Applegate, NEFMC
Tom Hoff, MAFMC

Atlantic States Marine Fisheries Commission / State personnel:

Mark Gibson, RI
Anne Lange, MD
David Stevenson, ME

One Scientist from:

Canada - **Doug Pezzack, DFO**
Academia - **Jeremy Collie, URI**
Other Region - **Mary Fabrizio, USF&WS/ NFRC/GL**

shop participants reviewed the conclusions and recommendations from the report and sought the SARC's endorsement. It was agreed to include the report in the NEFSC Reference Document series along with other selected documents from this meeting.

Presentations and discussions at this meeting led to the development of candidate terms of reference for the SARC Assessment Methods Subcommittee. These include: (1) potential biases in SARC assessment results, (2) methods for medium-term stochastic projections, (3) multiple indices of abundance within the DeLury model, (4) catch per unit effort (CPUE)-based indices of abundance for VPA tuning, (5) calibration of recruitment indices, (6) effects of outliers in survey data, (7) sensitivity of ADAPT results to multiple indices, and (8) extending the time series of stock-recruitment data. The complexity and amount of work needed to address these terms of reference is summarized in a separate section of this report.

Participants also discussed the current SAW process and offered suggestions on how to improve it. Of particular interest was a better understanding of the roles of the SARC itself and its Subcommittees. This discussion is summarized under other business.

Table 2. List of participants

National Marine Fisheries Service

Northeast Fisheries Science Center
Frank Almeida
Vaughn Anthony
Betsy Arden
Jon Brodziak
Steve Clark
Ray Conser
Brenda Figuerido
Mike Fogarty
Kevin Friedland
Wendy Gabriel
Ruth Haas
Dan Hayes
Tom Helser
J. Idoine
Marjorie Lambert
Phil Logan
Ralph Mayo
Nancy McHugh
Steve Murawski
Helen Mustafa
Loretta O'Brien
Greg Power
Paul Rago
Fred Serchuk
Tim Sheehan
Gary Shepherd
Terry Smith
Katherine Sosebee
Mark Terceiro
Jim Weinberg
Susan Wigley

Northeast Regional Office
Pete Colosi

Mid-Atlantic Fishery Management Council

Tom Hoff

New England Fishery Management Council

Andrew Applegate

Connecticut Department of Environmental Protection

David Simpson

Maine Division of Marine Resources

David Stevenson

Maryland Department of Natural Resources

Anne Lange

Massachusetts Division of Marine Fisheries

Mike Armstrong
Steve Cadrin
Paul Caroso
Steve Correia
Tom Currier
Bruce Estrella
David Pierce

New York Division of Marine Resources

John Mason

Rhode Island Division of Fish and Wildlife

Mark Gibson

University of Rhode Island

Jeremy Collie

U.S. Fish and Wildlife Service

Mary Fabrizio

Department of Fisheries and Oceans, Canada

Doug Pezzack

Table 3. Subcommittee meetings, participants, and analyses prepared

Subcommittee/Participants	Meeting Date(s) and Meeting Place	Analyses Prepared
Northern Demersal	24-18 May 1993, Woods Hole, MA	Pollock Silver hake (2 stocks) Witch flounder
A. Applegate, NEFMC D. Hayes, NEFSC T. Helser, NEFSC R. Mayo, NEFSC (Chair) L. O'Brien, NEFSC K. Sossebee, NEFSC S. Wigley, NEFSC B. Figuerido, NEFSC S. Murawski, NEFSC G. Power, NEFSC		
Sooouthern Demersal	25-27 May 1993, Woods Hole, MA and SAW Summer Flounder W.G. 27-29 October 1992	Summer flounder Tilefish Goosefish
A. Applegate, NEFMC S. Correia, MADM T. Currier, MDMF L. DiTommaso, NYDEC W. Gabriel, NEFSC (Chair) M. Gibson, RIDFW H. Goodale, NERO A. Lange,MDDNR M.Lambert, NEFSC S. Michels, DEDFW R. Monaghan, NCDMF C. Moore, MAFMC J. Musick, VIMS P. Rago, NEFSC L. Rugolo, MDDNR G. Shepherd, NEFSC D. Simpson, CTDEP M. Tereeiro (Chair, SF WG)		
Pelagic/Coastal Subcommittee	24-25 May 1993, Boothbay Harbor, ME	Atlantic herring Butterfish
J. Brodziak, NEFSC K. Friedland, NEFSC D. Libby, MEDMR W. Overholtz, NEFSC (Chair) H. Russell, NEFMC D. Stevenson, MDMR		
Invertebrate Subcommittee	1-4 June 1993, Woods Hole, MA	American lobster Squids *Illex* *Loligo*
T. Angell, RIDFW M. Blake, CTDEP P. Briggs, NYDEC J. Brodziak, NEFSC S. Cardin, MADMF R. Conser, NEFSC B. Estrella,MADMF M. Fogarty, NEFSC D. Hayes, NEFSC J. Idoine, NEFSC S. Murawski, NEFSC (Act. Chair) A. Richards, NEFSC H. Russell, NEFMC R. Seagraves, MAFMC K. Sosebee, NEFSC J. Weinberg, NEFSC		

Table 4. Agenda for the 16th Northeast Regional Stock Assessment Workshop (16th SAW) Stock Assessment Review Committee (SARC) Meeting

NEFSC Aquarium Conference Room
Woods Hole, Massachusetts
June 21 (9:00 AM) - 25, 1993

Monday, June 21 -- 9:00 AM

Opening — Chairman, V. Anthony

Species/Stock	Subcommittee/ Presenter(s)	Rapporteur(s)
First Priority		
Pollock (A)	Northern Demersal/ R. Mayo	L. O'Brien
Summer flounder (B)	Southern Demersal/ W. Gabriel	M. Terceiro
Tuesday, June 22 -- 9:00 AM		
Summer flounder (continued)		
Herring (C)	Pelagic-Coastal/ W. Overholtz	K. Friedland
Review available draft report sections		
Wednesday, June 23 -- 9:00 AM		
Lobster (D)	Invertebrate/ S. Murawski	J. Idoine
Second Priority		
Silver hake	Northern Demersal/ GOM-NGB (E) SGB-MidAtl (F)	A. Applegate R. Mayo
Review available draft report sections		
Thursday, June 24 -- 9:00 AM		
Review drafts		
Tilefish (G)	Southern Demersal/ W. Gabriel	T. Hoff
Butterfish (H)	Pelagic/Coastal W. Overholtz	T. Hoff
Squids *Illex* (I) *Loligo* (J)	Invertebrate/ S. Murawski	A. Lange

Table 4. Continued

Species/Stock	Subcommittee/ Presenter(s)	Rapporteur(s)
Third Priority (if sufficient time)		
Witch Flounder (K)	No. Demersal/ R. Mayo	P. Colosi
Goosefish (L)	So. Demersal/ W. Gabriel	A. Applegate
Consensus Report		
Review draft report sections		
Advisory Report	Chief Rapporteur, T.P. Smith	
Review draft report sections		
Friday, June 25 -- 9:00 AM		
Consensus Summary of Assessments Complete draft		
Advisory Report on Stock Status Complete draft		

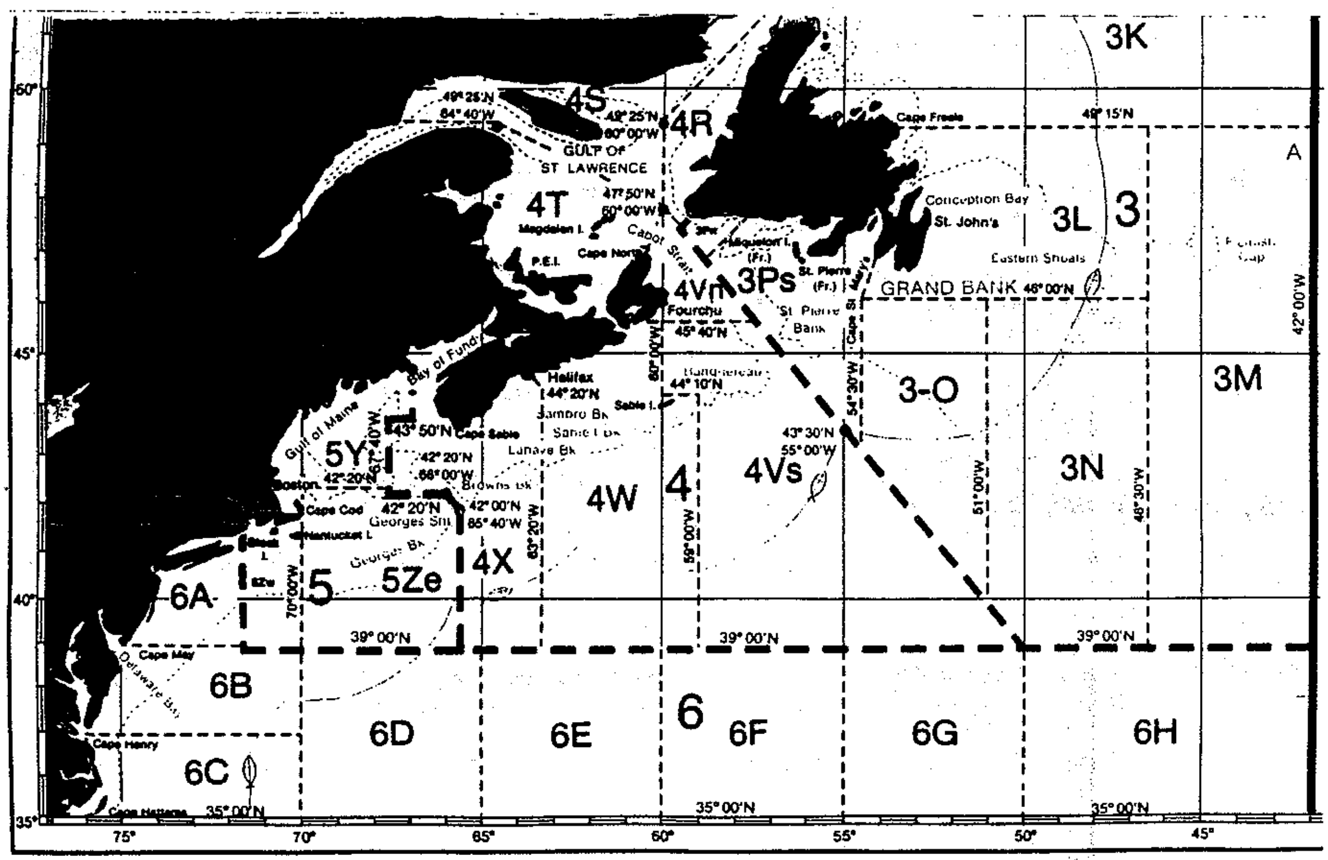

Figure 1. NAFO Divisions and principal geographic features of the Northeastern United States.

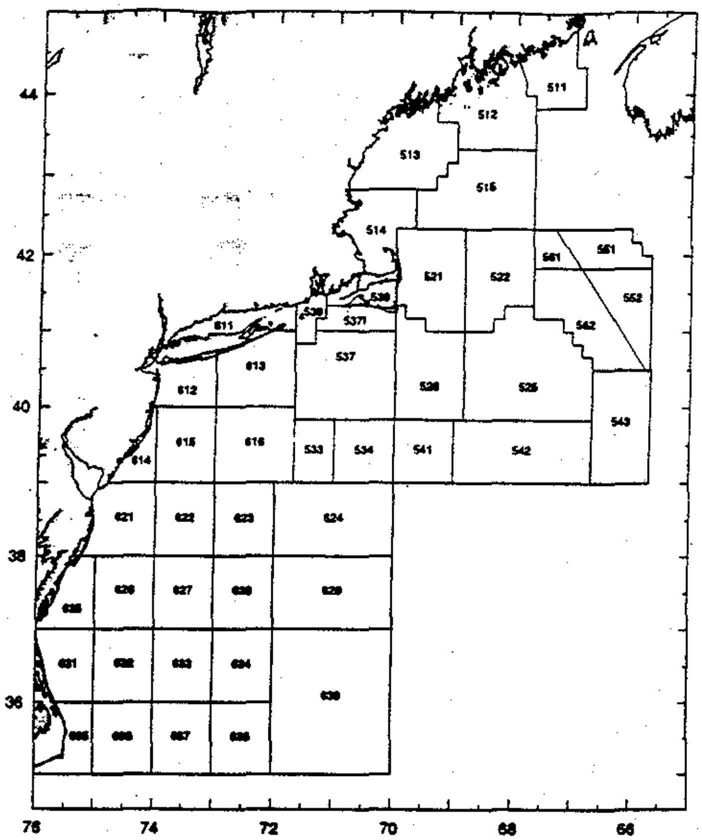

Figure 2. Three-digit statistical reporting areas off the Northeast United States.

Table 5. NEFSC Reference Documents associated with the 16th Northeast Regional Stock Assessment Workshop (16th SAW)

Number	Title/Author(s)
CRD 93-13	Assessment of pollock, *Pollachius virens*, L., in Divisions 4VWX and Subareas 5 and 6, 1993 by R. K. Mayo and B. F. Figuerido
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A. POLLOCK

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Evaluate estimation procedures for discards and recreational catches, and include these estimates in the catch at age matrix if appropriate (See section on the fishery on this page.)

b. Assess the status of pollock in Divisions 4VWX and SA5 through 1992 and perform bootstrap replications of the assessment to characterize the variability of the estimates. (See section on estimates of stock size and fishing mortality, page 16.)

c. Investigate the utility of incorporating additional age-disaggregated tuning indices in the ADAPT formulation. (See section on estimates of stock size and fishing mortality, page 16.)

d. Revise estimates of F_{med}. (See section on biological reference points, page 22.)

e. Provide catch and spawning stock biomass (SSB) options at various levels of F and F_{max}, $F_{20\%}$, F_{sq} and F_{92}-10%. (See section on short-term projections, page 27.)

f. Evaluate gillnet sea sampling data for pollock as means of measuring CPUE. (See section on analyses of sink gillnet fishery effort measures page 32.)

THE FISHERY

Commercial Landings

Total landings for this stock have increased from about 9,000 mt annually during the late 1920s to an annual average of 38,000 mt during 1960-1966. Landings then declined to an average of 24,500 mt during 1967-1971, but increased to well over 65,000 mt in 1986 and 1987; the 1986 total (68,500 mt) was the highest on record. Total pollock landings have since declined to 42,431 mt by 1992 (Table A1, Figure A1). The general increase observed through the mid-1980s appears to reflect a general increase in directed effort associated with increased Canadian and U.S. harvesting capacity and declining abundance of traditional groundfish stocks.

For Canada, landings were relatively constant during 1928-1942, averaging about 5,000 mt, and then increased to an average of 29,300 mt during 1960-1964 (Table A1, Figure A1). Landings subsequently declined to only 10,800 mt in 1970, but increased to a peak of 45,300 mt in 1987. Canadian pollock landings have since declined to 33,146 mt by 1992. United States landings during 1935-1960 were relatively stable, about an annual average of 13,400 mt, and then decreased to less than 4,000 mt in the late 1960s. Landings increased steadily to an annual average of 18,000 mt during 1978-1987, reaching a maximum of 24,542 mt in 1986. (Table A1, Figure A1). United States pollock landings have since declined precipitously, reaching 7,183 mt by 1992.

Nominal catches by other nations have fluctuated considerably, increasing from zero in 1962 to 12,300 mt in 1966, and then declining sharply to only 1,500 mt in 1968. The combined total averaged 9,800 mt during 1970-1973, but declined to less than 1,000 mt annually between 1981 and 1987 (Table A1, Figure A1). Landings by distant water fleets have since increased to between 2,000 and 3,000 mt in 1991 and 1992.

The distribution of nominal catch by area is given in Table A2. Since 1960, 60% of the total has been taken on the western Scotian Shelf and in the Gulf of Maine (NAFO Divisions 4X and 5Y), the apparent center of distribution of this stock. More than 90% of the Canadian nominal catch has been taken on the Scotian Shelf; U.S. landings were taken primarily on Georges Bank and in the Gulf of Maine during the 1960s and early 1970s, but in more recent years have come primarily from the western Gulf of Maine.

Historically, most of the catch has been taken by bottom trawling; bottom trawls have remained the predominant gear in recent years in spite of a substantial increase in gill net effort by Canadian and U.S. fleets beginning in the mid-1970s. Since 1970, more than 70% of the nominal catch has been taken by bottom trawling, with most of the remainder (20%) being taken by gill nets.

Discards

Some discarding of pollock is likely to have occurred in U.S. fisheries due to imposition of minimum size regulations, and in Canadian fisheries due to the cod-haddock-pollock (CHP) com-

Table A1. Commercial landings (mt) of pollock for Divisions 4VWX+5+6 for United States, Canada, and distant-water fleet (DWF)[1]

Year	Canada	USA	FRG	GDR	Japan	Spain	USSR	UK	Others	Total DWF	Total
1960	29470	10132	0	0	0	783	0	0	1	784	40386
1961	26323	10265	0	0	0	982	0	0	1	983	37571
1962	31721	7391	0	0	0	0	0	0	0	0	39112
1963	28999	6650	126	0	0	0	793	28	0	947	36596
1964	30007	6006	208	0	0	0	4603	374	55	5240	41253
1965	27316	5303	71	0	0	1361	2667	11	0	4110	36729
1966	18271	3791	0	0	0	2384	9865	12	0	12261	34323
1967	17567	3312	0	0	0	1779	644	1	14	2438	23317
1968	18062	3276	0	0	0	1128	372	0	7	1507	22845
1969	15968	3943	1188	2195	0	1515	227	0	7	5132	25043
1970	10753	3976	3233	4710	40	532	527	0	0	9042	23771
1971	11757	4890	633	6849	15	912	2216	0	3	10628	27275
1972	18022	5729	475	4816	8	616	3495	4	54	9468	33219
1973	26990	6303	1124	948	1570	3113	3092	0	36	9883	43176
1974	24975	8726	149	2	40	1500	2348	48	14	4101	37802
1975	26548	9318	236	96	0	709	2004	0	124	3169	39035
1976	23568	10863	994	24	0	303	1466	0	390	3177	37608
1977	24654	13056	368	0	1	2	268	0	53	692	38402
1978	26801	17714	0	0	110	0	502	0	180	792	45307
1979	29967	15541	7	0	19	0	1025	0	73	1124	46632
1980	35986	18280	0	0	81	0	950	0	131	1162	55428
1981	40270	18171	0	0	15	0	358	0	90	463	58904
1982	38029	14357	0	0	3	0	297	0	128	428	52814
1983	32749	13967	0	0	6	0	226	0	283	515	47231
1984	33465	17903	0	1	1	0	97	0	169	268	51636
1985	43300	19457	0	0	17	0	336	0	143	496	63253
1986	43249	24542	0	0	51	0	564	0	468	1083	68874
1987	45330	20353	0	0	82	0	314	0	371	767	66450
1988	41831	14960	0	0	1	0	1054	0	225	1280	58071
1989	40976	10553	0	0	28	0	1221	0	577	1826	53355
1990	36221	9645	0	0	9	0	1052	0	264	1325	47191
1991	37936	7950	0	0	38	0	2690	0	626	3354	49240
1992	33146	7183	0	0	72	0	1006	0	1024	2102	42431

[1] 1988-1992 Canadian Data Preliminary

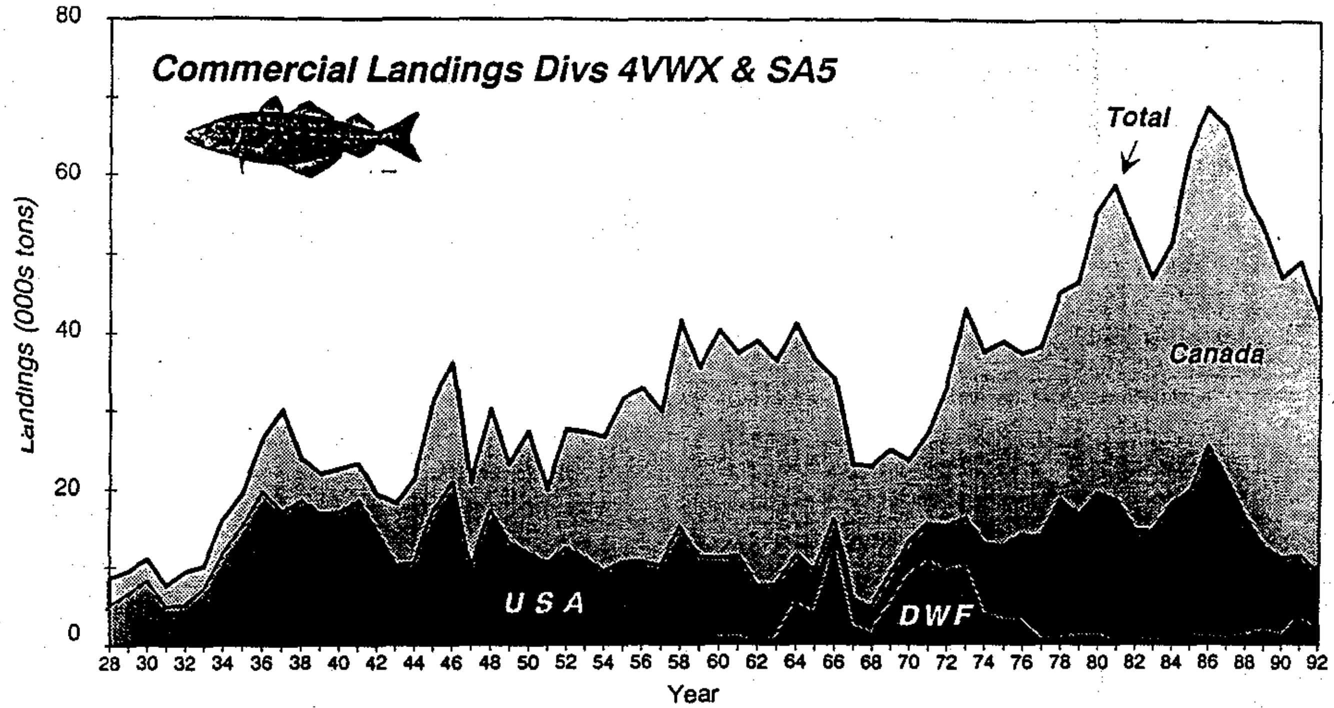


Figure A1. Commercial landings of Divisions 4VWX and Subareas 5 and 6 pollock (metric tons, live) for Canada, the United States (USA), and distant-water fleets (DFW), 1928 to 1992.

bined quota system imposed in the western Scotia-Fundy region in 1989 (Mohn *et al.* 1990). Any inclusion of discards in the catch-at-age would have to account for both of these potential sources of discarding. No analyses have yet been performed.

Recreational Catches

Catch Trends

Recreational catch estimates obtained for 1960, 1965, and 1970 totaled 4.3 million fish (9,800 mt), 3.8 million fish (4,200 mt), and 2.5 million fish (2,500 mt), respectively (Table A3). Estimates from Marine Recreational Fishery Statistics Surveys including pollock reportedly caught and released alive declined from a 1979-1980 average of 4.1 million fish to 0.6 million in 1984. Catches temporarily increased in 1985, to 2.1 million fish, before declining sharply to an average of 0.6 million in 1986-1987 (Table A3). Catches increased slightly in 1988 but have remained at less than 0.5 million since 1990. Total weight, however, increased from about 1,000 mt in 1979 to 2,800 mt in 1983 as mean size increased. Total weights declined substantially in 1984 and have remained at less than 500 mt since 1990. Mean weights have remained in the range of 0.4 to 0.6 kg since 1984.

Sampling Intensity

Commercial Fishery Sampling Levels

Sampling of pollock catches was negligible between 1969 and 1976 when 10 or fewer samples were taken (and 1000 or fewer fish were measured) per year. Sampling intensity increased substantially in 1977 and, since then, sampling of the catch has been adequate to derive commercial catch-at-age estimates. Between 1977 and 1981 the sampling intensity ranged from 1 to 4 samples per ton landed; since 1982, the intensity has increased to between 4 and 9 samples per ton landed.

Recreational Fishery Sampling Levels

Sampling of the recreational pollock catch has been relatively poor since 1979 when intercept sampling commenced (Table A3). During 1979-1982, between 300 and 600 pollock were measured from this fishery per year, but sampling

Table A2. Commercial landings (mt) of pollock for Divisions 4VWX+5+6 for United States, Canada, and distant-water fleet (DWF)[1]

Year	4V	4W	4X	Total 4VWX	5Y	5Ze	5Zw	Total 5Z	5NK	Total SA5	SA6	Total 4VWX+5	Total 4VWX-6
1960	1503	8354	20132	29989	6545	0	0	3834	18	10397	0	40386	40386
1961	1864	13167	14321	29352	5017	0	0	3177	25	8219	0	37571	37571
1962	1292	12045	19624	32961	2560	0	0	3576	15	6151	0	39112	39112
1963	674	9152	20645	30471	2168	0	0	3947	10	6125	116	36596	36712
1964	474	12488	19283	32245	1754	0	0	7250	0	9004	4	41249	41253
1965	1205	13134	13390	27729	1933	0	0	7065	0	8998	2	36727	36729
1966	788	11040	12648	24476	953	0	0	8846	0	9799	48	34275	34323
1967	657	5836	8290	14783	1728	0	0	6790	14	8532	2	23315	23317
1968	1013	5954	10656	17623	1416	3724	82	3806	0	5222	0	22845	22845
1969	300	3938	10983	15221	4635	5025	162	5187	0	9822	0	25043	25043
1970	649	2952	8194	11795	6281	5157	123	5280	0	11561	415	23356	23771
1971	531	1802	9739	12072	7016	7096	142	7238	58	14312	891	26384	27275
1972	597	3419	16190	20206	6419	6519	51	6570	0	12989	24	33195	33219
1973	1004	5871	23225	30100	5202	6235	1618	7853	0	13055	21	43155	43176
1974	307	4740	20362	25409	6106	6233	5	6238	0	12344	49	37753	37802
1975	799	5697	18668	25164	6015	7848	3	7851	0	13866	5	39030	39035
1976	1102	3424	19700	24226	6441	6915	11	6926	12	13379	3	37605	37608
1977	1347	6082	14700	22129	8278	7846	79	7925	36	16239	34	38368	38402
1978	2931	4910	15161	23002	12238	9943	17	9960	91	22289	16	45291	45307
1979	4877	4963	18340	28180	9856	8356	11	8367	221	18444	8	46624	46632
1980	3893	7511	20485	31889	11388	11883	20	11903	245	23536	3	55425	55428
1981	2316	15678	18842	36836	12475	9298	21	9319	247	22041	27	58877	58904
1982	2939	9373	21036	33348	9416	9903	15	9918	129	19463	3	52811	52814
1983	5491	5787	18137	29415	8458	9217	25	9242	113	17813	3	47228	47231
1984	5474	6043	19486	31003	12543	7819	28	7847	236	20626	7	51629	51636
1985	12085	3262	26837	42184	15615	5169	19	5188	261	21064	5	63248	63253
1986	15250	4046	23071	42367	18900	7387	14	7401	204	26505	2	68872	68874
1987	12820	4425	26858	44103	14841	7393	12	7405	101	22347	0	66450	66450
1988	11871	4240	24656	40767	11356	5942	5	5947	0	17303	1	58070	58071
1989	12074	5598	23780	41452	7143	4752	8	4760	0	11903	0	53355	53355
1990	8155	5257	22578	35990	6094	5011	9	5020	86	11200	1	47190	47191
1991	4072	9121	26447	39640	5320	4208	7	4215	64	9599	1	49239	49240
1992				0				0		0		0	42431

[1] Totals are for all countries

Table A3. United States catches of pollock (numbers and total weight), mean weights, and number of fish measured estimated from data collected in U.S. recreational fishery surveys, 1960-1992[1]

Year	Number (thousands)	Weight (mt)	Mean Weight (kg)	Number of Fish Measured
1960	4,335	9,834	2.27	n/a
1965	3,756	4,240	1.13	n/a
1970	2,451	2,533	1.03	n/a
1974	481	496	1.03	n/a
1979	3,648	1,021	0.28	348
	2,349[1]	*658*		
1980	4,446	2,134	0.48	572
	1,997	*959*		
1981	2,724	1,226	0.45	376
	1,602	*721*		
1982	1,686	2,563	1.52	375
	882	*1,341*		
1983	1,314	2,799	2.13	146
	590	*1,257*		
1984	642	276	0.43	171
	405	*174*		
1985	2,147	862	0.40	89
	1,860	*747*		
1986	447	219	0.49	121
	359	*176*		
1987	664	269	0.40	131
	264	*107*		
1988	1,421	542	0.38	192
	490	*198*		
1989	670	696	1.04	138
	306	*401*		
1990	404	171	0.42	46
	223	*94*		
1991	458	289	0.63	42
	106	*79*		
1992	185	84	0.49	56
	91	*40*		

[1] Numbers in italics exclude data for pollock caught and released alive; weights calculated by multiplying numbers caught by mean weight of pollock available for identification in intercept (creel) survey work.

declined sharply thereafter to fewer than 100 measurements per year since 1989.

Commercial Catch at Age

The combined catch, mean weight, and total weight at age matrices for all countries and gear types are presented in Table A4. Canadian and U.S. catches by number have been dominated by age 3 to age 7 fish throughout the series, although considerable interannual variability is evident as dominant year classes progress through the fishery. Landings by Canada and the U.S. have been supported by the same dominant year classes (1971, 1976, 1979, 1982, and 1985, 1987), and catches of the 1969, 1974, and 1980 and 1988 year classes have also been reasonably high. The lack of age 2 fish in the U.S. catch-at-age since 1988 likely reflects the imposition of a minimum landing size of 48 cm, which corresponds to the size of a pollock at the beginning of its third year (Mayo *et al.* 1989). The total weight over all ages represents a sum of products that compares favorably with total annual landings listed in Table A1. In most years, sums of products are within 1% of the tabulated landings.

Commercial Mean Weights at Age

Mean weights at age are given for the combined catch-at-age in Table A4. Combined mean weights-at-age represent averages taken over the three fleet components weighted by numbers landed on an annual basis. Catch biomass estimates are computed as the product of numbers-at-age times mean weights-at-age. Mean weights-at-age for Canada during 1977-1987 appear to be slightly lower at a given age than the U.S. weights, particularly at the intermediate ages. This is likely due to the different length-weight relationships employed in the computations and the different areas fished by each country. Canadian mean weights in 1991 and 1992 for oldest ages are extremely low relative to earlier years. Since the overall mean weight at age matrix (Table A4) is dominated by Canadian catches, a similar decline is evident in the oldest age groups in the last two to three years.

Table A4. Total catch at age for pollock in Divisions 4VWX and SA 5 for all countries combined

	Numbers (thousands)landed at age											
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**	**Total**
1970	567	589	1543	1360	892	686	464	212	123	44	8	6488
1971	1518	2428	2392	2001	1575	541	232	3	8	1	1	10700
1972	798	2170	2655	1852	924	483	110	355	26	60	85	9518
1973	1168	2696	9131	5279	723	289	103	256	87	15	5	19752
1974	261	7332	3445	3034	1359	404	213	96	100	81	45	16370
1975	260	1436	5297	2566	2400	1041	263	80	85	56	49	13533
1976	234	2190	3085	5314	1454	1342	272	41	15	21	57	14025
1977	56	1751	3779	2443	2980	1049	673	206	81	45	274	13337
1978	115	1548	3618	3682	1887	2084	602	411	151	103	229	14430
1979	299	4087	7487	4478	2184	765	531	160	62	39	112	20204
1980	361	704	3798	6802	4096	1605	469	334	110	45	78	18402
1981	1465	2750	1303	3853	4691	2749	955	301	268	63	148	18546
1982	236	5104	2249	847	2600	2622	1344	553	264	180	218	16217
1983	83	2743	11227	1867	422	868	980	540	277	131	262	19400
1984	128	1278	5183	9770	1249	203	368	325	193	59	137	18893
1985	235	2345	2871	5812	8035	1394	213	238	353	137	177	21810
1986	114	1578	6169	4443	5207	4482	477	139	263	259	250	23381
1987	92	1424	3121	7631	4088	3046	2152	272	82	147	260	22315
1988	27	1046	3478	4145	5017	2304	1445	1164	69	40	174	18909
1989	72	721	5626	4728	2825	2473	1072	752	451	33	83	18836
1990	51	1830	3043	5131	2921	1751	997	612	295	125	102	16858
1991	300	1570	4443	3754	4602	1843	858	418	321	205	282	18596
1992	30	2055	5363	4063	2166	1430	505	261	200	96	88	16257

	Mean weights (kg) at age											
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**	**Mean**
1970	0.59	1.38	2.19	3.05	3.78	4.78	5.82	7.08	7.10	9.09	8.11	3.21
1971	0.78	1.70	2.12	3.16	4.00	4.99	6.24	7.25	9.62	0.00	0.00	2.55
1972	1.06	1.86	2.77	4.28	5.29	5.95	6.52	8.83	7.60	6.81	9.56	3.49
1973	0.50	1.27	1.95	2.65	3.96	4.86	6.23	6.81	7.42	9.17	9.77	2.19
1974	0.82	1.40	1.96	3.01	4.09	5.06	6.12	6.66	7.36	8.52	9.95	2.31
1975	0.86	1.28	1.99	3.07	3.85	5.09	6.52	7.51	7.65	8.47	9.99	2.88
1976	0.60	1.23	1.91	2.77	3.69	4.61	5.55	7.00	7.72	8.54	9.23	2.68
1977	0.83	1.13	1.60	2.61	3.53	4.56	5.67	6.81	7.06	8.79	9.06	2.88
1978	0.84	1.23	1.80	2.68	3.95	4.62	5.79	6.59	6.77	7.58	7.93	3.14
1979	0.73	1.19	1.64	2.72	3.53	4.65	5.65	6.75	7.47	8.18	8.31	2.31
1980	0.95	1.39	1.95	2.78	3.51	4.21	5.65	6.48	7.72	7.87	8.84	3.02
1981	0.64	1.47	2.48	2.95	3.43	4.38	5.84	6.72	7.44	7.70	8.23	3.18
1982	0.59	1.12	2.55	3.50	4.15	4.51	5.28	6.22	7.34	7.79	8.27	3.26
1983	0.77	1.16	1.66	3.06	4.16	4.88	5.18	6.02	6.72	7.71	8.86	2.43
1984	0.76	1.46	2.15	2.63	3.51	5.15	5.75	5.99	6.52	7.53	8.52	2.71
1985	0.71	1.05	1.93	2.75	3.23	3.74	5.14	6.36	6.33	6.62	8.59	2.87
1986	0.57	1.13	1.84	2.59	3.40	3.85	4.87	6.26	6.84	6.71	8.05	2.93
1987	0.72	1.13	1.95	2.58	3.04	3.88	4.28	5.19	7.13	7.34	8.44	2.96
1988	1.17	1.31	1.84	2.66	3.28	3.61	4.40	4.65	5.96	8.11	8.78	3.05
1989	0.68	1.21	1.74	2.52	3.31	3.90	4.26	4.96	5.35	7.39	8.69	2.83
1990	0.49	1.22	1.89	2.56	3.03	3.93	4.29	5.04	5.35	6.51	8.48	2.82
1991	0.47	0.97	1.68	2.32	2.92	3.47	3.96	4.84	5.00	5.27	6.79	2.56
1992	0.47	1.04	1.69	2.55	3.39	3.96	4.51	5.10	5.82	6.21	8.03	2.50

Table A4. Continued.

Year	Weight (mt) landed at age											Total
	2	3	4	5	6	7	8	9	10	11	12+	
1970	334	812	3373	4154	3371	3277	2699	1501	873	400	65	20859
1971	1190	4131	5078	6318	6300	2702	1448	22	77	0	0	27265
1972	846	4036	7356	7928	4888	2874	717	3133	198	409	813	33197
1973	584	3413	17764	13980	2864	1404	642	1745	646	138	49	43228
1974	215	10231	6741	9133	5555	2044	1303	639	736	690	448	37734
1975	223	1841	10545	7868	9246	5300	1714	601	650	474	490	38952
1976	140	2694	5881	14698	5364	6184	1508	287	116	179	526	37578
1977	47	1986	6058	6366	10521	4780	3816	1402	572	396	2482	38426
1978	97	1908	6519	9866	7459	9637	3488	2708	1022	781	1816	45300
1979	218	4850	12277	12194	7710	3560	3002	1079	463	319	931	46603
1980	343	980	7417	18927	14374	6752	2651	2164	850	354	690	55501
1981	940	4033	3238	11361	16087	12051	5575	2023	1994	485	1218	59004
1982	140	5698	5743	2967	10791	11830	7094	3441	1937	1402	1803	52847
1983	64	3178	18669	5720	1754	4236	5080	3251	1861	1010	2322	47144
1984	97	1860	11154	25731	4386	1045	2117	1946	1258	444	1167	51205
1985	168	2457	5539	16011	25957	5220	1095	1513	2233	907	1521	62621
1986	66	1783	11370	11485	17726	17244	2323	871	1799	1739	2013	68419
1987	66	1612	6081	19670	12435	11813	9212	1413	584	1079	2195	66160
1988	32	1367	6409	11023	16440	8311	6359	5416	412	324	1528	57621
1989	49	874	9788	11936	9346	9656	4567	3734	2414	244	721	53330
1990	25	2238	5753	13147	8853	6873	4273	3086	1580	814	865	47506
1991	141	1517	7447	8723	13436	6387	3398	2024	1606	1081	1915	47677
1992	14	2138	9039	10348	7341	5659	2279	1331	1164	596	707	40615

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial Landings per Unit Effort

Commercial CPUE indices were calculated for U.S. tonnage class (TC) 3 and 4 side and stern trawlers (tons landed per day fished), and Canadian TC 5 stern trawlers (tons landed per hour fished) using 1970-1992 landings and effort data from trips in which pollock constituted 50% or more of the total landed weight or were recorded as the main species for the trip.

United States indices increased between 1970 and 1977, declined slightly between 1977 and 1984, then dropped sharply from 1985 through 1988 (Figure A2). Indices have since increased slightly but the average CPUE in 1990-1992 remains at about half the level observed in 1983 and 1984.

The Canadian regional catch rate series reflects the same general trend, *i.e.*, an increase in CPUE from the early 1970s through the early 1980s, followed by a decline in recent years. The Canadian regional series, however, has exhibited considerable interannual variability since the early 1980s, a possible result of trip limits and other regulatory measures imposed since 1983 (Annand *et al.* 1988). The International Observer Program (IOP) CPUE series more closely matches the U.S. CPUE series indicating a steady decline since 1986 (Figure A3).

Research Vessel Survey Indices

Pollock abundance and biomass indices exhibit considerable interannual variability due to schooling behavior and changes in spatial distribution patterns. Retransformed biomass indices derived from NEFSC surveys are more variable over time than retransformed abundance indices, although results from both spring and autumn surveys indicate a gradual increase in biomass through the mid-1970s, followed by a sharp decline (Figure A4a, A4b). The autumn series has remained relatively low through 1992, while spring indices suggest a recent increase in biomass in 1991 and 1992.

Canadian summer survey indices suggest that abundance remained relatively stable between

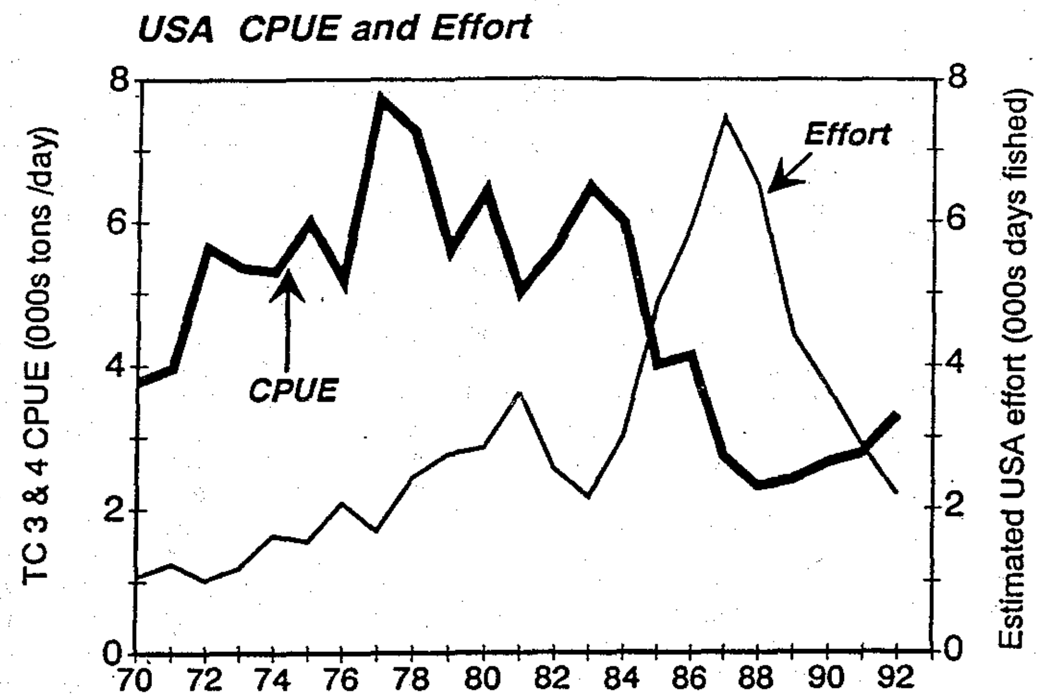


Figure A2. United States commercial pollock catch per unit effort (CPUE, landings per day fished, metric tons) and estimated fishing effort (days fished) based on otter trawl trips taking 50% or more pollock.

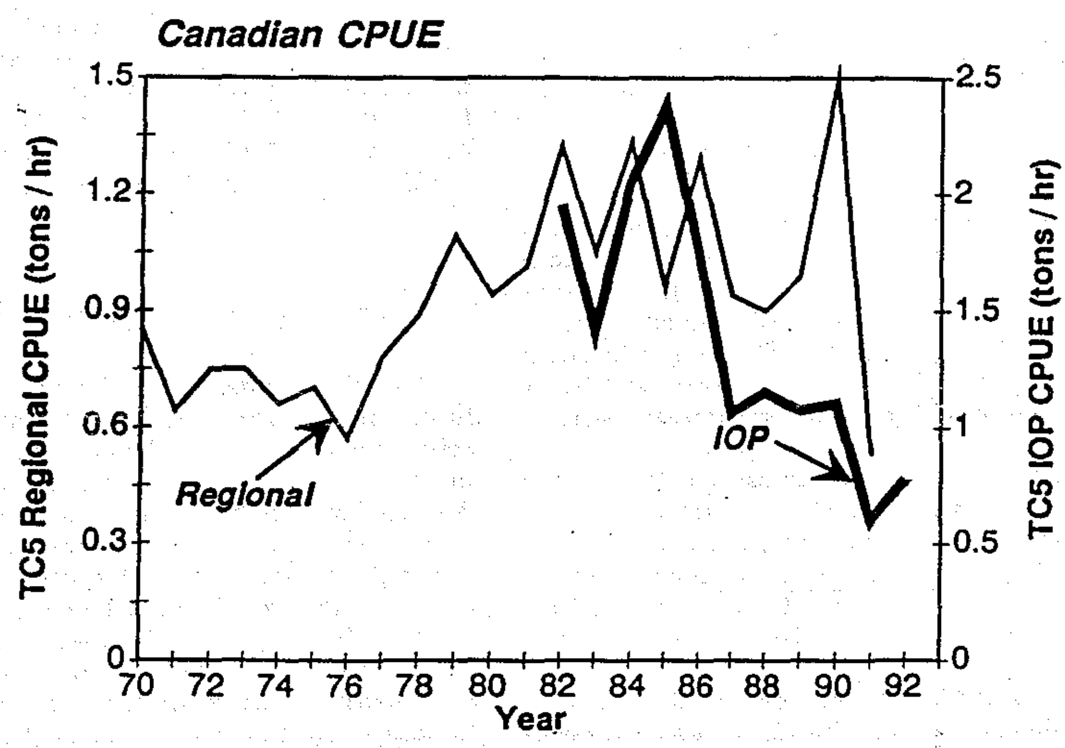
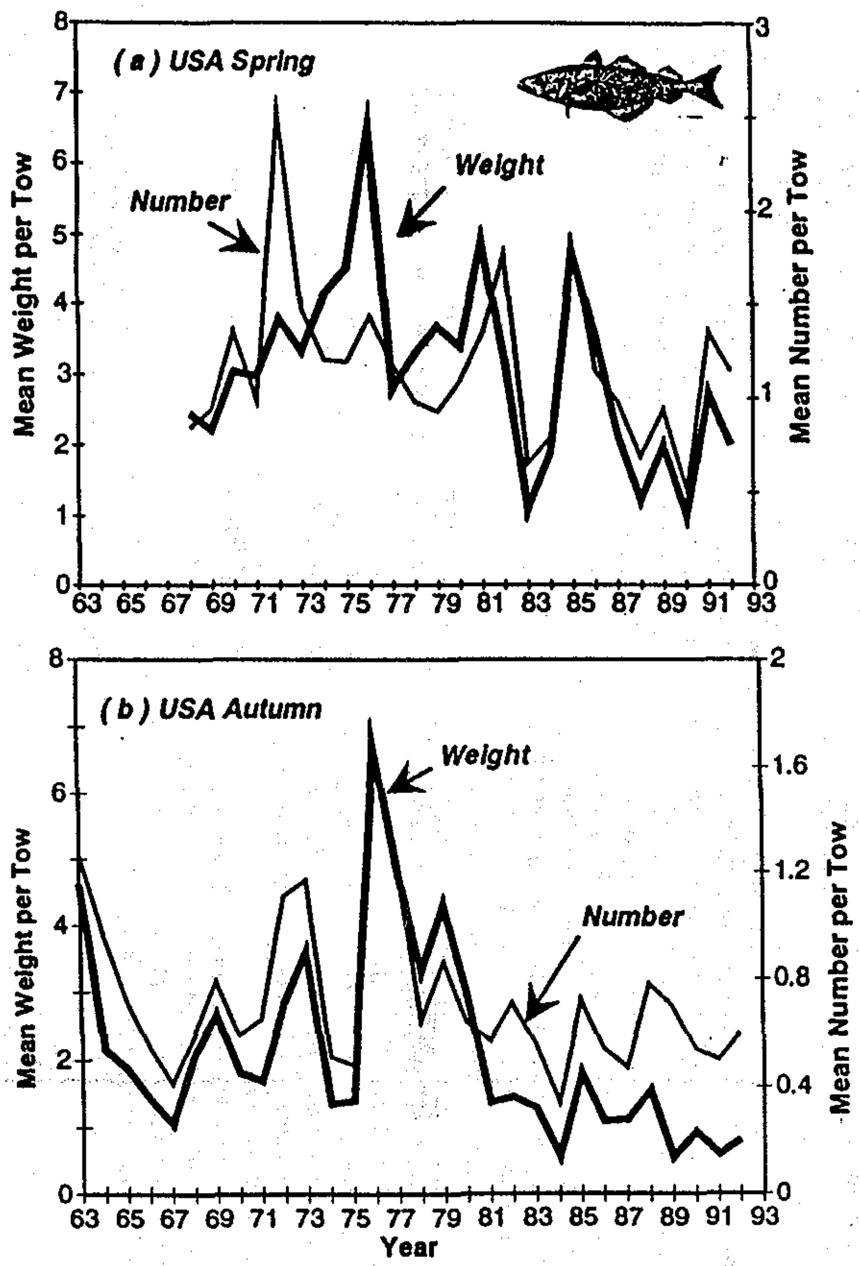


Figure A3. Canadian commercial pollock catch per unit effort (CPUE, landings per hour fished, metric tons) based on trip data and International Observer Program (IOP) logbooks.



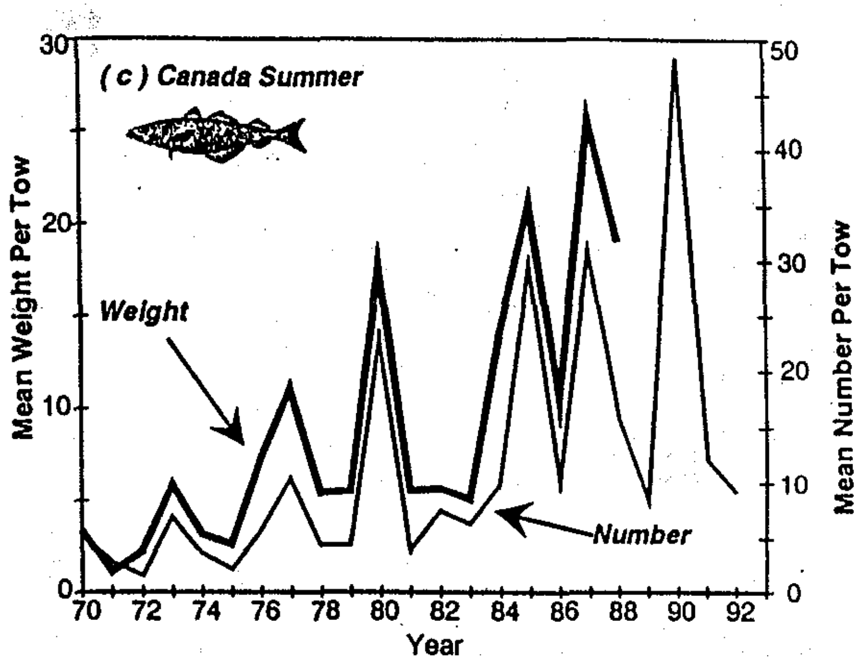


Figure A4. (a) United States (USA) spring and (b) USA autumn bottom trawl survey indices (retransformed stratified mean number and weight [kilograms] per tow), and (c) Canadian summer bottom trawl survey indices (stratified mean number and weight per tow) for Divisions 4VWX and Subareas 5 and 6 pollock.

Table A5. Stratified mean catch per tow in numbers and weight (kilograms) for pollock in Massachusetts inshore spring surveys, 1978-1992[1]

Year	Stratified Mean Number per Tow at Age				Total	Stratified Mean Weight Per Tow (kg)
	0	1	2	3+		
1978	2.07	0.01	0.13	0.06	2.27	0.11
1979	4.34	0.04	0.01	0.06	4.45	0.07
1980	0.30	8.37	0.20	0.02	8.89	0.72
1981	1.52	1.42	1.40	0.00	4.34	0.54
1982	1.79	0.00	0.06	0.00	1.85	0.03
1983	0.03	6.45	0.27	0.04	6.79	0.68
1984	0.04	0.00	0.02	0.00	0.06	0.01
1985	0.88	0.02	0.03	0.00	0.93	0.04
1986	0.22	0.01	0.00	0.00	0.23	<0.01
1987	0.23	0.01	0.03	0.00	0.27	0.02
1988	0.02	0.00	0.06	0.03	0.11	0.05
1989	0.01	0.36	0.45	0.20	1.02	0.34
1990	0.01	0.00	0.10	0.01	0.12	0.05
1991	0.00	0.00	0.02	0.03	0.05	0.03
1992	0.09	0.04	0.14	0.01	0.28	0.05

[1] Inshore surveys for Regions 1-5 (strata 11-21 and 25-36) (See Figure 4 and Howe *et al.* 1979).

1970 and 1983 except for a sharp increase in 1980 (Figure A4c). Canadian abundance and biomass indices increased in 1984 and but have fluctuated considerably since then. The 1991 and 1992 indices suggest only moderate to low levels of abundance on the Scotian Shelf.

Much of the variation in U.S. and Canadian offshore survey abundance indices may be explained by differences in year class strength. Peak abundance levels evident from NEFSC spring surveys in 1972, 1976, and 1982, and from NEFSC autumn surveys in 1972-1973 and 1976-1977 were due to recruitment of strong 1970, 1971, 1975, and 1979 year classes to offshore survey areas. Biomass indices are affected by recruitment and growth. Increases in NEFSC spring biomass indices during 1973-1975 and 1977-1981 resulted from growth in weight of individual fish from the 1971 and 1975 year classes. Relative strengths of dominant year classes derived from Canadian and USA bottom trawl surveys are consistent with commercial catch-at-age data. No relatively strong year classes are evident in the last two to three years in either survey series.

Indices from Massachusetts DMF surveys fluctuate considerably, but results for individual year classes appear to track incoming recruitment reasonably well (Table A5).

MORTALITY

Total Mortality

Research vessel catch per tow at age data available from U.S. and Canadian bottom trawl surveys have been analyzed on a cohort basis by Mayo *et al.* (1989) to estimate total instantaneous mortality (Z). These results suggest a general increase in Z on year classes prevalent during the mid-1980s compared to those that predominated in the 1970s. No further analyses of these data have been conducted.

Natural Mortality

As in previous Canadian and U.S. pollock assessments, M is assumed to equal 0.2.

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Virtual Population Analysis (VPA) Calibration

The ADAPT framework (Parrack 1986; Gavaris 1988; Conser and Powers 1990) was used to

Table A6. Estimates of instantaneous fishing mortality estimated from virtual population analysis (VPA) calibrated using the ADAPT procedure, 1970-1992

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
2	0.0217	0.0414	0.0336	0.0252	0.0111	0.0079	0.0056	0.0011	0.0037	0.0365	0.0178	0.0168	0.0044	0.0022	0.0025	0.0078	0.0038	0.0025
3	0.0564	0.1221	0.0767	0.1521	0.2176	0.0777	0.0855	0.0524	0.0364	0.1737	0.1129	0.1825	0.0748	0.0654	0.0421	0.0580	0.0662	0.0595
4	0.2455	0.3392	0.1904	0.5276	0.2962	0.2414	0.2384	0.2085	0.1458	0.2471	0.2424	0.3150	0.2232	0.2340	0.1695	0.1255	0.2132	0.1807
5	0.3301	0.5810	0.4811	0.7122	0.3313	0.3763	0.4073	0.3016	0.3228	0.2708	0.3726	0.4154	0.3481	0.2924	0.3288	0.2917	0.2912	0.4448
6	0.3887	0.8056	0.5876	0.3490	0.3953	0.4772	0.3802	0.4222	0.4036	0.3230	0.4270	0.4786	0.5525	0.2922	0.3251	0.4960	0.4630	0.4660
7	0.3718	0.4337	0.6230	0.3645	0.3355	0.6044	0.5406	0.5235	0.5954	0.2826	0.4189	0.5737	0.5431	0.3577	0.2224	0.7417	0.5754	0.5459
8	1.5197	0.2058	0.1448	0.2551	0.5041	0.3812	0.3078	0.5785	0.6582	0.2921	0.2805	0.4751	0.6213	0.3994	0.2519	0.3845	0.6153	0.6092
9	0.5922	0.0286	0.5571	0.5852	0.4018	0.3577	0.0925	0.4056	0.8777	0.3600	0.3019	0.2927	0.5623	0.5493	0.2217	0.2566	0.4679	0.8970
10	3.2804	0.0379	0.3670	0.2525	0.4771	0.7652	0.1037	0.2664	0.5939	0.2997	0.4524	0.4237	0.4530	0.6194	0.3851	0.3994	0.5022	0.5620
11	0.5815	0.2931	0.4375	0.3746	0.3955	0.5416	0.4260	0.5112	0.6427	0.2955	0.3708	0.5112	0.5671	0.4267	0.2525	0.5230	0.5798	0.5894
12+	0.5815	0.2931	0.4375	0.3746	0.3955	0.5416	0.4260	0.5112	0.6427	0.2955	0.3708	0.5112	0.5671	0.4267	0.2525	0.5230	0.5798	0.5894
6+(w)	0.5671	0.5421	0.5092	0.3637	0.3949	0.5006	0.4084	0.4544	0.5328	0.3102	0.4031	0.4929	0.5574	0.4030	0.2861	0.5049	0.5152	0.5298
6+(u)	1.1224	0.3008	0.4528	0.3635	0.4182	0.5212	0.3085	0.4512	0.6286	0.3088	0.3752	0.4592	0.5499	0.4408	0.2765	0.4669	0.5340	0.6116
7+(u)	1.3911	0.1988	0.4258	0.3664	0.4228	0.5300	0.2942	0.4570	0.6736	0.3060	0.3648	0.4553	0.5493	0.4705	0.2668	0.4610	0.5482	0.6407

	1988	1989	1990	1991	1992	GM F 1988-91	Partial Recruitment
2	0.0011	0.0016	0.0009	0.0108	0.0006	0.0020	0.0029
3	0.0348	0.0360	0.0518	0.0350	0.0952	0.0388	0.0565
4	0.2018	0.2647	0.2094	0.1717	0.1611	0.2093	0.3048
5	0.3875	0.4640	0.4119	0.4322	0.2348	0.4230	0.6160
6	0.5975	0.5009	0.5898	0.8174	0.4797	0.6163	0.8974
7	0.5393	0.6777	0.6776	0.9657	0.6538	0.6993	1.0183
8	0.5461	0.5212	0.6487	0.8676	0.7860	0.6363	0.9266
9	0.8080	0.6195	0.6481	0.6303	0.7199	0.6725	0.9793
10	0.5977	0.8877	0.5295	0.8775	0.7199	0.7046	1.0260
11	0.5966	0.6498	0.6615	0.8979	0.7199	0.6927	1.0087
12+	0.5966	0.6498	0.6615	0.8979	0.7199	0.6927	1.0087
6+(w)	0.5950	0.5842	0.6234	0.8456	0.5793		
6+(u)	0.6142	0.6428	0.6259	0.8427	0.6799		
7+(u)	0.6175	0.6711	0.6331	0.8477		0.6867	1.0000

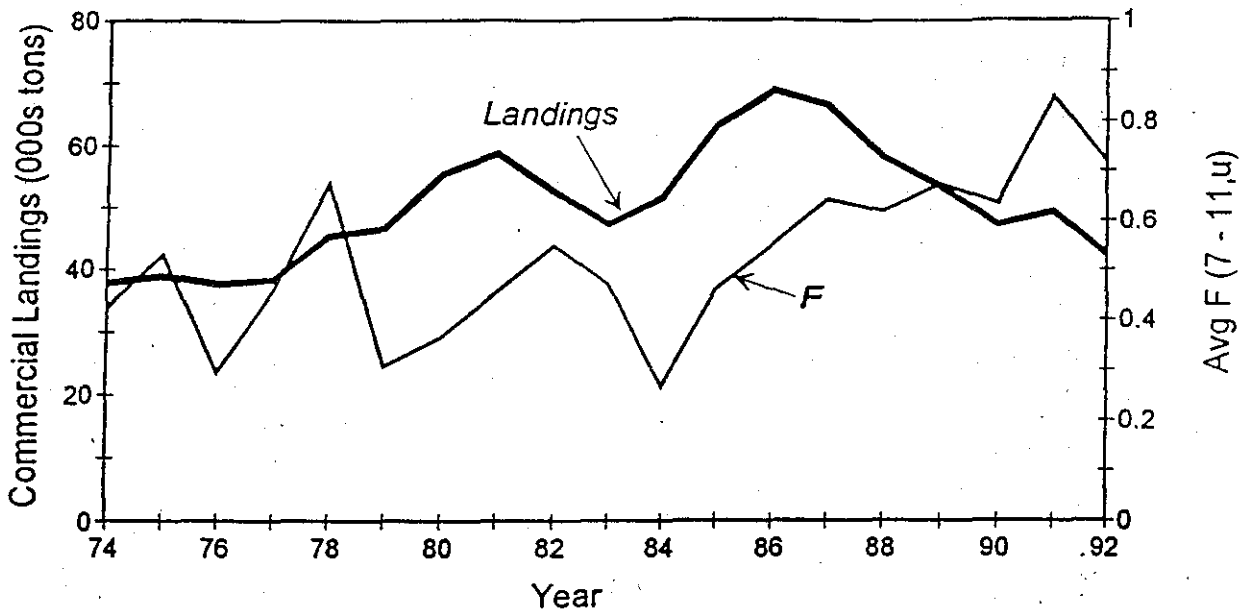


Figure A5. Trends in commercial landings (metric tons, live) and fishing mortality (F) for Divisions 4VWX and Subareas 5 an 6 pollock.

calibrate VPA stock sizes and derive estimates of terminal F values in 1992. The total stock catch-at-age (Table A4) was provided to the VPA with true ages 2 to 11 and a 12+ group represented from 1970 to 1992. Calibration of the VPA, however, was carried out only on data from 1974 to 1992 due to the poor quality of the catch-at-age estimates from 1970 to 1973 (Mayo et *al.* 1989). The initial formulation employed 35 age-specific indices including: U.S. spring and autumn and Canadian summer bottom trawl survey indices for ages 2 to 10; Massachusetts DMF spring bottom trawl survey indices for ages 1 to 3; and U.S. commercial otter trawl CPUE for ages 4 to 8 as in the previous assessment (NEFC 1989). All indices received equal weight. The U.S. autumn survey was lagged by one year and age to equate autumn abundance of a given cohort with corresponding January 1 stock sizes of the following year. Canadian summer survey and U.S. commercial CPUE indices were related to corresponding mid-year stock sizes. A flat-topped partial recruitment vector was employed with full recruitment on age 7 and older as indicated from a separable VPA (Pope and Shepherd 1982) on the 1981-1992 catch-at-age data.

The ADAPT formulation employed in the VPA calibration provided direct estimates of F on ages 2 through 8 in 1992. Since the age at full recruitment was defined as 7 years in the input partial recruitment vector, F's on ages 9 to 11 were estimated as the mean of fully recruited ages 7 and 8 in the terminal year. In all years prior to the terminal year, F on the oldest true age (11) was determined from weighted estimates of Z for ages 7 to 11. In all years, the age 11 F was applied to the 12+ group.

Several preliminary trials were attempted to estimate 1993 stock sizes at ages ranging from 2 to 10. Stock size estimates for ages 2 and 10 were in all cases non significant. A subsequent calibration was performed including only ages 3 through 9 with all indices receiving equal weight. Coefficients of variation (CVs) on the stock size estimates ranged from 37% (age 5) to 52% (age 3). Coefficients of variation on the estimated qs ranged from 26 to 30% except for the Massachusetts DMF surveys which ranged from 31 to 38%.

Additional indices were included in the final formulation by expanding the U.S. commercial CPUE to include ages 4 through 9, adding Canadian tonnage class 5 CPUE indices for ages 4 through 9 and adding age-aggregated commercial CPUE indices for U.S. and Canadian otter trawl fleets. Forty-four indices were included in final calibrations. High residuals in the U.S. autumn age 2 and Massachusetts spring age 1 indices were reduced by eliminating the terminal year index for these ages. Coefficients of variation on the age 3 through 9 stock size estimates were reduced from the original formulation, ranging from 29% (age 5) to 48% (age 9). Coefficients of variation on the estimated qs ranged from 21 to 31%. Correlations among parameters and indices were generally quite low with most values between 0.05 and 0.10.

Table A7. Estimates of beginning year stock sizes estimated from virtual population analysis (VPA) calibrated using the ADAPT proceudure, 1970-1992

Stock Numbers (Jan 1) in thousands - Totals

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
2	29149.049	41327.662	26676.482	51905.483	26209.027	36348.721	46595.211	58528.115	34730.802	9231.081
3	11875.564	23352.180	32462.685	21118.796	41439.765	21221.974	29524.558	37937.200	47868.096	28331.119
4	7834.904	9189.941	16922.203	24614.701	14851.166	27293.742	16075.736	22191.070	29475.982	37790.394
5	5346.433	5018.513	5359.716	11452.384	11890.742	9041.941	17553.302	10370.276	14749.131	20859.191
6	3061.201	3146.710	2298.231	2712.405	4599.783	6990.040	5081.103	9563.123	6279.946	8743.956
7	2441.674	1699.184	1151.189	1045.563	1566.532	2536.309	3551.351	2844.421	5133.207	3434.157
8	656.405	1378.355	901.657	505.478	594.536	917.014	1134.619	1693.308	1379.641	2317.033
9	524.285	117.575	918.579	638.682	320.652	294.035	512.815	682.831	777.408	584.842
10	141.249	237.423	93.548	430.852	291.271	175.663	168.348	382.759	372.659	264.600
11	110.280	4.350	187.147	53.065	274.031	147.988	66.910	124.259	240.085	168.477
12+	19.826	4.322	262.772	17.549	150.993	128.122	180.034	748.981	527.275	480.660
2+	61141.045	85471.892	86971.436	114477.409	102037.504	104967.428	120263.953	144317.363	141006.956	111724.849
6+	6935.095	6583.597	5550.351	5386.044	7646.804	11061.049	10515.145	15290.702	14182.945	15513.064

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
2	22647.299	97229.724	58770.705	41961.183	56278.771	33518.607	33428.692	41391.960	27560.800	48976.576
3	7287.223	18215.394	78279.378	47903.842	34279.809	45961.342	27230.078	27265.947	33805.625	22540.444
4	19497.488	5329.268	12425.200	59471.444	36738.380	26909.552	35508.120	20866.269	21034.981	26731.245
5	24165.640	12526.620	3184.233	8137.914	38532.490	25389.069	19433.890	23489.648	14259.858	14074.961
6	13026.200	13630.449	6769.591	1840.632	4973.429	22707.473	15527.896	11890.930	12326.883	7924.433
7	5182.780	6958.736	6915.075	3189.895	1125.140	2941.757	11320.938	8001.678	6108.882	5552.829
8	2119.449	2791.038	3209.933	3289.101	1826.266	737.505	1147.164	5213.319	3795.085	2916.784
9	1416.558	1310.889	1420.989	1411.970	1806.148	1162.240	411.088	507.611	2321.094	1799.663
10	334.054	857.564	800.909	663.032	667.411	1184.676	736.210	210.798	169.481	847.121
11	160.536	173.968	459.617	416.852	292.205	371.796	650.523	364.786	98.390	76.325
12+	276.096	404.572	550.539	826.453	674.543	475.421	620.898	637.887	423.096	189.608
2+	95837.227	159023.650	172235.630	168285.864	176520.049	160884.018	145394.599	139202.945	121481.080	131440.381
6+	22239.577	25722.644	19576.115	10811.481	10690.599	29105.448	29793.820	26189.122	24819.815	19117.155

	1990	1991	1992	1993
2	61602.709	30870.806	(34269.000)	(34675.000)
3	40033.480	50389.885	25003.427	(28040.000)
4	17802.167	31120.789	39835.154	18611.633
5	16795.077	11821.761	21459.354	27761.623
6	7245.532	9107.925	6282.080	13893.079
7	3931.812	3289.110	3292.877	3183.454
8	2308.609	1634.725	1025.280	1402.062
9	1418.075	988.006	562.049	382.485
10	793.001	607.261	430.689	224.004
11	285.482	382.328	206.731	171.651
12+	230.044	517.400	186.960	156.905
2+	152215.945	140212.596	155929.531	112952.850
6+	15982.511	16009.355	11799.705	19256.736

(Values in parentheses derived from RCT3)

Table A8. Estimates of mean (mid-year) biomass (metric tons) estimated from virtual population analysis (VPA) calibrated using the ADAPT procedure, 1970-1992

Mean (mid-year) Biomass (mt)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
2	15424.718	28639.246	25216.911	23238.199	19374.836	28223.889	25270.797	44006.284	26394.832	6001.246
3	14456.105	33940.359	52745.752	22607.860	47426.283	23718.277	31590.773	37887.593	52436.012	28131.440
4	13846.285	15059.531	38807.089	34101.532	22946.347	43912.101	24859.121	29147.940	44855.616	49974.144
5	12657.060	11006.603	16636.180	19907.493	27765.555	21098.061	36442.919	21284.168	30782.724	45251.252
6	8746.019	7937.933	8413.846	8265.744	14177.086	19550.752	14225.784	25133.417	18623.350	24035.265
7	8888.993	6280.344	4668.001	3882.863	6137.405	8869.328	11565.039	9231.600	16356.574	12667.215
8	1823.566	7069.677	4972.335	2529.870	2612.003	4534.313	4937.771	6670.940	5362.024	10339.612
9	2563.752	762.003	5688.600	3013.260	1604.594	1692.609	3112.350	3487.993	3135.620	3022.682
10	279.275	2032.599	542.667	2571.384	1557.418	861.938	1120.865	2159.630	1741.242	1555.644
11	695.595	31.214	942.402	370.142	1759.223	885.064	424.704	781.618	1229.751	1086.758
12+.	111.572	27.668	1857.564	130.422	1132.036	903.759	1235.084	4855.969	2825.487	3149.772
2+.	79381.368	112759.509	153633.785	120488.347	145360.751	153346.331	153550.124	179791.182	200917.746	182065.258
6+.	22997.200	24113.770	25227.852	20633.263	27847.730	36394.003	35386.514	47465.197	46448.561	52707.175
SSB	57072.664	61709.630	87392.715	99963.655	88968.623	107900.408	112496.423	121151.386	136903.410	154126.564

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1	53817.323	32529.991	23225.804	31150.688	18552.781	18503.012	22910.735	15255.093	27108.873	34097.524
2	19333.431	55943.975	31359.833	29253.194	38719.001	21488.530	17238.362	26979.038	29210.867	30161.309
3	8697.610	22250.160	76658.702	48806.399	44451.373	42535.712	27015.108	27137.961	39470.488	24294.634
4	30723.964	10329.439	25833.567	80090.105	66037.357	44330.795	53518.643	33840.276	31873.505	37200.716
5	51146.562	27596.382	8579.788	19664.593	78704.971	55154.153	39769.087	44666.480	28684.762	25918.433
6	33968.089	33942.901	19743.086	6047.212	13580.527	52839.637	38596.754	26391.258	27861.560	18856.486
7	16268.828	21221.072	22006.962	11931.748	4726.252	7127.192	30323.967	21880.423	15587.805	14416.087
8	9508.500	11852.397	11559.306	12815.260	8448.650	2870.628	3820.063	15297.898	11767.550	8852.837
9	7217.287	6955.497	6184.683	5981.627	8827.077	5934.333	1877.229	1599.758	6799.912	6092.569
10	1894.247	4747.018	4316.860	3041.317	3294.375	5640.506	3617.950	1051.849	695.979	2762.587
11	962.690	958.610	2500.123	2388.047	1769.786	1752.232	3031.058	1851.529	550.074	379.996
12+.	1859.738	2382.737	3179.224	5440.745	4622.619	2907.368	3470.766	3722.909	2560.843	1110.049
2+.	179721.209	195797.451	208742.911	220019.502	268559.369	239673.718	218808.221	200696.470	192502.502	168935.654
6+.	69819.641	79677.494	66311.020	42205.212	40646.666	76164.528	81267.021	68072.715	63262.880	51360.562
SSB	156623.661	146837.621	138795.873	154399.771	182932.336	203759.954	192095.242	172820.512	150703.151	136934.895

Table A8. Continued.

	1990	1991	1992
2	27346.257	13082.038	24628.559
3	43176.147	43558.798	22516.526
4	27610.086	43665.692	56506.616
5	32158.514	20327.792	44377.508
6	15179.089	16689.817	15453.599
7	10286.333	6739.142	8769.586
8	6675.278	3978.676	2940.075
9	4818.439	3248.712	1874.098
10	3011.601	1858.538	1638.833
11	1245.782	1223.025	839.353
12+	1307.641	2132.479	981.548
2+	171507.526	154372.229	179544.753
6+	41216.522	33737.909	31515.544
SSB	123812.747	121976.770	125134.568

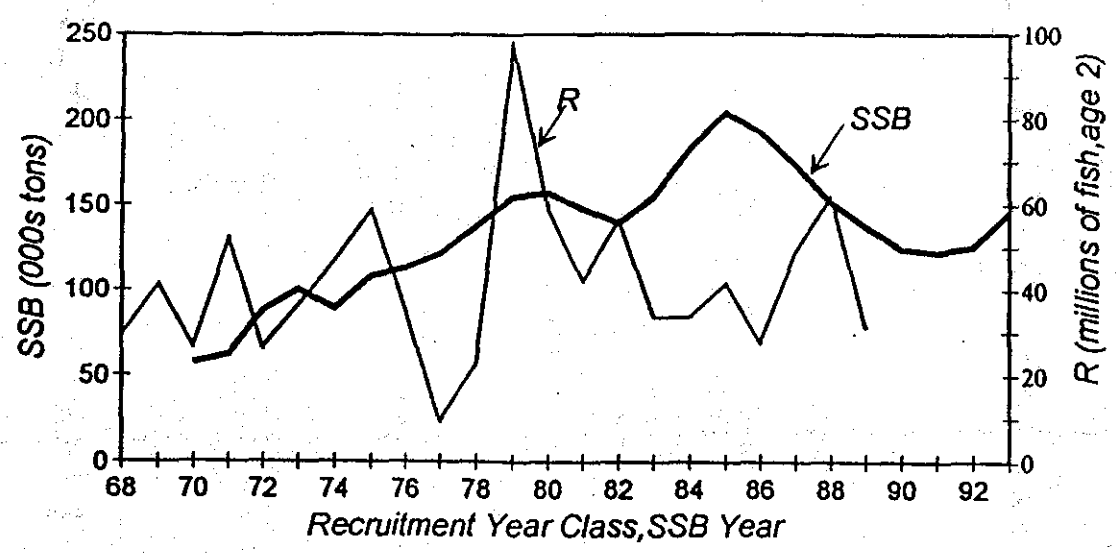


Figure A6. Trends in recruitment (R) and spawning stock biomass (SSB) for Divisions 4VWX and Subareas 5 and 6 pollock.

Fishing Mortality Estimates

Fishing mortality estimates for ages 7 and 8 in the terminal year equalled 0.65 and 0.79, respectively (Table A6, Figure A5). The mean of these (0.72) was applied to ages 9 through 12+. The mean unweighted F for ages 7 to 11 increased during the mid-1980s and has remained essentially unchanged since 1987, fluctuating between 0.6 and 0.7, except in 1991 when the mean F increased to 0.85. This suggests that exploitable stock size has declined approximately in proportion to the steady decline in landings since 1987.

Stock Size and Spawning Stock Biomass Estimates

Total (age 2+) stock size has declined from a peak level of 172 million fish in 1982 to 121 million fish in 1988 before increasing to an estimated 152 million fish in 1990 (Table A7). In recent years, age 6+ stock size has declined from 30 million fish in 1986 to 14 million in 1992, a decline of about 50%. Mean (mid-year) age 6+ stock biomass has also declined from a maximum of 81,000 mt in 1986 to approximately 31,000-34,000 mt in 1991 and 1992 (Table A8), a decline of about 60%. Total catch, after peaking at 69,000 mt in 1986 has declined to about 42,000 mt in 1992, a 40% decline (Table A1, Figure A5).

Spawning stock biomass (SSB), adjusted to the spawning period (January 1 for pollock), has declined in recent years from a maximum of 204,000 mt in 1985 to 122,000 mt in 1991 (Table A8, Figure A6), a 41% decline. Compared to the mid-1980s, when the SSB was dominated by up to six moderate to strong year classes, current SSB is composed of only two to three moderate year classes.

Recruitment Estimates

Since 1970, recruitment at age 2 has ranged from approximately 10 million (1977 year class) to 97 million (1979 year class) fish with most estimates between 25 and 50 million fish (Table A7, Figure A6). Over the 1970-1991 period, geometric mean recruitment for the 1968-1989 year classes equalled 38.2 million fish. The 1980 and 1982 year classes, at about 59 and 56 million fish, respectively, are the strongest to have recruited during the 1980s with the 1981 and 1985 year classes slightly above the long-term mean and the 1987 and 1988 year classes well above the mean. The 1990 year class, estimated to be about 58 million fish by the VPA is considered to be uncertain due to minimum catch-at-age data for age 2.

Precision of F and SSB

To evaluate the precision of the final estimates, a bootstrap procedure (Effron 1982) was used to generate distributions of the 1992 fishing mortality rate and spawning stock biomass. Figure A7 shows the distribution of the bootstrap estimates and a cumulative probability curve. The cumulative probability expresses the likelihood that the fishing mortality rate was greater than a given level (Figure A7b) or the likelihood that spawning stock biomass was less than a given level (Figure A7a) when measurement error is considered. The precision of the 1993 stock size, q, 1992 fishing mortality, and 1992 spawning stock biomass estimates are presented in Table A9.

Coefficients of variation for the 1993 stock size estimates ranged from 27% (age 6) to 55% (age 3), and CVs for qs among all indices ranged from 18 to 36%. The fully recruited fishing mortality for ages 7+ was reasonably well estimated (CV = 0.22). The mean bootstrap estimate of F (0.75) was slightly higher than the point estimate from the VPA (0.72) and ranged from 0.45 to 1.30 (Figure A7b). F_{med} is about equal to the lowest bootstrap estimate, and F_{1992} is almost certainly above the F_{med} level.

Although the abundance estimates of individual ages in 1993 had wider variances (CV = 0.27 to 0.55), the estimate of 1992 spawning stock biomass was robust (CV = 0.12). The bootstrap mean (128,800 mt) was slightly higher than the VPA point estimate (125,100 mt) and ranged from 100,000 to 190,000 t. Spawning stock biomass is currently at its lowest level since 1977.

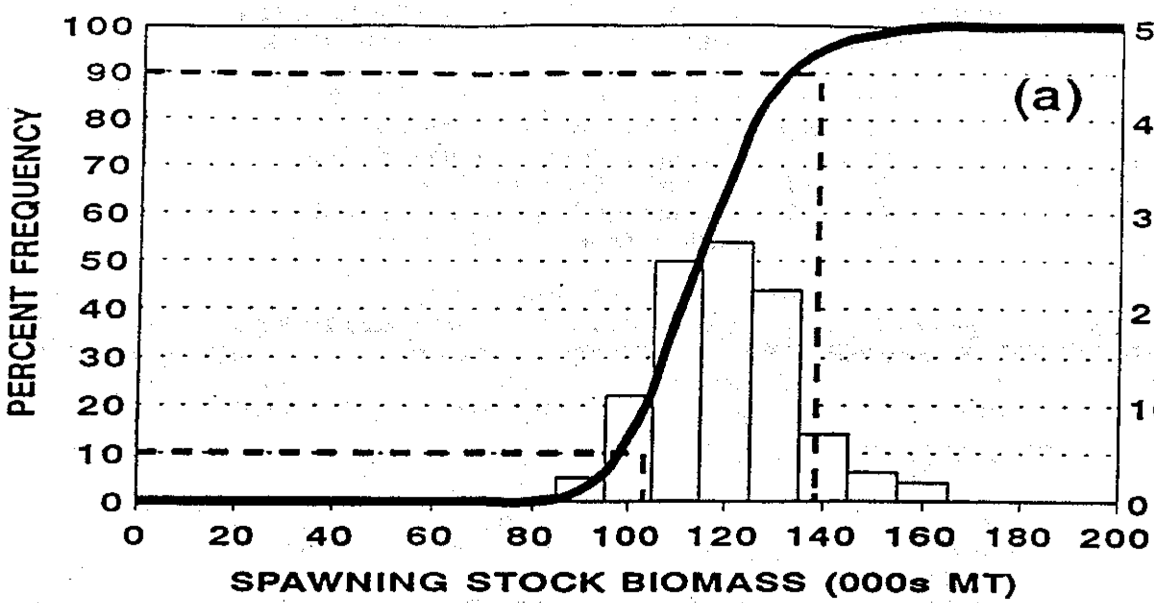
BIOLOGICAL REFERENCE POINTS

Stock Recruitment Relationship

An estimate of F_{med} was derived by calculating the median slope of the R/SSB plot based on 20 spawning stock biomass and recruitment esti-

SCOTIAN SHELF-GULF OF MAINE-GEORGES BANK POLLOCK

PRECISION ESTIMATES - SSB



SCOTIAN SHELF-GULF OF MAINE-GEORGES BANK POLLOCK

PRECISION ESTIMATES - FISHING MORTALITY

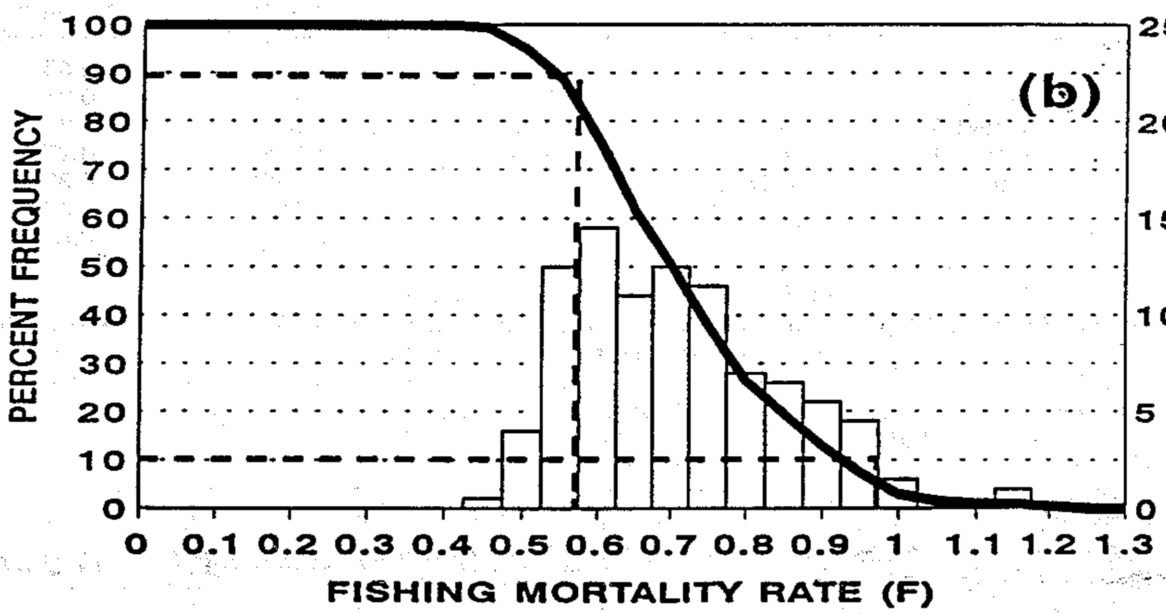


Figure A7. Precision estimates of spawning stock biomass (SSB) and fishing mortality (F) rate for Scotian Shelf-Gulf of Maine-Georges Bank pollock. The vertical bars display both the range of the estimators and the probability of individual values within the range. The solid line gives the probability that the SSB is less than any selected value on the X-axis, and the probability that SSB is greater than any selected value on the X-axis. The dashed lines indicate the value of the 10 to 90 percent probability levels. the precision estimates were derived from 200 bootstrap iterations of the final ADAPT formulation.

Table A9. Bootstrap results for stock size (N), catchability (q), and fishing mortality (F)

Bootstrap Results for Total Stock Timestamp 1993 6 19 14 41 41
Pollock: Scotian Shelf, Georges Bank, Gulf of Maine Stock

Seed for the random number generator: 74747
Main loop limit in Marquardt algorithm: 50
Number of bootstrap replications attempted: 200
Number for which NLLS Converged: 200
Results from the converged replications are used for computing the statistics that follow. Other replications are ignored.

Bootstrap Output Variable: N hat
Age-specific stock sizes (on Jan 1, 1993) estimated by NLLS

Age	NLLS Estimate	Bootstrap Mean	Bootstrap Std.Error	CV for NLLS SOLN
3	4.732E4	5.110E4	2.411E4	0.51
4	1.861E4	2.004E4	6.609E3	0.36
5	2.776E4	2.902E4	8.600E3	0.31
6	1.389E4	1.451E4	3.601E3	0.26
7	3.184E3	3.118E3	1.198E3	0.38
8	1.400E3	1.472E3	6.257E2	0.45
9	3.827E2	4.242E2	1.844E2	0.48

Age	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Est. Corrected for Bias	CV for Corrected Estimate
3	3.777E3	1.705E3	7.98	4.354E4	0.55
4	1.433E3	4.673E2	7.70	1.718E4	0.38
5	1.254E3	6.081E2	4.52	2.651E4	0.32
6	6.157E2	2.546E2	4.43	1.328E4	0.27
7	-6.552E1	8.469E1	-2.06	3.249E3	0.37
8	7.193E1	4.425E1	5.14	1.329E3	0.47
9	4.149E1	1.304E1	10.84	3.412E2	0.54

Bootstrap Output Variable: q unscaled
Catchability estimates (q) for each index of abundance used in the ADAPT run. Note that these q's have been rescaled to original units.

Index	NLLS Estimate	Bootstrap Mean	Bootstrap Std. Error	CV for NLLS SOLN
USRVSP 2	4.367E-6	4.413E-6	8.609E-7	0.20
USRVSP 3	5.865E-6	5.807E-6	1.194E-6	0.20
USRVSP 4	7.253E-6	7.332E-6	1.659E-6	0.23
USRVSP 5	9.715E-6	1.007E-5	2.125E-6	0.22
USRVSP 6	2.006E-5	2.054E-5	4.255E-6	0.21
USRVSP 7	2.546E-5	2.544E-5	4.965E-6	0.19
USRVSP 8	3.334E-5	3.358E-5	7.325E-6	0.22
USRVSP 9	4.435E-5	4.571E-5	1.032E-5	0.23
USRVSP10	6.918E-5	7.069E-5	1.706E-5	0.25
CNRVSU 2	4.937E-6	5.124E-6	1.081E-6	0.22
CNRVSU 3	2.151E-5	2.140E-5	3.972E-6	0.18
CNRVSU 4	4.499E-5	4.574E-5	9.780E-6	0.22
CNRVSU 5	9.624E-5	9.782E-5	2.212E-5	0.23
CNRVSU 6	1.149E-4	1.182E-4	2.415E-5	0.21
CNRVSU 7	1.337E-4	1.383E-4	2.847E-5	0.21
CNRVSU 8	1.802E-4	1.831E-4	3.606E-5	0.20
CNRVSU 9	1.503E-4	1.539E-4	3.172E-5	0.21

Table A9. Continued.

Index	NLLS Estimate	Bootstrap Mean	Bootstrap Std. Error	CV for NLLS SOLN
CNRVSU10	1.970E-4	2.083E-4	4.501E-5	0.23
USRVFL 2	2.372E-6	2.403E-6	5.250E-7	0.22
USRVFL 3	4.018E-6	4.079E-6	8.870E-7	0.22
USRVFL 4	5.480E-6	5.623E-6	1.036E-6	0.19
USRVFL 5	8.906E-6	9.048E-6	1.781E-6	0.20
USRVFL 6	1.247E-5	1.284E-5	2.773E-6	0.22
USRVFL 7	1.699E-5	1.714E-5	3.467E-6	0.20
USRVFL 8	3.145E-5	3.224E-5	6.636E-6	0.21
USRVFL 9	5.445E-5	5.519E-5	1.339E-5	0.25
USRVFL10	8.922E-5	9.085E-5	2.212E-5	0.25
MARVSP 1	3.054E-6	3.022E-6	9.092E-7	0.30
MARVSP 2	2.131E-6	2.219E-6	5.579E-7	0.26
MARVSP 3	1.123E-6	1.170E-6	3.835E-7	0.34
USCPUE 4	1.783E-5	1.834E-5	4.181E-6	0.23
USCPUE 5	2.839E-5	2.882E-5	5.235E-6	0.18
USCPUE 6	3.528E-5	3.656E-5	7.478E-6	0.21
USCPUE 7	3.891E-5	3.985E-5	9.012E-6	0.23
USCPUE 8	4.100E-5	4.152E-5	8.049E-6	0.20
USCPUE 9	3.823E-5	3.888E-5	8.130E-6	0.21
CNCPUE 4	9.127E-5	9.119E-5	1.955E-5	0.21
CNCPUE 5	1.614E-4	1.656E-4	3.658E-5	0.23
CNCPUE 6	2.123E-4	2.216E-4	4.540E-5	0.21
CNCPUE 7	2.411E-4	2.501E-4	4.992E-5	0.21
CNCPUE 8	2.096E-4	2.108E-4	4.130E-5	0.20
CNCPUE 9	1.790E-4	1.850E-4	3.609E-5	0.20
USCPUEAG	9.075E-5	9.388E-5	2.177E-5	0.24
CNCPUEAG	1.890E-5	1.949E-5	3.682E-6	0.19

Index	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Est. Corrected for Bias	CV for Corrected Estimate
USRVSP 2	4.633E-8	6.088E-8	1.06	4.320E-6	0.20
USRVSP 3	-5.767E-8	8.445E-8	-0.98	5.922E-6	0.20
USRVSP 4	7.906E-8	1.173E-7	1.09	7.174E-6	0.23
USRVSP 5	3.540E-7	1.503E-7	3.64	9.361E-6	0.23
USRVSP 6	4.855E-7	3.009E-7	2.42	1.957E-5	0.22
USRVSP 7	-1.756E-8	3.510E-7	-0.07	2.548E-5	0.19
USRVSP 8	2.410E-7	5.180E-7	0.72	3.310E-5	0.22
USRVSP 9	1.361E-6	7.299E-7	3.07	4.299E-5	0.24
USRVSP10	1.511E-6	1.206E-6	2.18	6.767E-5	0.25
CNRVSU 2	1.862E-7	7.642E-8	3.77	4.751E-6	0.23
CNRVSU 3	-1.123E-7	2.809E-7	-0.52	2.163E-5	0.18
CNRVSU 4	7.499E-7	6.915E-7	1.67	4.424E-5	0.22
CNRVSU 5	1.583E-6	1.564E-6	1.64	9.466E-5	0.23
CNRVSU 6	3.278E-6	1.707E-6	2.85	1.116E-4	0.22
CNRVSU 7	4.587E-6	2.013E-6	3.43	1.291E-4	0.22
CNRVSU 8	2.856E-6	2.550E-6	1.58	1.773E-4	0.20
CNRVSU 9	3.635E-6	2.243E-6	2.42	1.467E-4	0.22
CNRVSU10	1.127E-5	3.182E-6	5.72	1.858E-4	0.24
USRVFL 2	3.082E-8	3.712E-8	1.30	2.341E-6	0.22
USRVFL 3	6.137E-8	6.272E-8	1.53	3.957E-6	0.22
USRVFL 4	1.438E-7	7.324E-8	2.62	5.336E-6	0.19
USRVFL 5	1.420E-7	1.260E-7	1.59	8.764E-6	0.20
USRVFL 6	3.742E-7	1.960E-7	3.00	1.209E-5	0.23
USRVFL 7	1.434E-7	2.451E-7	0.84	1.685E-5	0.21
USRVFL 8	7.907E-7	4.693E-7	2.51	3.066E-5	0.22
USRVFL 9	7.466E-7	9.466E-7	1.37	5.370E-5	0.25

Table A9. Continued.

Index	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Est. Corrected for Bias	CV for Corrected Estimate
USRVFL10	1.628E-6	1.564E-6	1.82	8.759E-5	0.25
MARVSP 1	-3.164E-8	6.429E-8	-1.04	3.086E-6	0.29
MARVSP 2	8.845E-8	3.945E-8	4.15	2.042E-6	0.27
MARVSP 3	4.646E-8	2.712E-8	4.14	1.077E-6	0.36
USCPUE 4	5.078E-7	2.956E-7	2.85	1.732E-5	0.24
USCPUE 5	4.305E-7	3.702E-7	1.52	2.796E-5	0.19
USCPUE 6	1.285E-6	5.288E-7	3.64	3.399E-5	0.22
USCPUE 7	9.405E-7	6.372E-7	2.42	3.796E-5	0.24
USCPUE 8	5.232E-7	5.691E-7	1.28	4.048E-5	0.20
USCPUE 9	6.536E-7	5.749E-7	1.71	3.758E-5	0.22
CNCPUE 4	-7.343E-8	1.383E-6	-0.08	9.134E-5	0.21
CNCPUE 5	4.180E-6	2.586E-6	2.59	1.572E-4	0.23
CNCPUE 6	9.362E-6	3.210E-6	4.41	2.029E-4	0.22
CNCPUE 7	9.004E-6	3.530E-6	3.73	2.321E-4	0.22
CNCPUE 8	1.222E-6	2.921E-6	0.58	2.084E-4	0.20
CNCPUE 9	5.983E-6	2.552E-6	3.34	1.730E-4	0.21
USCPUEAG	3.133E-6	1.540E-6	3.45	8.762E-5	0.25
USCPUEAG	5.910E-7	2.603E-7	3.13	1.831E-5	0.20

Bootstrap Output Variable: F t
Full vector of age-specific terminal F's (in 1992)

Age	NLLS Estimate	Bootstrap Mean	Bootstrap Std. Error	CV for NLLS SOLN
2	5.735E-4	6.286E-4	2.509E-4	0.44
3	9.523E-2	9.781E-2	3.124E-2	0.33
4	1.611E-1	1.659E-1	4.467E-2	0.28
5	2.348E-1	2.380E-1	5.789E-2	0.25
6	4.797E-1	5.403E-1	1.877E-1	0.39
7	6.544E-1	6.978E-1	2.282E-1	0.35
8	7.857E-1	8.067E-1	2.543E-1	0.32
9	7.200E-1	7.523E-1	1.497E-1	0.21
10	7.200E-1	7.523E-1	1.497E-1	0.21
11	7.200E-1	7.523E-1	1.497E-1	0.21
12+	7.200E-1	7.523E-1	1.497E-1	0.21

Index	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Est. Corrected for Bias	CV for Corrected Estimate
2	5.515E-5	1.774E-5	9.62	5.183E-4	0.48
3	2.587E-3	2.209E-3	2.72	9.264E-2	0.34
4	4.817E-3	3.159E-3	2.99	1.563E-1	0.29
5	3.240E-3	4.093E-3	1.38	2.315E-1	0.25
6	6.052E-2	1.327E-2	12.62	4.192E-1	0.45
7	4.346E-2	1.614E-2	6.64	6.109E-1	0.37
8	2.105E-2	1.798E-2	2.68	7.646E-1	0.33
9	3.225E-2	1.058E-2	4.48	6.878E-1	0.22
10	3.225E-2	1.058E-2	4.48	6.878E-1	0.22
11	3.225E-2	1.058E-2	4.48	6.878E-1	0.22
12+	3.225E-2	1.058E-2	4.48	6.878E-1	0.22

Table A9. Continued.

Bootstrap Output Variable: F full t
Fully-recruited F in the terminal year (1992)

	NLLS Estimate	Bootstrap Mean	Bootstrap Std. Error	CV for NLLS SOLN
Ages 9-11	7.200E-1	7.523E-1	1.497E-1	0.21

	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Estimate Corrected for Bias	CV for Corrected Estimate
Ages 9-11	3.225E-2	1.058E-2	4.48	6.878E-1	0.22

Bootstrap Output Variable: SSB spawn t
SSB (males & females) at start of spawning season (1992)

	NLLS Estimate	Bootstrap Mean	Bootstrapp Std. Error	CV for Corrected Estimate
SSB	1.251E5	1.288E5	1.438E4	0.11

	Bias Estimate	Bias Std. Error	Percent Bias	NLLS Estimate Corrected for Bias	CV for Corrected Estimate
SSB	3.683E3	1.017E3	2.94	1.214E5	0.12

mates from the calibrated VPA. Spawning stock biomass and recruitment (age 2 stock size) for corresponding year classes was plotted from 1972 through 1991 (Figure A8). The median slope was computed to be 0.30 R/SSB which computes to an inverse of 3.3 SSB/R.

Yield and Spawning Stock Biomass per Recruit

Yield per recruit and spawning stock biomass per recruit analyses were performed using the method of Thompson and Bell (1934). Mean weights at age for application to yield per recruit were computed as the arithmetic average of catch mean weights at age (Table A4) over the 1989-1992 period. Mean weights at age for application to SSB per recruit were computed as the arithmetic average of January 1 stock mean weight at age estimates over the 1989-1992 period. The maturation ogive was taken from Mayo *et al.* (1989) since their data were based on both U.S. and Canadian samples collected throughout the range of the stock.

Partial recruitment for input to the yield and SSB per recruit analysis and short term projections was computed from the most recent four years of the F matrix derived from the VPA (Table A6). Geometric mean F at age was computed for the 1988-1991 period and divided by the geometric mean of the age 7+ F to derive the final partial recruitment vector. Results are similar to those obtained from the SVPA.

The yield per recruit analyses indicate that $F_{0.1}$ = 0.20 and F_{max} = 0.76 (Table A10, Figure A9). Mapping of the SSB/R value computed from the stock-recruitment curve indicates an F_{med} value of about 0.47 corresponding to 25% MSP. The $F_{20\%}$ is estimated at 0.65.

SHORT-TERM PROJECTIONS

Recruitment

Catches and stock sizes were projected through 1995 at various levels of F and recruitment assuming a status quo F in 1993 (Figure A10). The exploitation pattern, mean weights at age, and maturation ogive were as described earlier for the yield and SSB per recruit analyses. Survivors at ages 4-12+ in 1993 were taken from the final calibrated VPA. Age 2 recruitment in 1993 (1991 year class) was estimated from RCT3 regressions between Massachusetts spring age 1 stock sizes and VPA age 2 stock numbers for corresponding 1972-1989 year classes with shrinkage to the VPA mean applied. Preliminary RCT3 regressions had indicated poor correspondence between NEFSC spring and autumn age 2 indices and the VPA age 2 stock sizes. The estimate of the 1990 year class from RCT3 (34.2

Table A10. Results of the yield-per-recruit analysis

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: 22- 6-1993; Time: 09:09:21.00

POLLOCK 4VWX + SA 5 - 1993 UPDATED AVE WTS, FPAT AND MAT VECTORS

Proportion of F before spawning: .0000
Proportion of M before spawning: .0000
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is: 16
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> b:\ass\polypr.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	.0090	.000	.094
2	.0029	1.0000	.0750	.527	.485
3	.0565	1.0000	.3450	1.110	.969
4	.3048	1.0000	.7190	1.750	1.474
5	.6160	1.0000	.9070	2.488	2.141
6	.8974	1.0000	.9680	3.162	2.882
7	1.0000	1.0000	1.0000	3.815	3.585
8	1.0000	1.0000	1.0000	4.255	4.105
9	1.0000	1.0000	1.0000	4.985	4.700
10	1.0000	1.0000	1.0000	5.380	5.251
11	1.0000	1.0000	1.0000	6.345	5.961
12	1.0000	1.0000	1.0000	7.998	8.159
13	1.0000	1.0000	1.0000	9.025	9.025
14	1.0000	1.0000	1.0000	9.547	9.547
15	1.0000	1.0000	1.0000	10.004	10.004
16+	1.0000	1.0000	1.0000	10.403	10.403

Summary of Yield per Recruit Analysis for:
POLLOCK 4VWX + SA 5 - 1993 UPDATED AVE WTS, FPAT AND MAT VECTORS

Slope of the Yield/Recruit Curve at F=0.00: --> 11.6919
F level at slope=1/10 of the above slope (F0.1): -----> .199
Yield/Recruit corresponding to F0.1: -----> .8401
F level to produce Maximum Yield/Recruit (Fmax): -----> .763
Yield/Recruit corresponding to Fmax: -----> .9792
F level at 20 % of Max Spawning Potential (F20): -----> .650
SSB/Recruit corresponding to F20: --------> 2.6694

Listing of Yield per Recruit Results for:
POLLOCK 4VWX + SA 5 - 1993 UPDATED AVE WTS, FPAT AND MAT VECTORS

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	5.5167	14.5850	3.1215	13.3484	100.00
	.07	.11971	.53436	4.9207	10.1763	2.5282	8.9453	67.01
	.14	.19066	.75510	4.5684	7.9026	2.1784	6.6771	50.02
F0.1	.20	.22816	.84009	4.3826	6.8319	1.9945	5.6104	42.03
	.22	.23810	.85896	4.3334	6.5649	1.9459	5.3447	40.04
	.29	.27238	.91261	4.1642	5.7021	1.7791	4.4869	33.61
	.36	.29852	.94225	4.0355	5.1057	1.6527	3.8954	29.18
	.43	.31927	.95934	3.9336	4.6707	1.5531	3.4651	25.96
	.50	.33625	.96932	3.8505	4.3395	1.4721	3.1385	23.51
	.58	.35049	.97502	3.7810	4.0786	1.4047	2.8819	21.59
	.65	.36266	.97797	3.7217	3.8671	1.3475	2.6747	20.04
F20%	.65	.36298	.97803	3.7202	3.8618	1.3460	2.6694	20.00
	.72	.37323	.97911	3.6704	3.6919	1.2982	2.5035	18.75
Fmax	.76	.37896	.97916	3.6426	3.6001	1.2716	2.4141	18.09
	.79	.38254	.97899	3.6253	3.5438	1.2551	2.3593	17.68
	.86	.39082	.97800	3.5853	3.4167	1.2169	2.2361	16.75
	.94	.39826	.97639	3.5494	3.3062	1.1829	2.1293	15.95
	1.01	.40500	.97433	3.5170	3.2090	1.1523	2.0357	15.25
	1.08	.41116	.97197	3.4874	3.1227	1.1245	1.9528	14.63
	1.15	.41680	.96938	3.4603	3.0454	1.0991	1.8789	14.08
	1.22	.42202	.96664	3.4354	2.9756	1.0759	1.8124	13.58
	1.30	.42686	.96381	3.4123	2.9123	1.0544	1.7522	13.13
	1.37	.43137	.96091	3.3908	2.8544	1.0345	1.6974	12.72
	1.44	.43558	.95799	3.3707	2.8013	1.0160	1.6473	12.34

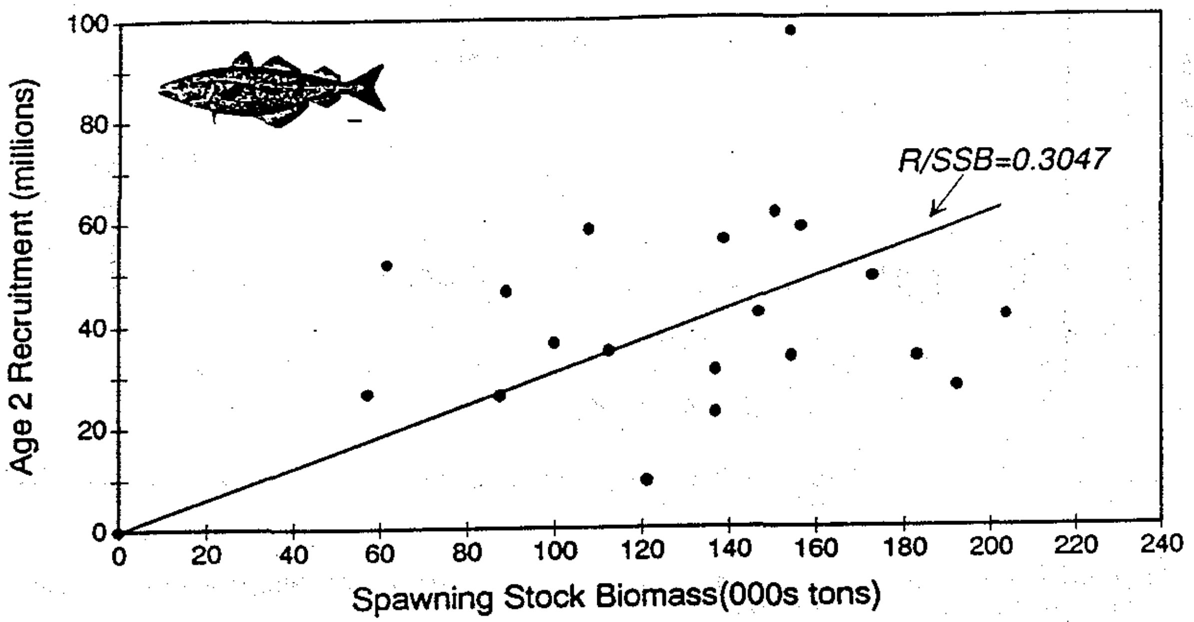


Figure A8. Spawning stock biomass-recruitment scatterplot and replacement line for Divisions 4VWX and Subareas 5 and 6 pollock.

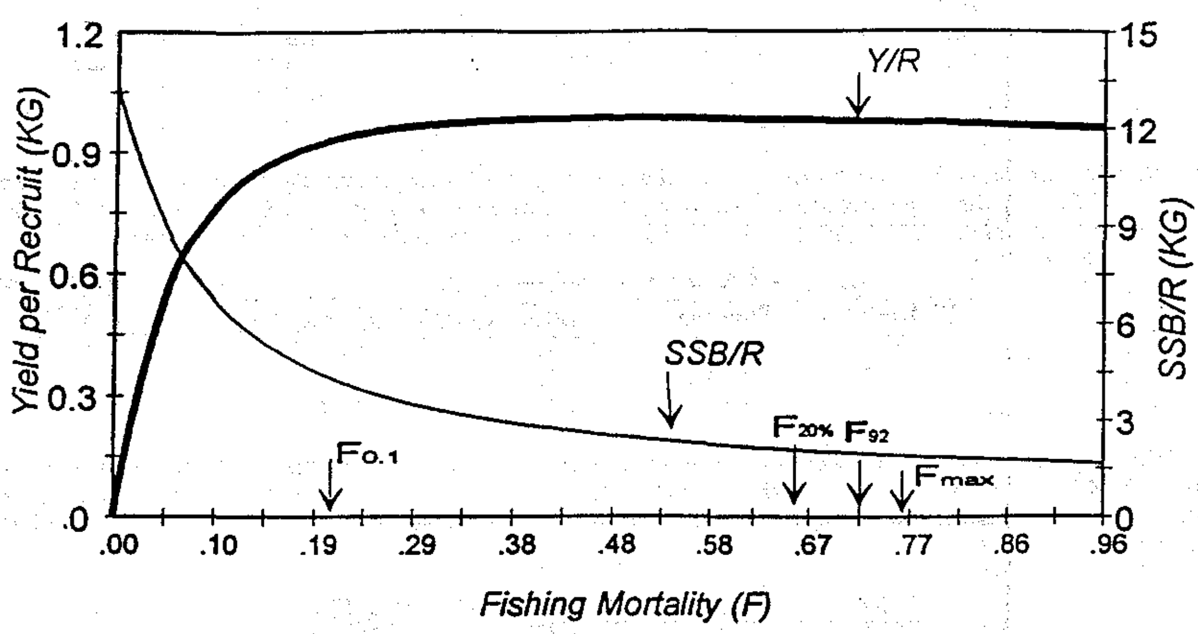


Figure A9. Yield and spawning stock biomass per recruit (SSB/R) results for Divisions 4VWX and Subareas 5 and 6 pollock.

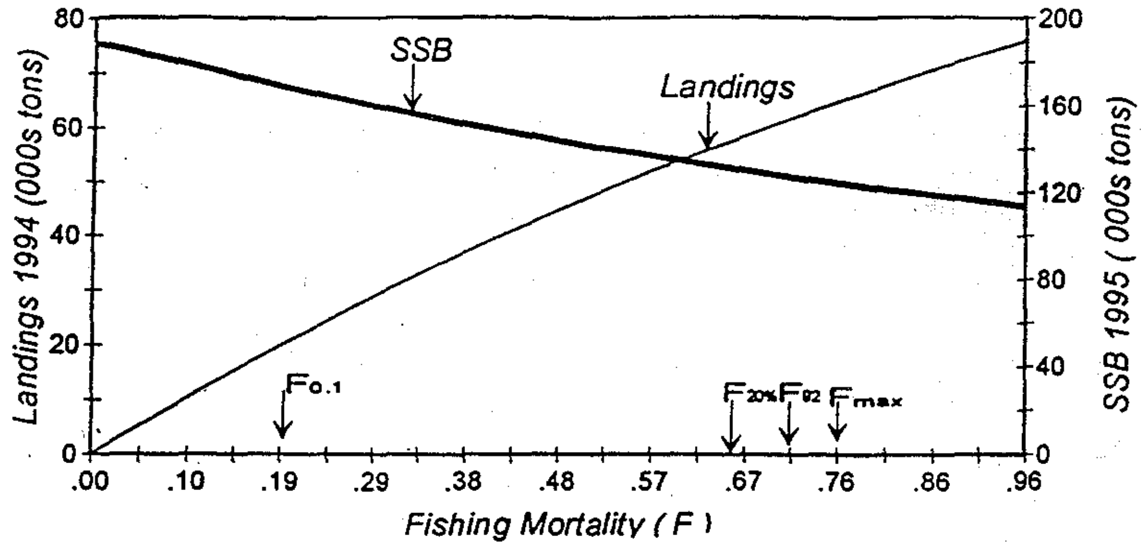


Figure A10. Short-term projections of 1994 landings and 1995 spawning stock biomass (SSB) results for Divisions 4VWX and Subareas 5 and 6 pollock.

Table A11. Projections of landings and spawning stock biomass (SSB) assuming A) fishing mortality of 0.72 and B) total landings of 43,000 mt in 1993

Age-Specific Input Data						
Age	Stock Size in 1993	Fishing Pattern	Natural Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
2	34675	0.0029	1.0000	0.0750	0.527	0.485
3	28040	0.0565	1.0000	0.3450	1.110	0.969
4	18612	0.3048	1.0000	0.7190	1.750	1.474
5	27762	0.6160	1.0000	0.9070	2.488	2.141
6	13893	0.8974	1.0000	0.9680	3.162	2.882
7	3183	1.0000	1.0000	1.0000	3.815	3.585
8	1402	1.0000	1.0000	1.0000	4.255	4.105
9	382	1.0000	1.0000	1.0000	4.985	4.700
10	224	1.0000	1.0000	1.0000	5.380	5.251
11	172	1.0000	1.0000	1.0000	6.345	5.961
12+	157	1.0000	1.0000	1.0000	7.998	8.159

A) The following forecasts for 1994 were performed assuming that fishing mortality in 1993 was the same as in 1992 (*i.e.* F= .72). This fishing mortality rate implies that commercial landings in 1993 will be about 60,000 mt. Average recruitment of age 2 fish (38.2 million) was assumed for the 1992 and 1993 year classes in 1994 and 1995, respectively.

	F(94)	SSB (94	Landings (94)	SSB (95)
$F_{20\%}$	0.65	130.3	49.8	122.3
F_{med}	0.47	130.3	38.3	133.6
$F_{(92)}$	0.72	130.8	53.9	118.3

B) The following forecasts for 1994 were performed assuming that total landings in 1993 remain the same in as in 1992 (*i.e.* 43,000 mt). This implies that the fishing mortality rate in 1993 will be about 0.48. Average recruitment of age 2 fish (38.2 million) was assumed for the 1992 and 1993 year classes in 1994 and 1995, respectively.

	F(94)	SSB (94)	Landings (94)	SSB (95)
$F_{20\%}$	0.65	147.0	57.3	131.9
F_{med}	0.47	147.0	44.1	144.8
$F_{(Landings\ 92)}$	0.48	147.0	44.8	144.2

Table A12. Number of pollock sink gillnet sea sampling trips by year and month, 1989-1992

Year	Month												Total Trips Per Year
	1	2	3	4	5	6	7	8	9	10	11	12	
89						1	1	11	25	19	14	14	85
90	5	2	3	10	9	5	7	7	8	10	11	6	83
91	4	0	1	7	11	102	99	118	92	86	82	43	645
92	16	5	5	17	35	77	94	90	78	47	108	58	630
Total	25	7	9	34	55	185	201	226	203	162	215	121	1443

Table A13. Summary of primary species sought by sink gillnet sea sample trips in which pollock were caught, 1989-1992

Primary Species	Year				Total Trips
	1989	1990	1991	1992	
Unknown	0	0	0	1	1
Cod	43	47	468	423	981
Pollock	25	12	74	87	198
American plaice	0	0	0	1	1
Witch flounder	0	0	3	1	4
Yellowtail flounder	0	1	0	6	7
Winter flounder	2	3	0	1	6
Flatfish, not specified	0	1	4	2	7
White hake	0	1	12	2	15
Groundfish, not specified	15	15	66	90	186
Mackerel	0	0	0	4	4
Dogfish	0	2	15	11	28
Fish, not specified	0	1	3	1	5
Total trips/year	85	83	645	630	1443

million) was considerably lower than the VPA-based estimate (57.8 million). The NEFSC spring and autumn and Massachusetts spring surveys all predicted that this year class was slightly below average strength; the RCT3 estimate was, therefore, accepted over that derived from the VPA. Numbers at age 3 in 1993 were adjusted by Z to reflect the revised strength of this year class at age 2 in 1992. Recruitment of the 1992 and 1993 year classes (38.2 million) was computed as the geometric mean of the 1972-1989 year classes.

Catch and Stock Size Projections

The SARC reviewed 1993 status quo F and landings projections, presented in Table A11a and A11b, respectively. The SARC believes that the F in 1993 is not likely to be as high as the F in 1992. The status quo landings projections are therefore considered to be the more likely outcome for 1994.

If fishing mortality in 1993 remains at the 1992 level (F_{sq}=0.72), catches are projected to increase to approximately 60,000 mt. Because of catch restrictions imposed by Canada to meet $F_{0.1}$ management objectives, it is unlikely that the 1993 Canadian catch will exceed the 35,000 mt multi-year annual total allowable catch (TAC), and total catch is not likely to exceed 43,000 mt in 1993, assuming status quo catch for U.S. and distant-water fleet (DWF) components. Under this scenario, F will decline to 0.48 in 1993 and SSB will increase to 147,000 mt in 1994 (Table A11b). Continued fishing at the 1993 F level (0.48) in 19984 will result in a stabilization of SSB at about the 1974-1992 mean in 1995. If F approximates the $F_{20\%}$ level (0.65), in 1994, SSB in 1995 (131,900 mt) will again decline below the

1974-1992 mean. Reducing F to F_{med} (0.47) in 1994, will stabilize SSB at the long-term mean in 1995.

The increase of projected catch in 1993 under the *status quo* F scenario is due primarily to growth in weight of the 1988 year class, which was estimated by the VPA to have been the strongest to appear since the 1979 year class. Thus, it is likely that F in 1993 will be considerably lower than 0.72. This suggests that the elevated levels of F estimated for 1992 and 1991 are the result of several years of below-average recruitment from the 1983, 1984, and 1986 year classes. This pattern appears to have been reversed in recent years as the 1987 and 1988 year classes are estimated to be well above average. However, the increase in stock biomass expected from growth of fish from the 1988 year class may be short-lived, as the 1989, 1990, and 1991 year classes are expected to be below average in strength.

ANALYSES OF SINK GILLNET FISHERY EFFORT MEASURES AND POLLOCK LENGTH COMPOSITION SAMPLES

Gillnet Effort Measures

Beginning in 1989, the NEFSC initiated a comprehensive domestic sea sampling program to collect catch, discard, and effort information as well as length and age composition of the catch. The NEFSC sea sampling data collected on board gillnet vessels was evaluated using information from all hauls where pollock were caught. Using analysis of variance (ANOVA) procedures in the form of a general linear model (GLM) several variables affecting overall fishing effort, and spatial and seasonal factors affecting CPUE were examined.

Total catch, pollock catch, effective effort measures (soak time, number of panels, and length and height of nets) and descriptors (area, month, vessel and crew size, and captain's experience) were extracted from the various sea sampling data sets and matched for each haul where pollock were caught. The characteristics of each variable (maximum, minimum, mean, variance, n) within month-statistical area cells were first examined to determine the extent of the overall variability of the observations.

To evaluate the impact of the various effort measures on catch of pollock, several ANOVAs were performed using the GLM approach. With the dependent variable $\log_e$ pollock catch, main classification variables were defined as year, month, area, and depth code and covariates as soak time, number of nets, net length and height, and captain's experience. Once the significant effort measures were determined, effective effort was computed as the product of these measures, and the pollock catch was divided by the effective fishing effort to compute CPUE.

The number of sampled trips in which some pollock were taken ranged from 83 to 85 in 1989 and 1990 to 630 to 645 in 1991 and 1992 when sea sample coverage increased tenfold (Table A12). In all years, most trips taking pollock occurred during the latter half of the year. On sampled trips taking pollock, the most frequent species sought was cod, followed by pollock. A significant number of trips were also recorded as seeking mixed groundfish (Table A13). The number of haul observations varied annually from a low of 267 in 1989 to a high of 2,462 in 1991. This variation also reflected changes in the sampling intensity from year to year. In all years, statistical area 513 had the highest number of observations.

The initial GLM explained about 38% of the total variability in the pollock catch. Year, area, and month were highly significant main classification effects and soak time, number of nets, and net length and height were highly significant covariates (Table A14). Depth code and the experience of the captain were not significant. When these effort measures were incorporated into the dependent variable as pollock CPUE, highest pollock CPUE relative to standard area 513 occurred in areas 511 and 512 along the Maine coast and in areas 521 in the Great South Channel and 561 on the Northern edge of Georges Bank. Highest seasonal catch rates relative to standard month November occurred during June and July. Lowest CPUE was evident in February and March at the end of the spawning season.

When two-way interaction terms for the main classification variables were introduced, the model explained approximately 45% of the total variability in $\log_e$ CPUE. All two-way interactions were highly significant as were the remaining classification variables. The type IV sum of squares suggested an imbalanced design with several missing cells.

Two additional analyses were performed after grouping areas as: 511+512, 513+514, and 521+522. In addition, areas on eastern Georges Bank (561), Scotian Shelf (464), and South of New England (537 and 538) were eliminated because of sporadic coverage. To eliminate the imbalance caused by the incomplete coverage in 1989, only

Table A14. Analysis of variance of pollock catches *vs* effective effort measures and main classification variables

General Linear Models Procedure

Dependent Variable: LHAIL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	32	306.62017995	9.58188062	14.70	0.0001
Error	781	508.93837345	0.65164965		
Corrected Total	813	815.55855340			

R-Square	CV	Root MSE	LHAIL Mean
0.375963	14.07695	0.80724819	5.73454097

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	3	51.92265080	17.30755027	26.56	0.0001
AREA	8	28.24541386	3.53067673	5.42	0.0001
MONTH	11	50.46782127	4.58798375	7.04	0.0001
TDEPTHCD	5	4.92744331	0.98548866	1.51	0.1835
CAPTYRS	1	0.00640241	0.00640241	0.01	0.9211
ACTOWDUR	1	24.07296469	24.07296469	36.94	0.0001
NNETHAUL	1	56.05612144	56.05612144	86.02	0.0001
NETLEN	1	3.16308162	3.16308162	4.85	0.0279
NETHGT	1	4.85039190	4.85039190	7.44	0.0065

Table A15. Analysis of variance of pollock logged LPUE *vs* year, division, and month

Dependent Variable: LLPUE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	103.42019189	9.40183563	12.91	0.0001
Error	591	430.25174782	0.72800634		
Corrected Total	602	533.67193970			

R-Square	CV	Root MSE	LLPUE Mean
0.193790	-10.21123	0.85323288	-8.35582917

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	3	32.84493311	10.94831104	15.04	0.0001
DIV	3	20.25936509	6.75312170	9.28	0.0001
MONTH	5	11.24209434	2.24841887	3.09	0.0092

months from July through December were analyzed. The main effects model indicated highly significant year, month, and division effects but the inclusion of two-way interaction terms suggested that much of the variability is taken up by interactions, rendering the main effects non-significant (Table A15).

Length Composition Comparisons

The suitability of length frequency measurements obtained on board gill net vessels was evaluated as a means of augmenting the limited number of samples collected in ports of landing. Since all length frequency records obtained from the sea sample program are coded as unclassified, the estimated length composition of gill net-caught pollock as determined from port sampling for the unclassified market category was compared with an estimated length composition based on the sea samples alone.

In 1989, most sea sample length measurements were well above the general range of the unclassified category. In 1990 and 1991, the sea sample length modes appeared to better coincide with the port samples, but this may simply be an effect of declining availability of larger pollock in the latter two years. In all cases, the sea samples tended to overestimate the mean weight of pollock (and underestimate the numbers landed) in the unclassified market category as follows:

1989: 5.9 *vs.* 2.5 kg;
1990: 3.9 *vs.* 2.4 kg;
1991: 3.7 *vs.* 3.1 kg.

This has resulted in rather large differences in the contribution to the estimated total age composition of pollock from this market category both in terms of number and proportion at age.

DISCUSSION

Assessment

The Scotian Shelf-Gulf of Maine-Georges Bank pollock stock has undergone a recent decline in spawning stock biomass resulting from below-average recruitment during the mid-1980s. Age 6+ mean biomass has declined by 60% since 1986 while total landings have declined by 40%. Fishing mortality (mean 7-11,u), which had fluctuated between 0.55 and 0.67 during the latter half of the 1980s, increased to more than 0.8 in 1991 and is estimated to have been 0.72 in 1992. Fishing mortality is likely to decline in 1993 and 1994 if the 1988 year class is as strong as had been estimated by the VPA and Canada continues to impose catch restrictions.

Estimates of the strength of subsequent year classes from 1989, 1990, and 1991 indicate another period of below average recruitment. However, these estimates, particularly those for the 1990 and 1991 year classes, are the least certain because little or no fishery data are yet included in the estimation process.

The decline in U.S. landings from this stock has been more severe than the decline in Canadian landings. The 1992 U.S. catch of 7,182 mt is less than 30% of the peak catch of 24,542 mt taken in 1986. In contrast, Canada has been able to take between 73% and 84% of its peak 1985 catch over the past three years.

These differences in landings between the U.S. and Canada from what is considered a unit stock may be explained by two very different hypotheses regarding stock definition. Under one scenario, the sharp decline in U.S. landings reflects a sharp decline in available biomass resulting from extremely high exploitation during 1985-1987 when annual U.S. landings equalled or exceeded 20,000 mt. This suggests a low degree of mixing of pollock between the Scotian Shelf and U.S.- managed waters. A second scenario would explain the decline in U.S. landings (and the relative stability of 4X Canadian landings) as a result of emigration of pollock from the Gulf of Maine to Canadian waters.

If the first hypothesis holds, the inclusion of U.S. 5Y+5Zu catch-at-age data with Canadian and DWF catch-at-age from Divisions 4VWX+5Zc may introduce more variability in estimated stock sizes if recruitment is not synchronous between the two areas. If the second hypothesis is true, the inclusion of the U.S. component to the Canadian+DWF catch-at-age data should provide a more complete evaluation and yield higher estimates of F than the Canadian assessment alone would indicate.

Gillnet Effort Measures

The effort measures incorporated into the ANOVAs calibrated gillnet fishing effort to the amount of net area fished (number of nets x length of net x height of net) times the actual fishing time (soaking time). This effective fishing effort, therefore, should account for most of the variation in fishing practices among hauls and operators. Inclusion of further refinements such as individual hanging practices in the model may account for additional variation in pollock catches, but these were considered variations that could not be quantified from the available data.

The number of years of experience of the captain and the depth zone fished proved not to be significant factors in explaining either the quantity of pollock caught or the CPUE. When the pollock catch on each haul was divided by the effective effort, variability in CPUE was explained by the year, month, and area main effects. However, the interaction model indicated potential problems due to missing cells. When the data were grouped in an attempt to minimize the number of missing cells, the main effects were only significant when interaction terms were removed from the model. Further analyses must be performed to evaluate the extent of the imbalance in the model.

Sea samples used in conjunction with port samples will have a disproportionate impact on the overall length composition because many fish are measured in the sea sampling program in some months and areas, but other times as few as five fish are measured in an entire month from a given area. If sea samples are to be considered as a means of augmenting port sampling, sample size constraints should be imposed on a time-area basis as is required in port sampling.

SUBCOMMITTEE COMMENTS [Reviewed and endorsed by SARC]

Assessment of the Status of the 4VWX+5+6 Pollock Stock

In the table of mean weights at age, the subcommittee noted a decline in the mean weight at age of older fish in the Canadian landings. The question of potential changes in aging protocol was raised but could not be resolved since these data were obtained directly from Canadian assessment documents. Previous discussions with Canadian scientists, however, suggest that aging procedures have been consistent throughout the time series. It was noted that an additional source of variation in mean weight at age from Canadian samples is that the Canadian length-weight equation is derived annually from resource surveys, whereas the U.S. assessment uses a single length-weight equation for the entire time period.

Commercial CPUE indices from the U.S. otter trawl fishery have shown a general decrease since 1977, with the most rapid decline since about 1986. During the last two years, however, CPUE indices have increased. The subcommittee noted that the presence of pair trawl data may be artificially inflating the index. The Canadian IOP CPUE index shows a similar decline since the mid-1980s. The Canadian regional index also suggests a decline, but considerable interannual variability is evident in the series. Because of quotas placed on the fishery and trip limits on individual vessels in the regional fishery index, this index may not be an accurate indicator of stock abundance. Hence, the subcommittee recommended not using the recent portion of the regional CPUE index for tuning. The subcommittee agreed, however, that the IOP index could be appended to the regional index since the two series are based on similar vessels (ton class 5) and the IOP data have been analyzed to remove the impact of fishery regulations.

In the NEFSC survey series, several index values appear aberrant compared with adjacent years, particularly the spring survey index during 1987. In some of these cases, the very high index value was due primarily to very large individual catches. To minimize the effect of individual high catches, analyses were presented using a log transformation on survey catches. Indices based on log transformed data smoothed the data considerably, removing the large "spikes" in abundance in the linear index. A graphic comparison of linear and corresponding log retransformed abundance and biomass proved useful in identifying potential outliers in the linear index. Although these log-transformed indices were not used in VPA calibration, the subcommittee suggested that these indices may provide a better indication of abundance thus increasing their utility as a tuning index.

Results of a separable VPA indicate that full recruitment occurs at age 7. After age 7, there was an indication of a slight dome in the partial recruitment. Thus, the subcommittee requested additional analyses during the meeting to resolve the shape of the partial recruitment vector. Results of these additional analyses indicated that a flat-topped partial recruitment curve adequately represented the selection pattern.

Initial ADAPT runs generally showed acceptable results, except for strong residuals noted in the spring survey series in 1988. Since the linear survey index, which was used in the tuning, conflicted greatly with the index derived from analysis of log-transformed data for 1987, the subcommittee recommended that the index for 1987 be set to missing. The committee further noted a very large residual for the U.S. fall survey at age 2 in 1993.

Final ADAPT runs were made deleting 1987 spring U.S. survey indices for ages 3 and 4 and incorporating aggregated U.S. and Canadian commercial CPUE indices tuned to midyear biomass. Results of these runs showed acceptable residual patterns, but showed relatively high loading of sums of squares on Canadian summer survey indices for ages 2 to 4, and on the Massachusetts age 1 survey index. The subcommittee judged that these results were acceptable, but notes that these indices may have a relatively large effect on the estimate of incoming recruitment. Also, the subcommittee noted that the inclusion of age-aggregated biomass indices from the commercial fishery as well as the age-disaggregated indices effectively may result in a disproportionate weight for the information incorporated from the commercial fishery.

Discussions during the meeting also noted problems in the incorporation of tuning indices for ages younger than ages for which population estimates are being obtained as model parameters. Yield per recruit and spawning stock biomass per recruit analyses were run with partial recruitment vectors reflecting two different periods of time: 1982-1991 and 1988-1991. The subcommittee felt that the partial recruitment vector representing 1988-1991 was most appropriate because of management actions (*i.e.*, minimum size regulation), but notes that F_{max} is sensitive to the partial recruitment vector used.

Analysis of the Sea Sampling Data on the Sink Gillnet Fishery

In the descriptive statistics section of this paper, the subcommittee noted that the sample sizes were presented in terms of hauls (of strings of gillnets) rather than trips. Since hauls within a trip are likely to be similar, they do not represent independent samples. Because of this, the subcommittee suggested that the number of trips within each sampling cell would be useful to indicate the number of independent samples. Analyses performed during the meeting were useful in demonstrating that during 1989 and 1990, relatively few trips were sampled, resulting in small sample sizes for some area-month combinations.

Initial GLM analyses of pollock catch focused on determining if net characteristics (*i.e.*, number of nets in a string, net length, net height, and soak time) could be used to standardize fishing effort. Additional factors, including year, area, month, depth, and captain's experience were also included in the GLM model. Results of this model indicated that the net characteristics chosen had a significant effect on the logarithm of catch and are appropriate for standardizing effective effort. In these analyses, the subcommittee noted that while log-transformed data are typically used in such analyses, the residuals should be tested for normality to ensure that this assumption of the GLM is met.

Further analyses were presented on $\log_e$(CPUE) where CPUE was computed as catch/(net length * number of nets * net height * soak time). These analyses examined the effect of captain's experience, depth, year, month, area as well as interactions between year and month, year and area, and month and area. In the GLM analyses with interaction terms included, the subcommittee observed that the type IV sums of squares differed from the type III sums of squares, indicating that not all model cells were filled. Results suggested, however, that the interaction terms were significant, and potentially important in determining annual trend in CPUE. As such, the committee recommended that additional analysis be performed dropping times and areas where pollock catches occur sporadically, and combining areas where catch rates are similar. Specifically, the subcommittee recommended that:

1. January through May be dropped from the analysis. This was recommended for two reasons. First, catch rates are generally low during this time of year, and occur sporadically across areas. Secondly, sea sampling during 1989 did not begin until June. Thus, no data are available from January to May for that year.

2. Combine areas 511 and 512; areas 513 and 514; areas 521 and 522, and retain area 515 as a single unit. Delete all other areas since catches occurred sporadically throughout the sampling period.

Results of these analyses suggested that the interaction terms were significant, but missing cells still occurred. Further, in these analyses, the main effects of year, area, and month did not appear significant. Because of the confounding of main effects with significant interaction terms, the problem of missing cells, and the short time series of data available, the subcommittee concluded that it was premature to use the results of these GLM analyses as tuning indices. The subcommittee agreed, however, that measures of effort present in the sea sampling data base (*i.e.*, number of nets in a string, net length, net height, and soak time) are sufficient to standardize effort. It is anticipated that if sea sampling of the gill net fishery is maintained at similar intensity as in 1991 and 1992, this database will provide a useful CPUE index as an index of abundance.

In addition to providing analyses of catch rates, the length composition of pollock measured in the sea sampling database was compared to the length composition of unclassified landings measured by the port sampling program. Strong differences in the length composition were observed, but the subcommittee noted that the unclassified landings in the port may not be the most appropriate basis for comparison since large pollock may be culled from this market category.

SARC DISCUSSION AND RESEARCH RECOMMENDATIONS

This assessment updated the previous assessment conducted during SAW-9 that incorporated both U.S. and Canadian landings and survey indices. At SAW-9, it was recommended that assessments be done on the entire stock. The distribution pattern of pollock is such that only about one-sixth of the total catch was taken by U.S. harvesters in 1992.

The lack of discards and recreational catch estimates results in an underestimate of removals from the fishery, however, estimates of Canadian discarded catch would be necessary since the majority of the fishery is prosecuted in Canadian waters. The representativeness of recreational catch data is problematic due to insufficient sampling of offshore party boats and the lack of sampling during fall and winter. Current sampling does not characterize the population since the majority of length frequencies are comprised of harbor pollock. Comparison of recent recreational catches with higher catches prior to 1979 is difficult because of differences in methodology and unknown variance of the expanded estimates. These catch estimates should include confidence intervals to evaluate trends.

A recent decline in weight at age of large fish is due to a trend in the Canadian weight at age estimates. The trend in mean weights could be due to the use of annual length-weight equations, a change in migration patterns, or to an areal shift in the fishing pattern of the Canadian fleet, since pollock exhibit different growth rates by area.

The apparent opposite trends in the U.S. and Canadian survey indices indicate that individual surveys are not representative of the entire stock. Again, this may be due to the temporal availability of stock components, or to differential removal of large fish by the respective fleets, or an actual shift in the migratory patterns of pollock during the last decade. Tagging of fish in U.S. waters would address this problem.

Bootstrap estimates of fully recruited F and beginning year SSB were consistently positively biased. The SARC chose to not adjust for the bias because the source of bias was undetermined. There is potential bias in the SSB estimates if the maturation schedule has shifted over time. If the L_{50} value is overestimated in recent years, then SSB will be underestimated. The estimate of F_{med} would be more representative of current stock conditions if earlier years with different environmental influences were excluded.

Research Recommendations

- The effect of missing cells and interaction terms on CPUE indices in the GLM analysis of gillnet CPUE should be investigated further.

- Comparisons are needed between the length composition estimated from the sea sampling data base and the overall length composition of landings from the gillnet fishery for comparable areas and time periods to determine if these two data sources are commensurate.

- A scientific programmer is needed for ongoing modifications to the ADAPT program. The program in general needs to be made more user friendly, thus accessible, to more assessment scientists and in particular, modifications are needed so that the VPA calculations can begin at ages other than age 1.
- The following items need to be addressed by the Methods Subcommittee:

  a. Explore the utility of computing age-disaggregated survey indices from transformed data.

  b. Examine the sensitivity of ADAPT results to the number of indices used in the calibration procedures.

  c. Determine the source of bias in the bootstrap estimates of F and SSB and the potential implications of these biases to management.

- Increased sampling of offshore party boats and extended coverage in the fall and winter is needed to quantify extent of recreational catches of pollock.

- Further research is needed for understanding basic biology and life history of pollock. Trends in the mean weight-at-age estimates of large fish in Canadian fishery need to be examined. An annual length-weight equation is needed for U.S. fishery. A tagging program for pollock in U.S. waters is needed to determine if migration patterns have shifted and to determine how migration affects interpretation of fishery information.

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B. SUMMER FLOUNDER

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Provide updated assessment for the coastwide stock of summer flounder and provide catch and SSB options at various levels of F. (See section on estimates of stock size and fishing mortality, page 45.)

b. Evaluate the utility of NMFS winter surveys in providing indices of relative recruitment strength and population size. Provide recommendations on the design and conduct of future such surveys. (See section on evaluation of NEFSC winter trawl survey, page 56.)

c. Evaluate NEFSC and North Carolina sea sampling data for area and time coverage, and recommend appropriate sea sampling coverage to improve the estimates of fishery discards. (See section on evaluation of NEFSC sea sampling program, page 56.)

INTRODUCTION

For assessment purposes, the previous definition of Wilk *et al.* (1980) of a unit stock of summer flounder extending from Cape Hatteras north to New England has been accepted.

The resource is managed under the Mid-Atlantic Fishery Management Council's (MAFMC) Fishery Management Plan (FMP) for Summer Flounder, as a single stock unit from the southern border of North Carolina, northeast to the United States-Canadian border. Amendment 2 to the FMP, approved by the Secretary of Commerce in August, 1992, enacted major regulations including:

1. an annual commercial fishery quota, to be distributed among states based on their shares of commercial landings during 1980-1989, beginning in 1993;

2. minimum commercially-landed fish size of 13 in. (33 cm);

3. minimum mesh size (5.5 in. (140 mm) diamond or 6.0 in. (152 mm) square) for otter trawls on vessels possessing 100 lb (45 kg) or more of summer flounder, except for the flynet fishery and vessels in an exempted fishery program off southern New England between 1 November and 30 April;

4. permit requirements for sale and purchase of summer flounder, and

5. a recreational fishing season limited to 15 May to 30 September, a minimum recreational-landed fish size of 14 in. (36 cm) and a 6 fish possession limit, beginning in 1993, and annually adjustable.

Additional restrictions may be implemented by individual states (*e.g.*, seasonal commercial quotas or more restrictive minimum size regulations). No directed foreign or joint venture fisheries for summer flounder are permitted, nor is retention of summer flounder as bycatch in foreign fisheries.

FISHERY DATA

Northeast Region (NER; Maine to Virginia) commercial landings for 1980-1992 were derived from the Northeast Fisheries Science Center (NEFSC) commercial landings files. North Carolina commercial landings were provided by the North Carolina Division of Marine Fisheries (NCDMF). In 1992, total commercial landings were 7,300 mt, about 75% higher than the near-record low level in 1990, but still 25 to 50% lower than levels in the early to mid-1980s (Table B1). Between 1980 and 1988, landings ranged from 10,000 to 17,000 mt. Recreational landings were based on statistics from the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS), for type A +B1 landings. Landings were estimated by wave, state, mode, and area and then aggregated. In 1992, recreational landings were 3,400 mt, similar to 1991 levels, but more than twice the record low observed in 1989 (1,500 mt). Landings are still well below levels in the early 1980s, when landings ranged between 5,000 and 14,000 mt (Table B1).

Age samples were available to construct the landings-at-age matrix for the NER (Maine to Virginia) commercial landings for the period 1982-1992 (Table B2). A landings-at-age matrix for 1982 to 1992 was also developed for the North Carolina winter trawl fishery (Table B3), which historically accounts for about 99% of summer

Table B1. Commercial and recreational landings (metric tons, A+B1 recreational type) of summer flounder, Maine to North Carolina (NAFO Statistical Areas 5, 6) as reported by NMFS Fisheries Statistics Division (U.S.) and NEFSC (foreign)

Year	U.S. Commercial	U.S. Recreational[1]	Foreign[2]	Total	U.S. % Comm.	U.S. % Rec.
1980	14,159	14,149	75	28,383	50	50
1981	9,551	4,852	59	14,462	66	34
1982	10,400	9,621	35	20,056	52	48
1983	13,403	16,357	**[3]	29,760	45	55
1984	17,130	13,147	**	30,277	57	43
1985	14,675	7,558	2	22,235	66	34
1986	12,186	8,497	2	20,685	59	41
1987	12,271	5,658	1	17,930	68	32
1988	14,686	8,487	**	23,173	63	37
1989	8,125	1,460	NA[4]	9,585	85	15
1990	4,199	2,435	NA	6,634	63	37
1991	6,224	3,533	NA	9,757	64	36
1992	7,302	3,364	NA	10,666	68	32
Average	11,101	7,624	19	18,739	59	41

[1] Recreational landings are aggregated from wave/state/mode/area estimates.
[2] Foreign catch includes both directed foreign fisheries and joint venture fishing.
[3] ** = Less than 0.5 mt
[4] NA = not available

Table B2. Commercial landings at age of summer flounder (thousands), Maine to Virginia, 1982-1992[1]

Year	Age 0	1	2	3	4	5	6	7	8	9	Total
1982	1,441	6,879	5,630	232	61	97	57	22	2	0	14,421
1983	1,956	12,119	4,352	554	30	62	13	17	4	2	19,109
1984	1,403	10,706	6,734	1,618	575	72	3	5	1	4	21,121
1985	840	6,441	10,068	956	263	169	25	4	2	1	18,769
1986	407	7,041	6,374	2,215	158	93	29	7	2	0	16,326
1987	332	8,908	7,456	935	337	23	24	27	11	0	18,053
1988	305	11,116	8,992	1,280	327	79	18	9	5	0	22,131
1989	96	2,491	4,829	841	152	16	3	1	1	0	8,430
1990	0	2,670	861	459	81	18	6	1	1	0	4,096
1991	0	3,755	3,256	142	61	11	1	1	0	0	7,227
1992	110	5,555	3,448	326	19	21	0	1	0	0	9,479

[1]Does not include discards, assumes catch not sampled by NEFSC weighout has same biological characteristics as weighout catch.

flounder commercial landings in North Carolina. The matrix is based on NCDMF fishery length frequency samples and age-length keys from NEFSC commercial and spring survey data (1982 to 1987) or NCDMF commercial fishery data (1988 to 1992). NCDMF length and age composition data for 1992 are provisional.

Discards from the commercial fishery during 1989-1992 were estimated using observed discards and days fished from NEFSC sea sampling trips to calculate fishery discard rates by two-digit statistical area and calendar quarter. These rates were applied to the total days fished (days fished on trips landing any summer flounder) from the weighout data base in the corresponding area-quarter cell, to provide estimates of fishery discard by cell. Discard estimates were then aggregated over all cells (for example, see Table B4). That total was then raised to reflect potential discard associated with general canvas and North Carolina EEZ landings. Discussion of sampling adequacy appears later, in the section on evaluation of the NEFSC Sea Sampling Program (page56).

Table B3. Number (thousands) of summer flounder at age landed in the North Carolina commercial winter trawl fishery, 1982-1992[1]

Year	Age 0	1	2	3	4	5	6	7	8	Total
1982	981	3,463	1,022	142	52	19	6	4	2	5,692
1983	492	3,778	1,581	287	135	41	3	3	<1	6,321
1984	907	5,658	3,889	550	107	18	<1	0	0	11,130
1985	198	2,974	3,529	338	85	24	5	<1	0	7,154
1986	216	2,478	1,897	479	29	32	1	1	<1	5,134
1987	233	2,420	1,299	265	28	1	0	0	0	4,243
1988	0	2,917	2,225	471	228	39	1	6	<1	5,878
1989	2	49	1,437	716	185	37	1	2	0	2,429
1990	2	142	730	418	117	12	1	<1	0	1,424
1991	0	382	1,641	521	116	20	2	<1	0	2,682
1992	0	49	1,316	963	147	26	1	1	0	2,503

[1] The 1982-1987 NCDMF length samples were aged using NEFSC age-lengths keys for comparable times and areas (*i.e.*, same quarter and statistical areas). The 1988-1992 NCDMF length samples were aged using NCDMF age-lengths keys.

Table B4. Summary of sea sample data for summer flounder by NAFO division and quarter for 1989[1]

DIV	QTR	SSTRIPS	KDF	DDF	WO DF	SS EST LAND (mt)	WO LAND (mt)	SS EST DISC (mt)
51	1	0	0	0	85	0	2	0
	2	1	66	<1	137	9	4	<1
	3	0	0	0	75	0	3	0
	4	1	19	<1	157	3	3	<1
52	1	1	756	48	1319	998	687	64
	2	5	3	8	1250	4	129	10
	3	2	280	<1	536	150	9	<1
	4	1	35	40	1545	54	98	61
53	1	4	588	41	689	405	473	29
	2	10	68	<1	2045	138	224	2
	3	5	260	2	1619	421	298	4
	4	3	91	6	898	82	330	6
61	1	4	544	51	1661	904	528	84
	2	5	107	4	1391	149	165	5
	3	0	213	24	513	109	106	13
	4	5	142	38	575	82	125	22
62	1	5	934	84	1867	1744	1460	158
	2	2	244	101	922	225	85	93
	3	8	213	24	216	46	104	5
	4	1	672	17	1118	752	361	19
63	1	2	1116	110	490	546	323	54
	2	0	244	101	41	10	9	4
	3	0	213	24	40	9	<1	1
	4	0	672	17	616	415	292	10
Total/Mean		65	296	28	19,805	7,255	5,817	642

[1] DIV = NAFO Division; QTR = Quarter; SSTRIPS = Number of sea sampling trips; trips in more than one statistical area are split KDF, DDF = kept and discard rates, kilograms per day fished); WODF = NEFSC weighout database days fished on trips landing any summer flounder; SS EST LAND MT = Estimate of landings calculated from sea sampling kept rates and NEFSC weighout database days fished; WO LAND MT = Landings as recorded in the NEFSC weighout database; SS EST DISC MT = Sea sampling estimate of discard in mt

Table B5. Summary of Northeast Region sea sample data to estimate summer flounder discard at age in the commercial fishery, 1989-1992[1]

Year	Lengths	Ages	Sea Sample Discard (mt)	Sampling Intensity (mt/100 lengths)	Raised Discard Estimate (mt)
1989	2,337	54	642	26	886
1990	3,891	453	1,121	29	1,516
1991	5,326	190	993	19	1,315
1992	-----	---	956	--	1,111

Discard Numbers at Age (thousands)

Year	0	1	2	Total
1989	969	2,035	118	3,122
1990	1,800	3,441	84	5,325
1991	1,114	4,280	<1	5,394
1992	1,160	2,916	60	4,137

Discard Mean Length at Age

Year	0	1	2	All
1989	25.9	31.5	44.2	30.2
1990	29.0	31.7	38.9	30.9
1991	24.0	30.9	37.0	29.5
1992	26.8	31.3	42.0	30.2

Discard mean weight at age

Year	0	1	2	All
1989	0.182	0.296	0.909	0.284
1990	0.235	0.304	0.559	0.285
1991	0.124	0.275	0.491	0.244
1992[2]	0.190	0.290	0.763	0.269

[1] Estimates developed using sea sample length samples, age-length data, and estimates of total discard in mt. Age-length keys applied on semi-annual basis because of length frequency sample size limitations. The 1989 quarter 1 and 2 lengths were aged with combined commercial and survey keys, due to lack of discard age samples.

[2] Because 1992 length data were not available to the committee, mean 1989-1991 proportions, mean lengths, and mean weights at age were assumed for the 1992 discard.

A discard-at-age matrix for 1989-1992 was developed using sea sampled length frequency and age-length distribution samples from 1989-1991, and assuming biological characteristics of 1992 discards were the same as 1989-1991 averages (Table B5), because sea sample length frequency data necessary to characterize the 1992 discard were not available in time to be used in the assessment. Sampling intensity was at least one 100 length sample per 26 mt. Although data are inadequate to develop a commercial discard-at-age matrix for 1982-1988, it is likely that discard numbers were small relative to landings during that period, because there was no minimum size limit for fish caught in the EEZ, but increased in 1989-1992 with the initial implementation of minimum size regulations for the EEZ in 1989. Not accounting directly for commercial fishery discards will result in underestimation of fishing mortality and population sizes in 1982-1988.

The procedure to estimate total discard uses strata that are on a much finer scale (division and quarter) than that subsequently used when length

Table B6. Estimated recreational catch at age of summer flounder (thousands), MRFSS 1982-1992 (catch type A+B1+B2)[1]

Year	Age 0	1	2	3	4	5	6	7	8	Total
1982	2,802	8,728	5,678	440	167	<1	5	0	0	17,820
1983	9,541	17,374	2,857	231	2	<1	0	0	0	30,005
1984	9,746	15,250	3,619	1,233	393	157	106	0	0	30,504
1985	1,391	7,518	3,913	1,511	1,315	120	105	0	0	15,873
1986	3,788	6,651	2,394	1,472	108	371	120	12	0	14,916
1987	1,828	7,710	1,671	451	247	4	8	37	0	11,955
1988	3,104	7,188	3,187	693	289	44	44	7	0	14,556
1989	150	688	747	427	19	12	0	0	0	2,043
1990	250	4,469	566	118	4	1	1	0	0	5,409
1991	677	5,107	2,443	96	37	10	<1	0	0	8,371
1992	187	4,943	1,667	276	<1	31	0	0	0	7,105

[1] Includes catch type B2 (fish released alive) allocated to age groups 0 and 1 with 25% hooking mortality.

Table B7. Total catch at age of summer flounder (thousands), Maine to North Carolina, 1982-1992

Year	Age 0	1	2	3	4	5	6	7	8	9	Total
1982	5,225	19,070	12,329	814	280	116	68	26	4	0	37,932
1983	11,989	33,271	8,790	1,072	167	103	16	20	5	2	55,436
1984	12,056	31,614	14,242	3,401	1,075	247	110	5	1	4	62,755
1985	2,427	16,933	17,510	2,805	1,663	313	135	5	2	1	41,794
1986	4,411	16,170	10,665	4,166	295	496	150	20	86	0	36,458
1987	2,393	19,038	10,426	1,651	609	28	32	63	11	0	34,251
1988	3,409	21,221	14,404	2,444	843	162	63	22	6	0	42,574
1989	1,217	5,263	7,131	1,984	356	65	8	3	7	0	16,034
1990	2,052	10,723	2,241	995	202	36	8	2	1	0	16,259
1991	1,791	13,524	7,340	759	214	40	4	1	0	0	23,674
1992	1,457	13,463	6,491	1,565	167	78	2	1	0	0	23,223

and age samples are applied to estimate the age composition of the discard. This is inconsistent, and so use of a coarser stratum level in the estimation of total discard may be sufficient.

Estimates of recreational landings at age (type A+ B1) were developed from MRFSS sample length frequencies, and NEFSC commercial and survey age-length data. Estimates of recreational discards at age were based on assumptions that the ratio of age 0 : age 1 fish in type B2 catches were the same as in A + B1 landings and that 25% of type B2 catches die of hooking mortality. Type B2 catches have become a more significant component of total recreational catches (up to 60% in recent years) as minimum size regulations have been implemented on a state-by-state basis. The combined recreational catch at age matrix (landed plus discarded dead) is displayed in Table B6.

NER commercial and North Carolina winter trawl landings at age, total commercial discard at age, and recreational catch at age totals were summed to provide a total fishery catch-at-age matrix (Table B7). The numbers and proportions at age of fish age 4 and older are low and quite variable, reflecting the limited numbers of fish available in the stock and thus available to be sampled. For assessment purposes, ages 0 to 4 and an ages 5+ grouping were used in further analyses. Overall mean lengths and weights at age for the total catch were calculated as weighted means (by number in the catch at age) of the respective mean values at age from the NER (Maine to Virginia) commercial, North Carolina

Table B8. Mean length (centimeters) at age of summer flounder catch, Maine to North Carolina, 1982-1992

Year	Age 0	1	2	3	4	5	6	7	8	9	Mean Length All Ages
1982	29.1	34.8	39.3	52.5	56.8	61.0	60.3	68.0	70.6		36.2
1983	28.0	35.1	41.9	48.9	50.3	53.6	60.6	65.1	69.4	72.0	35.0
1984	28.8	33.8	39.1	46.0	51.9	58.3	70.8	68.4	74.0	70.7	35.2
1985	30.3	34.6	38.7	46.5	54.5	58.9	68.1	74.5	73.3	75.0	38.0
1986	29.8	35.4	39.6	47.6	54.3	59.3	65.2	72.4	77.8		38.0
1987	29.2	35.3	39.6	46.5	55.6	63.1	66.5	70.6	73.5		37.2
1988	31.3	35.8	39.1	46.2	54.3	60.0	72.7	68.7	72.8		37.7
1989	27.0	35.5	40.7	45.7	50.8	58.7	60.0	63.1	59.0		38.9
1990	29.3	35.1	42.0	47.0	51.4	59.3	64.2	71.4	75.2		36.3
1991	26.7	34.3	40.6	47.0	54.4	60.9	65.6	68.4			36.3
1992	26.9	35.9	41.2	48.7	54.6	63.4	61.4	74.0			37.9

Table B9. Mean weight (kilograms) at age of summer flounder catch, Maine to North Carolina, 1982-1992

Year	Age 0	1	2	3	4	5	6	7	8	9	Mean Weight All Ages
1982	0.254	0.435	0.654	1.687	2.135	2.795	2.621	3.762	4.284		0.534
1983	0.218	0.447	0.786	1.297	1.466	1.706	2.567	3.169	3.875	4.370	0.475
1984	0.228	0.399	0.640	1.055	1.592	2.245	3.476	3.620	4.640	4.030	0.484
1985	0.282	0.426	0.612	1.092	1.782	2.343	2.670	4.682	4.780	4.800	0.610
1986	0.256	0.454	0.659	1.173	1.790	2.503	3.268	2.994	4.415		0.622
1987	0.239	0.446	0.648	1.117	1.934	2.853	3.080	3.020	4.140		0.559
1988	0.287	0.468	0.628	1.109	1.787	2.480	3.888	3.701	4.319		0.581
1989	0.206	0.451	0.711	1.041	1.504	2.454	2.577	3.105	2.251		0.655
1990	0.244	0.432	0.800	1.176	1.561	2.519	3.026	4.555	5.029		0.525
1991	0.184	0.402	0.700	1.167	1.892	2.674	3.394	3.817			0.520
1992	0.208	0.458	0.756	1.380	1.955	3.005	2.878	4.590			0.607

commercial winter trawl, and recreational (Maine to North Carolina) fisheries and commercial discards (Tables B8 and B9).

STOCK ABUNDANCE INDICES

Standardized indices of abundance (general linear models or GLM) based on year category regression coefficients were developed based on the NEFSC commercial weighout data base for the NER (trips landing more than 10% summer flounder). The time series was split into two separate periods because low numbers of age 0 and age 1 fish in the landings in 1989-1992 may reflect effects of individual state minimum landed sizes rather than abundance during the latter period. Those GLMs, incorporating main effects of year, tonnage class, and fishing area main, explained 22% and 12% of the variance in landings per unit effort for the 1982 to 1988 and 1989 to 1992 models, respectively. The model results indicate a decline in stock size from 1982 to 1988. Lowest levels were observed in 1990, with a slight increase since then.

Mean catch per trip (unstandardized) was calculated for summer flounder harvested from the North Carolina winter trawl fishery for 1982 to 1991. Index levels from 1985 to 1991 are lower relative to levels observed in 1983 and 1984, but show an increasing trend since 1989.

A GLM of the MRFSS estimates of catch rate (mean catch number per angler per trip, A + B1+ B2 type catch, intercept data, 1982 to 1992) was used to produce a standardized index of abundance incorporating effects of year, subregion and mode, which accounted for about 41% of the variance in CPUE. No trend in abundance has been clear in recent years, as the index has been highly variable, although the low level in 1989 was likely due to the poor 1988 year class recruiting to the recreational fishery at age 1.

An index based on the New York Department

Table B10. NEFSC spring trawl survey (offshore strata) mean number of summer flounder per tow at age (delta values)

Year	Age										Total
	1	2	3	4	5	6	7	8	9	10	
1976	0.03	1.70	0.68	0.28	0.01	0.01	0.01				2.72
1977	0.61	1.30	0.70	0.10	0.09	0.01		0.01			2.82
1978	0.70	0.95	0.66	0.19	0.04	0.03	0.03			0.02	2.62
1979	0.06	0.18	0.08	0.04	0.03			0.01			0.40
1980	0.01	0.71	0.31	0.14	0.02	0.06	0.03	0.01		0.01	1.31
1981	0.59	0.53	0.17	0.08	0.05	0.03	0.02	0.01			1.48
1982	0.69	1.41	0.12	0.03							2.24
1983	0.32	0.39	0.19	0.04	0.01				0.01		0.95
1984	0.17	0.33	0.09	0.05		0.01	0.01				0.66
1985	0.55	1.56	0.21	0.04	0.02						2.38
1986	1.49	0.43	0.20	0.02	0.01						2.15
1987	0.46	0.43	0.02	0.02							0.92
1988	0.59	0.79	0.07	0.03							1.47
1989	0.06	0.23	0.02	0.01							0.32
1990	0.62	0.03	0.06								0.71
1991	0.81	0.28		0.02							1.11
1992	0.75	0.41	0.01		0.01						1.19

of Environmental Conservation (NYDEC) party boat angler survey (1985 to 1992) showed declines to low levels in 1989, with 1990 to 1992 levels below those of 1985 to 1988.

Age-specific mean catch rates, in numbers, from the NEFSC spring offshore survey (Table B10; 1976-1992), the Massachusetts Department of Marine Fisheries (MADMF) spring and fall inshore surveys (Table B11; 1978-1992), the Connecticut Department of Environmental Protection (CTDEP) spring to fall trawl survey (Table B12; 1984-1992), and the Rhode Island Division of Fish and Wildlife (RIDFW) fall trawl survey (Table B13; 1979-1992) were available as indices of abundance. (Only two years of observations from the NEFSC winter trawl survey were available. Utility of that survey is discussed later in the section on evaluation of NEFSC winter trawl survey, page 56).

Young-of-year (YOY) survey indices were also available from NCDMF Pamlico Sound trawl survey (1987-1992), Virginia Institute of Marine Science (VIMS) juvenile fish trawl survey (1979-1992), Maryland Department of Natural Resources (MDDNR) trawl survey (1972-1991), Delaware Division of Fish and Wildlife (DEDFW) Delaware Bay trawl survey (1980-1992) and MADMF beach seine survey (Table B14). The Virginia, North Carolina, and Rhode Island YOY indices have correlated best with VPA estimates of age 0 fish, and so receive high weight in the tuning procedure (Figure B1a). The Massachusetts, Maryland, and Delaware YOY indices do not track the VPA estimates as well, and receive less weight in the tuning (Figure B1b). Because values of zero were observed in the Rhode Island and Massachusetts YOY time series, a value of 1 was added to each value in the series when used for VPA tuning. Most surveys agreed that the 1980, 1983 and 1985 year classes were the largest of the past decade, with the 1988 year class the poorest since 1980. Most surveys reflect a trend of improved recruitment since 1988.

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

ADAPT tuning for the VPA (1982 to 1992) was used. All survey indices were included in the tuning procedure, weighted by the inverse of their residual variances. Commercial and recreational fisheries indices were not included be-

Table B11. Stratified mean number per tow at age from MADMF Spring and Fall survey cruises, 1978-1992

	Age									Total
	0	1	2	3	4	5	6	7	8+	
Spring										
1978		0.097	0.520	0.274	0.221		0.042			1.15
1979			0.084	0.087	0.147	0.048	0.011			0.37
1980		0.055	0.061	0.052	0.075	0.053	0.055	0.011		0.36
1981	0.010	0.395	0.558	0.074	0.031	0.043	0.060		0.031	1.20
1982		0.376	1.424	0.118	0.084	0.020		0.010		2.03
1983		0.241	1.304	0.544	0.021	0.009	0.003			2.12
1984		0.042	0.073	0.063	0.111	0.010				0.30
1985		0.142	1.191	0.034	0.042					1.41
1986		0.966	0.528	0.140	0.008					1.64
1987		0.615	0.583	0.012			0.011			1.22
1988		0.153	0.966	0.109	0.012					1.24
1989			0.338	0.079			0.010			0.43
1990		0.247	0.021	0.079	0.012					0.36
1991		0.029	0.048	0.010						0.09
1992		0.274	0.320	0.080		0.011	0.011			0.70
Fall										
1978		0.011	0.124	0.024		0.007				0.17
1979			0.047	0.101		0.019				0.17
1980		0.114	0.326	0.020	0.020	0.010				0.49
1981	0.009	0.362	0.367	0.011						0.75
1982		0.255	1.741	0.016						2.01
1983		0.026	0.583	0.140	0.004					0.75
1984	0.033	0.453	0.249	0.120	0.008					0.86
1985	0.051	0.108	1.662	0.033						1.85
1986	0.128	2.149	0.488	0.128						2.89
1987		1.159	0.598	0.010	0.004					1.77
1988		0.441	0.414	0.018						0.87
1989			0.286	0.024						0.31
1990		0.108		0.012						0.12
1991	0.021	0.493	0.262	0.010						0.79
1992		1.055	0.233							1.29

Table B12. Summer flounder index of abundance from the CTDEP spring to fall (April to September) trawl survey, 1984-1992[1]

Year	Age								Total
	1	2	3	4	5	6	7	8	
1984	0.609	0.201	0.042	0.027	0.014	0.005			0.98
1985	0.496	0.344	0.061	0.024	0.016	0.012			0.95
1986	1.775	0.278	0.107	0.020			0.004	0.004	2.19
1987	1.347	0.205	0.031	0.021	0.003	0.007			1.61
1988	0.680	0.382	0.064	0.034	0.006				1.17
1989	0.021	0.082	0.023	0.009	0.003	0.003			0.15
1990	0.524	0.205	0.037	0.013	0.007				0.78
1991	0.780	0.324	0.118	0.009	0.003	0.006			1.23
1992	0.821	0.411	0.127	0.028	0.006	0.004	0.004		1.40

[1] Delta mean number per tow at age

Table B13. Summer flounder index of abundance, RIDFW fall trawl survey

Year	Mean #/tow	Mean kg/tow	Proportion[1] Age 0	Mean Age 0 #/tow	Proportion[2] Age 1	Mean Age 1 #/tow
1979	0.24	0.13	0.00	0.00	0.67	0.16
1980	0.81	1.37	0.10	0.08	0.31	0.25
1981	3.24	2.13	0.05	0.16	0.65	2.13
1982	0.83	0.68	0.00	0.00	0.43	0.36
1983	0.62	0.57	0.03	0.02	0.40	0.25
1984	1.35	0.95	0.12	0.16	0.63	0.85
1985	0.95	0.52	0.35	0.33	0.35	0.33
1986	3.49	2.05	0.18	0.63	0.63	2.20
1987	1.41	0.90	0.31	0.44	0.51	0.72
1988	0.57	0.42	0.03	0.02	0.71	0.40
1989	0.07	0.10	0.00	0.00	0.60	0.04
1990	0.83	0.54	0.07	0.06	0.57	0.47
1991	0.23	0.23	0.19	0.04	0.31	0.07
1992	1.26	1.11	0.00	0.00	0.56	0.71

[1] Proportion of catch < 30 cm
[2] Proportion of 30 cm ≤ catch < 40 cm

cause of trends in residuals observed in initial runs, potentially indicating changes in catchability over time that could bias the estimates of stock size and F. Natural mortality was assumed to be 0.2. Fishing mortality rates and abundances of ages 1 to 3 were estimated for 1993 in the tuning. Abundance of ages 4 and 5+ were estimated from F's estimated in 1992 and the input partial recruitment pattern. Because no recruitment indices were available for 1993, stock size at age 0 was not estimated. The F on the age 5+ group was set equal to the rate for age 4.

Fishing mortality in 1990-1992 has declined from peak levels in 1988-1989 but is estimated to exceed 1.0. For the final VPA, the fully recruited fishing mortality rate (ages 2-4,u) in 1992 was estimated to be about 1.1 (Table B15, Figure B2). This trend in F is consistent with the fishing mortality rates estimated in the previous assessment for summer flounder made through 1990 (NEFSC 1992).

Stock size in numbers in 1991-1992 (97 million in 1992) has increased from lowest time series value in 1989 (56 million), but remains below levels estimated for the early-mid 1980s (140 to 180 million) (Table B15). Spawning stock biomass on 1 November 1992 was estimated to be 15,000 mt, 2.5 times larger than the 1989 low (5,600 mt) (Table B15, Figure B3). Although spawning stock biomass is 67% of the 1983 peak (22,000 mt), only about 11% of the spawning stock is composed of fish aged 3 or older. In contrast, at the overfishing definition level of F_{max} = 0.23 (Figure B6), about 77% of the spawning stock biomass would be expected to be of fish aged 3 and older, at a spawning stock biomass of 116,000 mt given average recruitment of 52 million fish.

Summer flounder spawn in the late autumn and into winter (peak spawning on November 1), and age 0 fish recruit to the fishery in the autumn of the following year. For example, summer flounder spawned in autumn 1987 (from the 1987 spawning stock biomass) recruit to the fishery in autumn 1988, and appear in VPA tables as age 0 fish in 1988. The abundance of the 1992 year-class at age 0 was estimated using catchability coefficients estimated for each age 0 index by ADAPT. This year class, as indicated by the available YOY indices, was estimated to be about 42 million fish, somewhat below the strength of the 1991 year class. The 1982 and 1983 year classes are the largest of the series, at 81 million and 95 million fish, respectively. The 1988 year class was the smallest of the series, at only 17 million fish (Table B15, Figure B3).[1]

Coefficients of variation for VPA estimates of stock size at ages 1, 2, and 3 were 26%, 36% and 69%, respectively. These estimates are less precise, but also less biased, than those obtained in previous assessments, due in part to reliance in the current analysis on only survey indices in the tuning procedure.

The distribution of bootstrapped F estimates was highly skewed (Figure B4), leading to high coefficients of variation for F on fully-recruited ages (149% for the fully-recruited F; coefficients of variation for F at age 0 and 1 were 25% and

[1] Note that year classes are plotted for the year of the SSB that produced them, not the year in which they appear in VPA tables.

Table B14. Summary of recruitment indices from state, federal, and university research surveys, North Carolina to Massachusetts

Survey	Year Class												
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
NEFSC[1] (age 1)	0.59	0.69	0.32	0.17	0.55	1.49	0.46	0.59	0.06	0.62	0.81	0.75	
NEFSC[1] (age 2)	1.41	0.39	0.33	1.56	0.43	0.43	0.79	0.23	0.03	0.28	0.41		
MA[2] (age 1)	0.40	0.38	0.24	0.04	0.14	0.97	0.62	0.15	0.00	0.25	0.03	0.27	
MA[2] (age 2)	1.42	1.30	0.07	1.19	0.53	0.58	0.97	0.34	0.02	0.05	0.32		
CT[3] (age 1)					0.50	1.78	1.35	0.68	0.02	0.52	0.78	0.82	
RI[4] (age 1)	2.13	0.36	0.25	0.85	0.33	2.20	0.72	0.40	0.04	0.47	0.07	0.71	
RI[5] (age 0)	0.08	0.16	0.00	0.02	0.16	0.33	0.63	0.44	0.02	0.00	0.06	0.04	0.00
MA[6] (age 0)			3.00	3.00	1.00	19.00	5.00	5.00	2.00	3.00	11.00	4.00	0.00
DE[7] (age 0)	0.18	0.06	0.19	0.04	0.07	0.11	0.14	0.18	0.01	0.21	0.41	0.14	0.66
MD[8] (Age 0)	4.71	4.56	1.61	12.46	17.72	7.31	26.24	10.72	0.46	1.90	3.87	5.96	
VIMS[9] (age 0)	4.89	4.16	2.47	1.96	0.84	0.72	0.81	0.52	0.35	0.50	1.12	1.24	0.44
NC[10] (age 0)								13.25	1.70	4.77	4.56	5.92	10.97

[1] Number per tow (fitted delta stratified mean number per tow), NEFSC spring offshore trawl survey
[2] Number per tow (stratified mean number per tow), MADMF spring trawl survey
[3] Number per tow (delta mean number per tow), CTDEP trawl survey
[4] Number per tow (stratified mean number per tow), RIDFW fall trawl survey
[5] Number per tow (stratified mean number per tow), RIDFW fall trawl survey - value of 1 was added to each observation in VPA tuning
[6] Total number, MADMF beach seine survey (fixed stations) - value of 1 was added to each observation in VPA tuning
[7] Number per tow, DEDFW 16 foot headrope trawl survey
[8] Geometric mean number per tow, MDDNR Seaside trawl survey
[9] Geometric mean number per tow, VIMS young fish survey (fixed stations)
[10] Number per tow (stratified mean number per tow), NCDMF Pamlico Sound trawl survey

34%, respectively). This distribution also resulted in a bootstrap mean (1.4) higher than the point estimate from the VPA (1.1). The bootstrap results showed a relatively large percent bias (29%) of the VPA estimate of fully recruited F (ages 2 to 5+) in 1992 relative to the bootstrap estimate. This may indicate errors in the catch at age matrix for summer flounder due to the inclusion of estimated, rather than directly reported, catch at age for the recreational fishery and commercial discard, as well as imprecision in the survey indices used for tuning. Errors in the catch at age are usually considered to be very small relative to the error associated with the tuning indices, but in the case of summer flounder they may contribute significantly to the imprecision of the bootstrap estimates. Pending further investigation of the influence of other possible errors not accounted for in the ADAPT model on the estimation procedures, the estima-

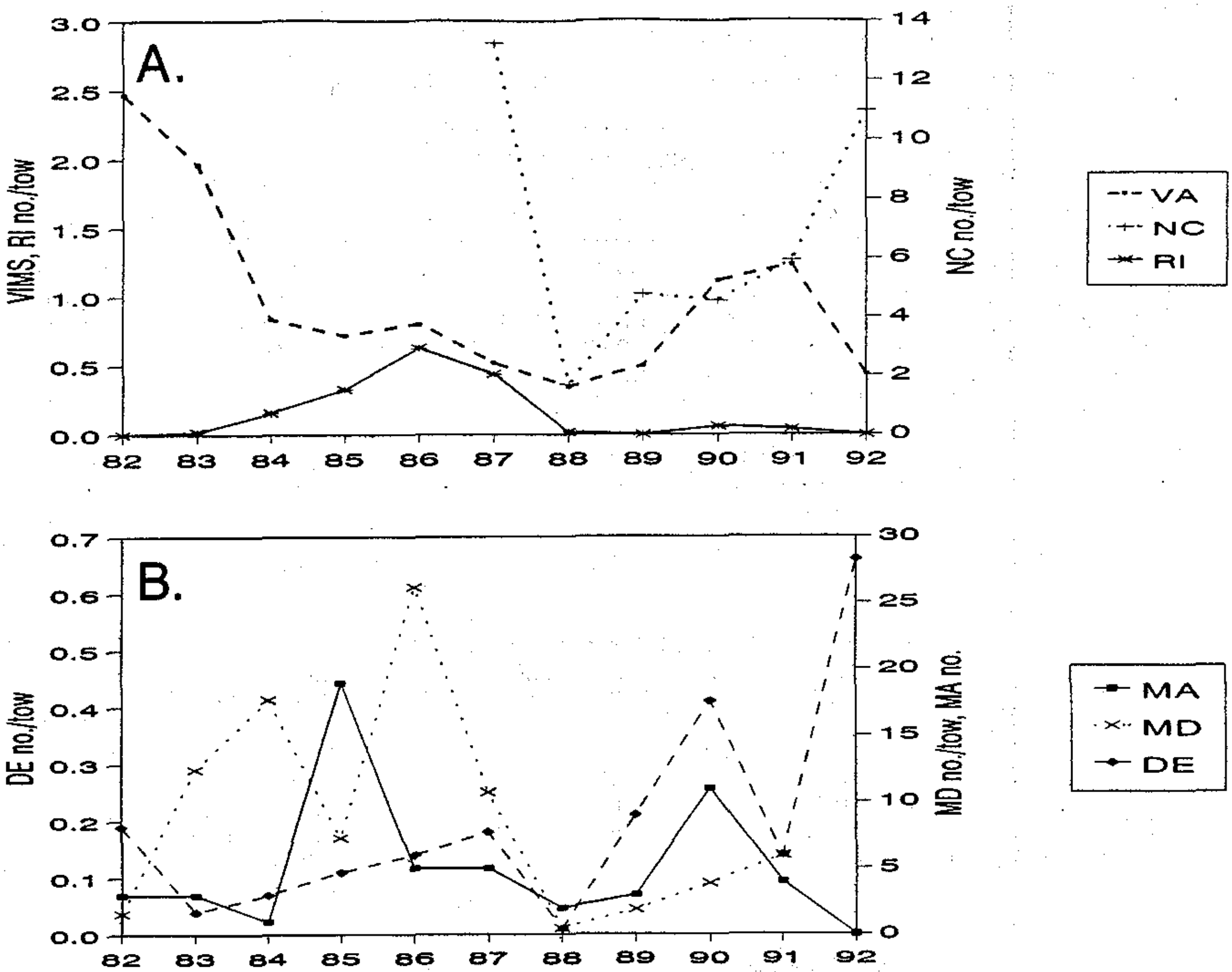

Figure B1. Trends in age 0 recruitment indices for summer flounder, 1982-1992.

tion of fully-recruited F from the VPA is considered to be the best point estimate of current F. Bootstrap results suggest there is a high probability (> 95%) that F in 1992 was above the 1993 management target (F_{tgt}) of 0.53, and a 50% probability that F in 1992 was at least 1.0 (Figure B4).

The bootstrap estimate of spawning stock biomass was estimated with a coefficient of variation of 26%. This estimate is relatively precise, in spite of the imprecision of the estimates for individual ages, because it represents an aggregate of ages 0 to 5+. The bootstrap results indicate a high (> 95%) probability that spawning stock biomass in 1992 was at least 10,000 mt, and a 50% probability that it was at least 15,000 mt, both substantial increases over the VPA estimate of 5,600 mt in 1989 (Figure B5).

The calculation of biological reference points for summer flounder using the Thompson and Bell (1934) model was detailed in the Report of the Eleventh SAW (NEFC 1990). Since partial recruitment pattern has remained stable (in spite of the addition of commercial discards in the catch at age matrix for 1989 to 1992), no revised analysis was performed. The 1990 analysis indicated $F_{0.1}$ = 0.14 and F_{max} = 0.23, Figure B6).

In summary, VPA results indicate that fishing mortality rates on summer flounder have declined since 1989, but remained above 1.0 during 1992, well above the levels of the MAFMC target for 1993 (F_{tgt} = 0.53) and overfishing definition (F_{max} = 0.23). Improved recruitment since 1988 has resulted in an increase in SSB, but this biomass continues to be concentrated in a few age classes.

Yield and stock size projections were made for 1993 to 1995. Recruitment at age 0 in 1993 to 1995 was assumed equal to the geometric mean of VPA estimates of recruitment during 1988 to 1992 $\pm$ one standard error. Stock size at age 1 in 1993 was assumed equal to the VPA point esti-

Table B15. Summer flounder VPA tuned with survey indices only, one iterative re-weight.

Fishing Mortality - SAW16

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	0.0742	0.1498	0.2535	0.0579	0.0862	0.0595	0.2553	0.0420	0.0637	0.0381	0.0393
1	0.6756	0.9141	0.7351	0.6831	0.6642	0.6431	1.0914	0.7953	0.6191	0.7532	0.4406
2	1.5166	0.7839	1.5203	1.3259	1.4017	1.3568	1.7947	1.6711	0.9995	1.2612	1.0753
3	1.1309	0.4743	0.8265	1.9634	1.6278	0.8652	1.7467	1.8587	1.3314	1.2388	1.0753
4	1.5754	0.7462	1.3602	1.4593	1.5445	1.3121	1.9502	1.8484	1.1192	1.3168	1.0753
5+	1.5754	0.7462	1.3602	1.4593	1.5445	1.3121	1.9502	1.8484	1.1192	1.3168	1.0753

Average F for ages 2 to 4

1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1.4076	0.6681	1.4582	1.5829	1.5247	1.1780	1.8305	1.7927	1.1150	1.2723	1.0753

Back-Calculated Partial Recruitment

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	0.05	0.16	0.17	0.03	0.05	0.04	0.13	0.02	0.05	0.03	0.04
1	0.43	1.00	0.48	0.35	0.41	0.47	0.56	0.43	0.46	0.57	0.41
2	0.96	0.86	1.00	0.68	0.86	1.00	0.92	0.90	0.75	0.96	1.00
3	0.72	0.52	0.54	1.00	1.00	0.64	0.90	1.00	1.00	0.94	1.00
4	1.00	0.82	0.89	0.74	0.95	0.97	1.00	0.99	0.84	1.00	1.00
5+	1.00	0.82	0.89	0.74	0.95	0.97	1.00	0.99	0.84	1.00	1.00

Stock Numbers (Jan 1) in thousands - SAW 16

	1982	1983	1984	1985	1986	1987
0	80737.786	95232.518	59506.721	47659.942	59054.722	45769.811
1	42910.904	61374.733	67121.695	37811.263	36824.620	44358.679
2	17456.868	17877.227	20144.535	26349.066	15635.632	15518.228
3	1328.326	3136.734	6683.115	3606.256	5729.087	3151.281
4	390.184	351.004	1598.155	2394.319	414.484	921.027
5+	290.356	302.619	532.925	640.327	1029.214	198.091
0+	143114.423	178274.834	155587.146	118461.173	118687.759	109917.117

	1988	1989	1990	1991	1992	1993
0	16718.554	32704.943	36767.988	52973.262	41778.275	0.000
1	35307.875	10603.403	25675.355	28246.356	41750.275	32886.810
2	19091.520	9706.089	3919.173	11318.631	10889.139	22000.408
3	3271.415	2597.536	1494.278	1181.007	2625.405	3041.973
4	1086.164	466.986	331.485	323.098	280.155	733.429
5+	315.716	105.596	75.613	66.406	133.306	115.504
0+	75791.244	56184.553	68263.892	94108.760	97456.555	58778.125

Table B15. Continued.

Summaries for ages 2-5+

1982	1983	1984	1985	1986	1987
19465.734	21667.584	28958.730	32989.968	22808.417	19788.627
1988	**1989**	**1990**	**1991**	**1992**	**1993**
23764.815	12876.207	5820.549	12889.142	13928.005	25891.314

SSB at the Start of the Spawning Season (Nov 1) - males & females (MT)

	1982	1983	1984	1985	1986	1987	1988
0	6206.571	5901.057	3538.509	4123.002	4530.322	3351.300	1249.479
1	6497.816	7835.176	8873.751	5572.544	5875.310	7075.406	4073.458
2	2471.901	5588.414	2782.827	4090.109	2453.985	2485.944	2060.778
3	742.482	2324.582	3007.599	653.813	1474.072	1454.083	721.039
4	190.847	234.633	696.884	1076.366	174.393	507.754	325.804
5+	192.109	291.430	339.235	391.727	651.253	175.271	148.544
0+	16301.725	22175.291	19238.804	15907.562	15159.336	15049.758	8579.102

	1989	1990	1991	1992
0	2104.442	2739.064	3039.753	2707.301
1	1510.595	4046.532	3706.183	8089.610
2	1314.279	1042.666	2120.403	2570.823
3	489.679	492.956	417.536	1257.158
4	128.285	173.115	173.588	190.046
5+	47.698	68.984	52.083	139.924
0+	5594.977	8563.316	9509.545	14954.861

mate, ± one standard error. Stock sizes at age 2 to 5+ were assumed equal to the VPA point estimates. These combinations of starting stock sizes for 1993 provided worst, average, and best case scenarios that bracket the range of uncertainty about the estimates of stock sizes at ages 0 and 1 in 1993.

Partial recruitment was based on the geometric mean of F at age for 1990 to 1992. Weight at age was based on geometric means of 1990 to 1992 values. Total catch was apportioned between landings and discard for 1993 to 1995 on the basis of the proportion of each in the total catch for 1990 to 1992. The projections assume that these patterns of discarding, which are currently due to the impact of minimum size regulations, will continue over the time span of the projections. Different discarding patterns that could develop during 1993 to 1995 due to trip and bag limits and fishery closures have not been evaluated.

Fishing mortality in 1993 (F_{93}) was assumed to be the F realized if the 1993 commercial and recreational landings quotas are taken, assuming the range of starting stock sizes for ages 0 and 1 in 1993. Fishing mortality in 1994-1995 was assumed to be the MAFMC target F for that period of 0.53 (F_{tgt} = 0.53).

If landings in 1993 equal quota amounts (9,400 mt), realized F_{93} could range from 0.46 to 0.52, given the uncertainty of stock sizes at ages 0 and 1 estimated for 1993 (Table B16; these stock size estimates depend on imprecise survey estimates of YOY abundance). With fishing mortality at the F_{tgt} = 0.53 level in 1994-1995, average levels of recruitment will result in landings increasing to 14,400 mt in 1994 and 16,200 mt in 1995. Assumption of the worst and best case scenarios for recruitment will result in landings about 20% below or 20 to 30% above the average case in 1994-1995. Landings projected for 1994 under average stock sizes for age 0 in 1993-1994

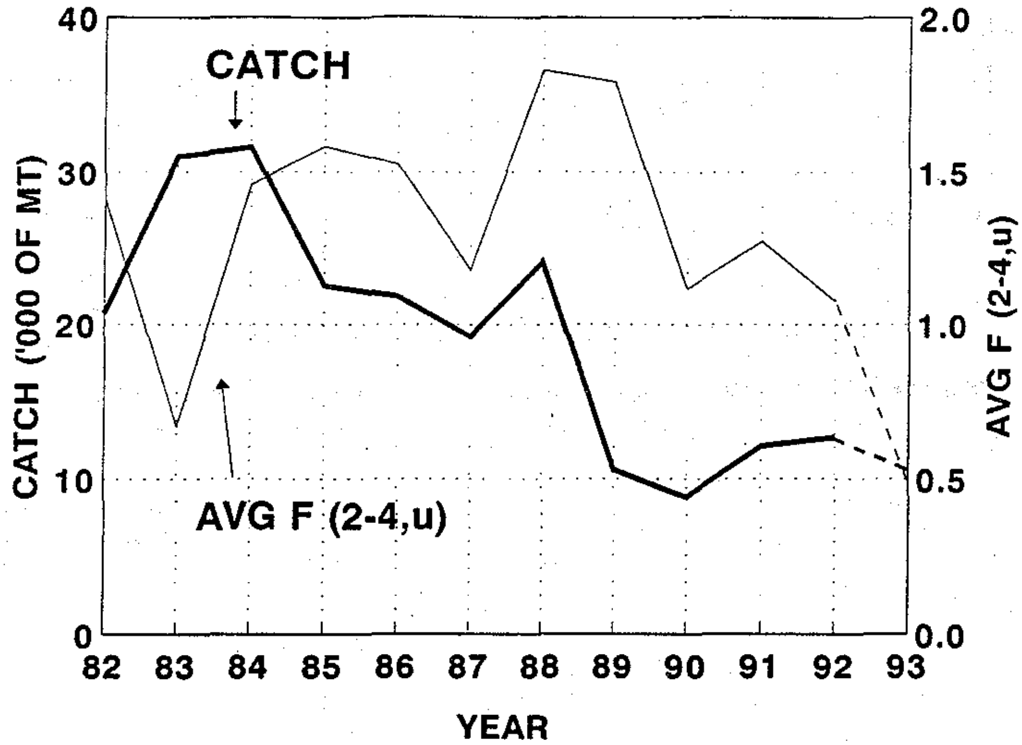

Figure B2. Trends in total catch, (landings and discard, thousands of metric tons)and fishing mortality (fully recruited F, ages 2 to 4, unweighted) for summer flounder, 1982-1992.

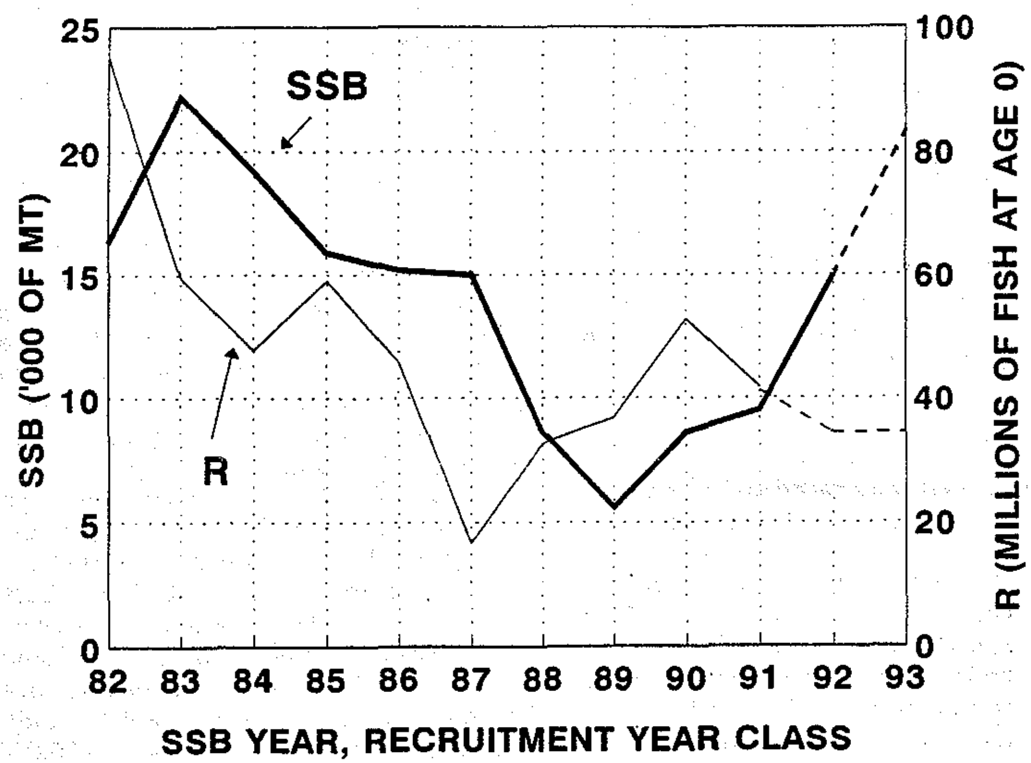

Figure B3. Trends in spawning stock biomass (SSB ages 0 to 5, thousands of metric tons) and recruitment (millions of fish at age 0) for summer flounder, 1982-1992. Note that because summer flounder spawn in late autumn, fish recruit to the fishery at age 0 the following autumn. For example, fish spawned in autumn 1987 recruit to the fishery in autumn 1988 and appear in VPA table at age 0 in 1988.

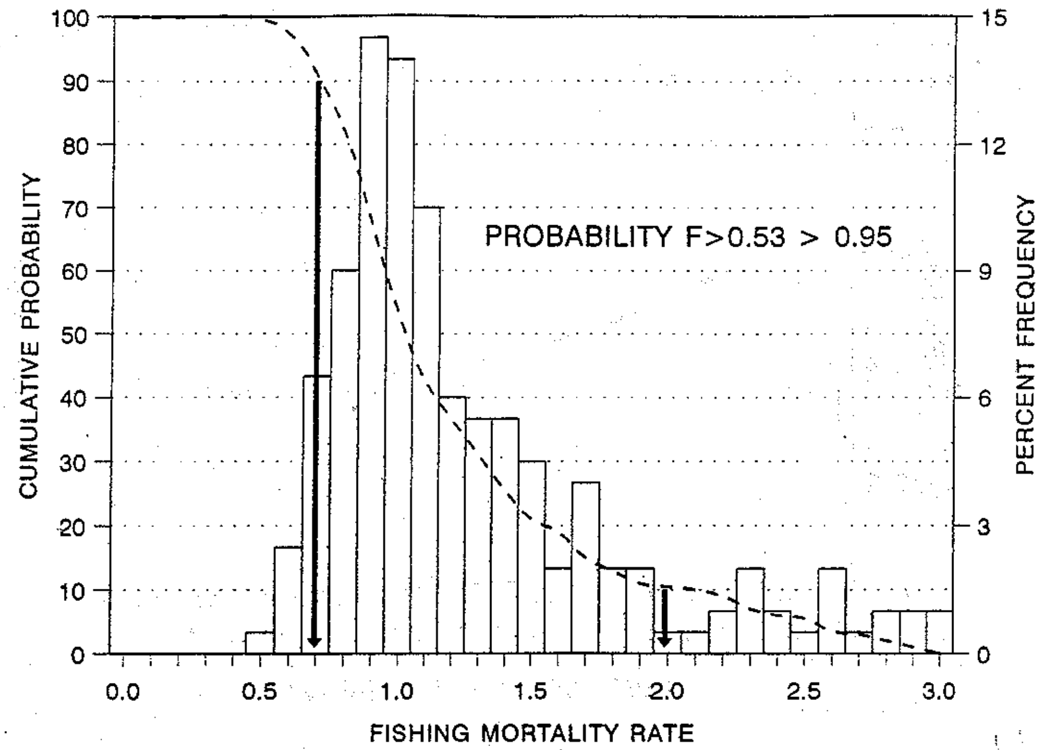

Figure B4. Precision of the estimates of fully recruited F (ages 2-4,u) in 1992 for summer flounder. Vertical bars display the range of the bootstrap estimate and the probability of individual values in that range. The dashed line gives the probability that F is greater than any value along the X axis.

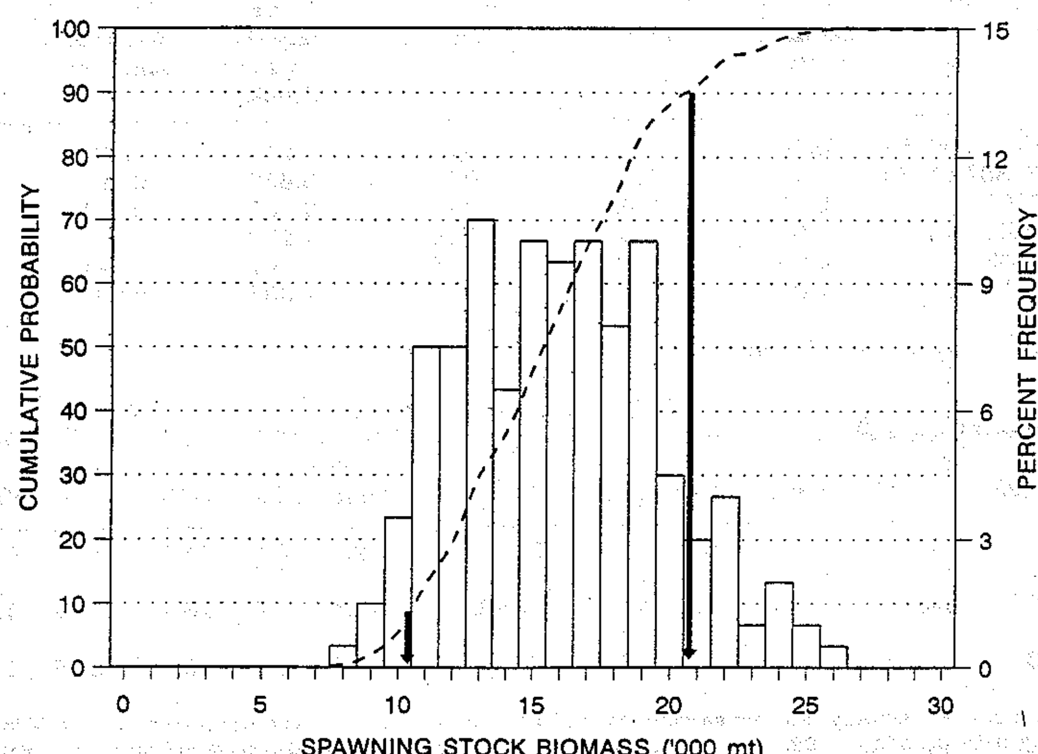

Figure B5. Precision of the estimates of spawning stock biomass on November 1, 1992 for summer flounder. Vertical bars display the range of the bootstrap estimate and the probability of individual values in that range. The dashed line gives the probability that SSB is less than any value along the X axis.

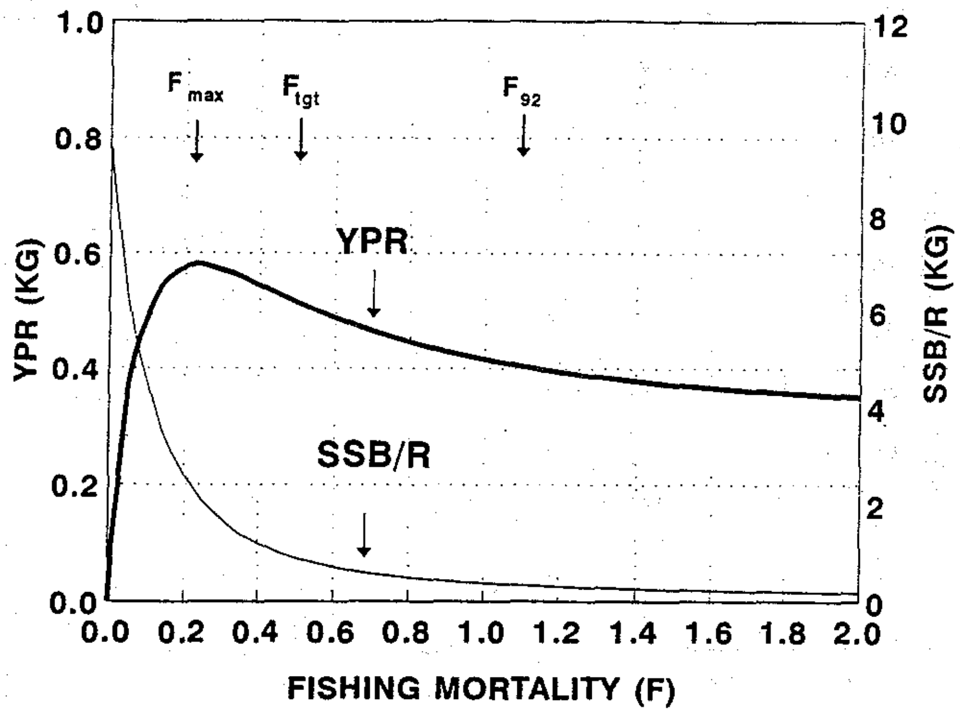

Figure B6. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for summer flounder.

Table B16. Input parameters and projection results for summer flounder, landings, discard, and spawning stock biomass (thousands of mt)[1]

	Stock Size in 1993	Fishing Mortality Pattern	Proportion Landed	Proportion Mature	Mean Weights Spawning Stock	Mean Weights Landings	Mean Weights Discards
0	22721, 33858, 50453	0.04	0.150	0.38	0.211	0.282	0.192
1	24492, 32887, 41282	0.49	0.580	0.72	0.430	0.491	0.352
2	22000	0.91	0.990	0.90	0.751	0.801	0.604
3	3042	1.00	1.000	1.00	1.237	1.237	1.237
4	733	1.00	1.000	1.00	1.794	1.794	1.794
5+	116	1.00	1.000	1.00	2.835	2.835	2.835

F_{93} = F realized if 1993 quota is taken

F_{93}	Stock size at age 0 in 1993-95	Stock size at age 1 in 1993	1993 Land.	1993 Disc.	1993 SSB	$F_{1994-95}$	1994 Land.	1994 Disc.	1994 SSB	1995 Land.	1995 Disc.	1995 SSB
0.52	22721	24492	9.4	0.9	18.2	F_{tgt}=0.53	12.1	0.6	21.0	12.6	0.7	21.8
0.48	33858	32887	9.4	1.1	21.1	F_{tgt}=0.53	14.4	1.0	26.1	16.2	1.0	28.8
0.46	50453	41282	9.4	1.3	24.4	F_{tgt}=0.53	17.0	1.5	32.6	20.8	1.5	38.1

[1] Starting stock sizes on 1 January 1993 are as estimated by VPA, except age 0 which is the geometric mean of VPA estimated numbers at age 0 (thousands) for 1988-92, + 1 standard error. Stock size at age 1 is also examined for a range of values (VPA point estimate + 1 standard error). Fishing mortality was apportioned among landings and discard based on the proportion of F associated with landings and discard at age during 1990-92. Mean weights at age (spawning stock, landings, and discards) are geometric means of 1990-92 values. Recruitment levels in 1994-95 are also estimated as the geometric mean of numbers at age 0 (thousands), + 1 standard error, during 1988-92. F_{93} is the F realized if fishery landings quotas, plus associated discard, are caught in 1993 (commercial landings = 5600 mt, recreational landings = 3800 mt). F_{tgt} = 0.53 is the target designated by the MAFMC. Proportion of F, M before spawning = 0.83 (spawning peak at 1 November).

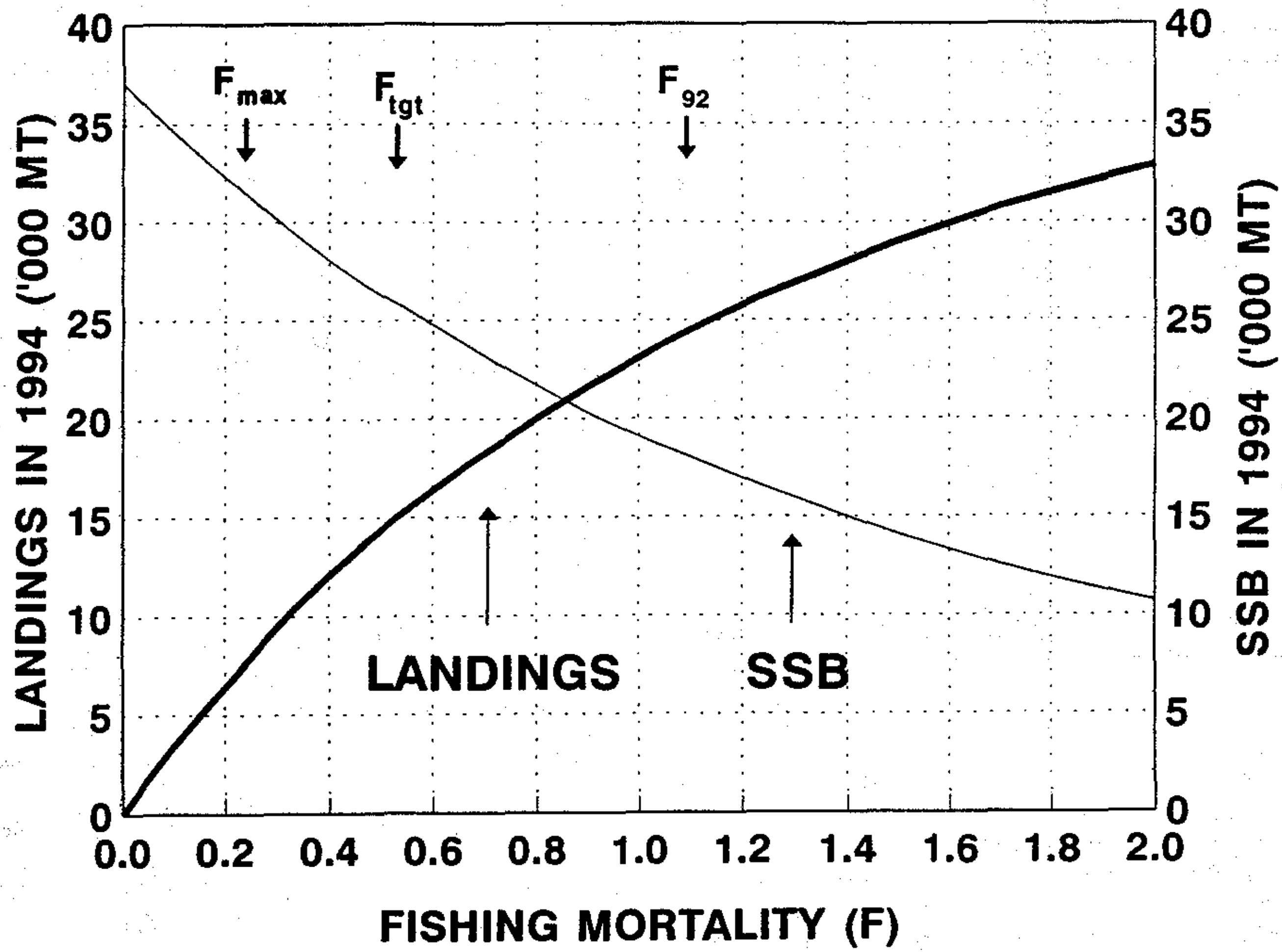

Figure B7. Predicted landings in 1994 and and spawning stock biomasses (SSB) in 1994 of summer flounder over a range of fishing mortalities in 1994, from F - 0 to F - 2.0.

Table B17. Summary of NEFSC trawl survey data for summer flounder, spring 1991 to winter 1993 surveys, Great South Channel to Cape Hatteras (offshore strata 1-12, 61-76)

Survey	Stations in Strata (#)	Stations withFluke (%)	Stratified Mean (kg/tow)	CV	Stratified Mean (#/tow)	CV	Mean Length (cm)	Length Range (cm)	Largest Tow (kg)	Largest Tow (#)
Spring 1991	96	33.3	0.35	17.1	1.08	17.0	30.4	21-63	3.5	11
Autumn 1991	95	10.5	0.13	32.6	0.39	34.0	30.2	19-45	1.7	6
Winter 1992	92	71.2	5.96	15.5	15.01	15.6	32.8	19-71	44.5	128
Spring 1992	92	38.0	0.46	17.9	1.19	17.5	32.0	21-72	5.0	9
Autumn 1992	93	14.0	0.38	42.0	0.67	32.7	35.4	25-66	10.3	10
Winter 1993	98	68.0	6.02	10.1	15.03	13.1	33.1	20-69	58.3	220

and age 1 in 1993 may be optimistic if the estimated stock sizes are too high. Adopting a landings quota for 1994 that is lower than the projected 14,400 mt would be a risk-averse strategy that will improve chances that the fishing mortality target is met in 1994 (Figure B7).

Spawning stock biomass will continue to increase under any of the three age 0 and 1 stock size scenarios for 1993-1995. However, even though projected spawning stock biomass levels in 1993-1995 Table B16, Figure B7) would be equal to or larger than the high levels observed in the early 1980s, the age structure of the stock remains truncated.

EVALUATION OF NEFSC WINTER TRAWL SURVEY

A new series of NEFSC winter trawl surveys was started in February 1992 specifically to provide improved indices of abundance for flatfish, including summer flounder. This survey targets flatfish during the winter when the fish are concentrated offshore. A modified 36 Yankee trawl is used in the winter survey that differs from the standard trawl employed during the spring and autumn surveys in that 1) long trawl sweeps (wires) are added before the trawl doors, to better herd fish to the mouth of the net, and 2) the large rollers used on the standard gear are absent, and only a chain "tickler" and small spacing "cookies" are present on the footrope.

The survey is a promising source of coastwide data on relative abundance of summer flounder. Review of data from the first two years of the survey indicates that the performance of the survey is superior to that of the NEFSC spring and autumn bottom trawl surveys in terms of: higher percentage of stations at which summer flounder were present; higher number and weight of summer flounder caught (minimum, mean, and maximum catches over survey); and lower coefficients of variation around stratified mean estimates of abundance (Table B17). Most fish have been taken in strata 61 to 76 (27 to 110 m; 15 to 60 fathoms), off the Delaware and Chesapeake Bays. Other concentrations of fish were found in strata 1 to 12, south of Long Island, New York and Rhode Island coasts, in slightly deeper waters. A few large summer flounder were captured along the southern flank of Georges Bank. The current gear, survey design, and spatial coverage require no revision at this point.

The performance of these survey indices as tuning indices for virtual population analysis cannot be assessed until next year because only two observations are available. Based on the characteristics mentioned above, however, the performance is likely to be superior to the NEFSC indices currently used for tuning. The length distribution sampled from fish available at the time of the survey indicates that fish age 1 and older are available to the survey. An improvement in estimation of relative abundance of age 1 fish may be realized, as the current combined suite of NEFSC and state indices provides imprecise estimates for this age group. Fishery-independent estimation of relative abundance of age 0 fish will continue to remain problematic in future assessments, however.

EVALUATION OF NEFSC SEA SAMPLING PROGRAM

The 1989-1992 NEFSC sea sample data show that summer flounder landings and discard occur in many different components of the Southern New England (SNE) and Mid-Atlantic (MA) otter trawl fishery, as characterized by area and time strata (NAFO division and calendar quarter). In the current estimation procedure, the geometric mean discard rate (kilograms/day fished) from the sea sampling data is multiplied by the number of days fished recorded by the weighout sampling program, within division/quarter strata, to estimate total discard. The basis for combining the two sampling programs to estimate discards rests with the good agreement between a) landings estimated from the sea sample landings rates and days fished recorded in the weighout data base (SS_est), and b) landings reported directly in the weighouts (WO_est).

Consideration of the variation in catch and discard rates in the different area/time strata has proven necessary to obtain what appear to be reasonable estimates of summer flounder discard during 1989-1992. Valuable information on summer flounder catch and discard rates is received from sea sample trips that do not target summer flounder. Current sea sampling effort (*i.e.*, number of trips) for summer flounder varies considerably across division and quarter. The relative error between landings estimated from data collected by the sea sampling and weighout systems was considered to evaluate the efficacy of the current allocation of sea sampling in the SNE/MA otter trawl fishery for summer flounder.

Relative error was defined as $(SS\_est_{y,d,q} - WO\_est_{y,d,q})/WO\_est_{y,d,q}$ where $SS\_est_{y,d,q}$ is the sea sampling estimate of landings for year y,

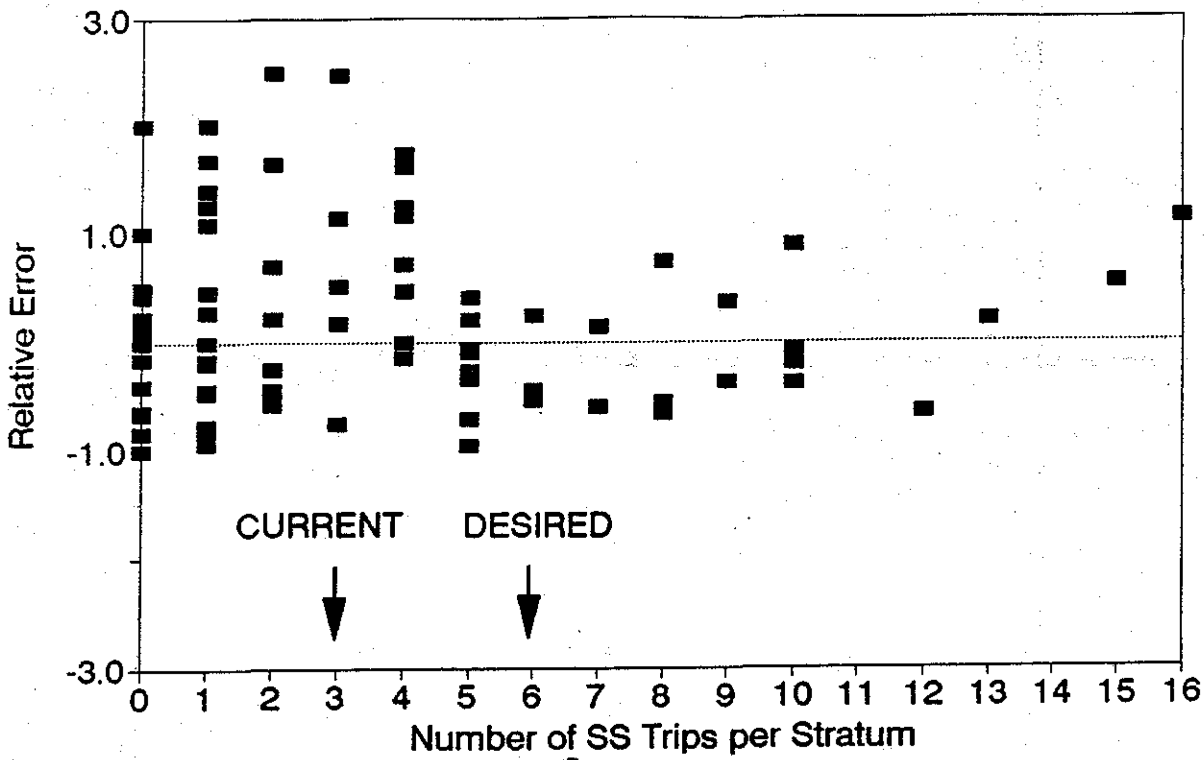

Figure B8. Relative error in the estimates of landings from sea sample and weighout data versus the number of sea sampling trips per year in division/quarter stratum. Sea sampling trips are those catching any summer flounder, split by division, in the Southern New England/Mid-Atlantic otter trawl fishery, 1989-1992.

division d, and quarter q and $WO\_est_{y,d,q}$ is the associated weighout estimate. Standard sampling theory suggests that the accuracy of estimate should improve with the number of representative samples per cell. A plot of relative error versus the number of sea sampling trips per division/quarter stratum illustrates the expected pattern of decreasing error with increasing number of trips (Figure B8). When no sample trips were conducted in a given cell, estimates were imputed from appropriate adjacent cells. The analysis suggests that little reduction in relative error occurs at sampling intensities greater than 6 trips per cell, and that the overall relative error of the discard estimates could be minimized by doubling the current sea sampling effort in the SNE/MA otter trawl fishery (from the 1989 to 1992 average of 78 trips per year, split by division, which caught any summer flounder, to 156 trips per year). A preliminary examination of a general linear model with year, division, quarter, and number of sea sampling trips as factors showed significant division and division by sea sampling trip interaction effects, suggesting varying allocation of trips by division will be necessary to optimize sampling effort. Allocation of effort among cells should be investigated further.

In summary, an increase in number of sea sampled trips, up to double the amount currently in place, will improve the quality of discard estimation. Future advice on reallocation and optimization of sea sampling will need to be based on this year's experience and data, reflecting the reaction of the fishery to quota restrictions. This includes balancing needs for information on discarding in the exempted fishery, large-mesh fishery, and bycatch/discard fishery after quotas are met. Additional information on discard practices (*e.g.*, prevalence of high-grading) could be collected under the present system. The state of North Carolina maintains a computerized form of data collected under the North Carolina sea sampling program. Analyses of these data have been rescheduled for later in this year, when participation by key investigators becomes possible.

DISCUSSION AND CONCLUSIONS

Recommendations for the Steering Committee

- Continue NEFSC winter trawl survey, as initial analyses suggest this series will provide more reliable and precise indices of abundance for use in mortality estimation and VPA tuning than currently used indices, *e.g.*, NEFSC spring and autumn survey time series.

- Continue/expand NEFSC sea sampling program collection of data for summer flounder, with special emphasis on:

  a) Improved areal and temporal coverage;

  b) Timely availability of sea sample data for use in assessments;

  c) Continued sampling (after commercial fishery quotas are reached) of fisheries that take significant quantities of summer flounder; and

  d) Adequate length and age sampling.

- Continue research to determine length and age frequency and discard mortality rates of both commercial and recreational fishery summer flounder discards.

- Continue review of available information on mesh selectivity of diamond and square mesh for summer flounder. This information will be important in the future to make accurate projections of landings, discard, and spawning stock biomass under various mesh size/minimum length/quota combinations.

Recommendations to the Southern Demersal Subcommittee

- Undertake research to determine if the maturity ogive used in the assessment (based on gross examination of ovaries) accurately reflects spawning potential of summer flounder (especially age 0 and 1 fish).

- Examine North Carolina sea sampling data for comparison of discard rates and total discard estimates with those from NEFSC sea sampling program.

- Investigate allocation of NEFSC sea sampling trips to optimize sampling effort.

- Develop a standardized index of abundance from NEFSC sea sampling data (catch = kept + discard) to provide a commercial fishery index that accounts for all removals by the fishery.

- In the next assessment, use the 80% commercial fishery discard mortality rate accepted in Amendment 2 of the FMP.

- Investigate the utility of alternative strata sets for the NEFSC spring trawl survey time series for summer flounder.

- Incorporate the impact of discards in future calculation of biological reference points.

Major Sources of Uncertainty

- VPA estimates of stock size in 1993 are not precise (coefficients of variation at age were 26% for age 1, 36% for age 2, and 69% for age 3) because they depend on imprecise survey indices. Projected landings should be considered with caution.

- Indices of recruitment are not available for 1993, so estimates of age 0 abundance in 1993 are based on a geometric mean ($\pm$ 1 standard error).

- Sea sampling length frequency data for 1992 and 1993 are unavailable, so 1989-1991 mean proportions at age, length at age, and weights at age have been used to characterize the 1992 commercial fishery discard. Effects of quota restrictions on discard patterns in 1993 cannot be incorporated into projections.

- North Carolina commercial landings at age for 1992 are based on provisional length frequency data (data for quarters 1 and 4 only) and may be revised somewhat in the future.

- Current assumptions accepted to allow characterization of age composition of recreational discard are based on data from a limited geographic area (Long Island, N.Y.).

- The present maturity ogive for summer flounder is based on gross examination of ovaries, and may not accurately reflect the spawning potential of age 0 (and age 1) fish.

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C. ATLANTIC HERRING COASTAL STOCK COMPLEX ASSESSMENT

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Describe the status of the coastal stock complex of Atlantic herring.

b. Provide an age structured assessment of the coastal stock complex of Atlantic herring including estimates of fishing mortality on fully recruited ages, spawning stock biomass, and exploitable biomass at the beginning of 1992. Perform bootstrap replications of the assessment to characterize the variability of the estimates.

c. Specify data deficiencies and research needs.

INTRODUCTION

This assessment constitutes a revision of an earlier assessment on the same stock complex performed by the SARC in the fall of 1991 (NEFSC 1992). Following the advice of the SARC at that meeting, data from U.S. coastal fisheries in the Gulf of Maine were combined with data from south of Cape Cod, fixed gear catches from New Brunswick, and historical Georges Bank information, into a single catch-at-age matrix for the years 1967 to 1991. This approach is based on the fact that the virtual population analysis used to assess this resource is tuned using spring NMFS bottom trawl survey data, which is collected at a time of year when Atlantic herring that might otherwise be assigned to individual spawning stocks (*e.g.*, Gulf of Maine, Georges Bank, as in earlier assessments), are mixed as a result of their migratory behavior and can not be separated. New Brunswick fixed-gear catches are not considered to be part of the Nova Scotian 4WX stock and are excluded from that assessment (Stephenson *et al.* 1992). Herring caught in Subarea 5 of the Bay of Fundy are transboundary in nature and have been included in the coastal stock complex assessment.

The basic methodology employed in the current assessment is the same as that used in 1991. The ADAPT methodology was used to tune the VPA. Two additional years of data (1991 and 1992) have been added for this analysis. In addition, some of the input parameters for this assessment have been changed, notably in the catch-at-age estimates and the bottom trawl survey catch rates used to tune the assessment.

COMMERCIAL LANDINGS

The commercial fishery for Atlantic herring currently is active in coastal waters of the Gulf of Maine, principally in New Brunswick, Maine, and Massachusetts, with some minor landings in southern New England and the mid-Atlantic region (Table C1, Figure C1). Domestic landings currently are stable at 70,000 to 90,000 mt a year.

Historically, foreign catches on Georges Bank in the late 1960s and early 1970s far exceeded catches along the coast, but there has been no fishing on Georges since that stock collapsed in the mid-1970s. This is true despite the fact that herring began returning to the bank to spawn in 1986 (Stephenson and Kornfield 1990). Larval survey results and reports of large concentrations of adult herring on the bank in the fall of recent years, suggest that at least some recovery of this stock has occurred. Fishing on Georges Bank is currently not being pursued by any U.S. vessels because of the limited market demand for herring. Canada, however, will permit a 5000 mt exploratory fishery for herring on Georges Bank in the fall of 1993.

Atlantic herring juveniles are utilized in the Maine and New Brunswick canning industry, (age 2), whereas adults are used for bait, primarily in the lobster fishery, throughout New England and along the U.S. East Coast. They are caught primarily with purse seines and trawls, although a small quantity is still taken in Maine in weirs and stop seines. The summer fishery (May to October) takes place primarily in Maine and New Brunswick while fishing in Massachusetts and south of Cape Cod is primarily from November to April.

Two recent developments in the fishery are Internal Waters Processing (IWP) operations and the incidental taking of Atlantic herring in the Atlantic mackerel joint venture (JV) operations (with mid-water trawls) off the mid-Atlantic states

Table C1. Landings (metric tons) of Atlantic herring from fisheries in Georges Bank (GB), Gulf of Maine (GOM), Southern New England(SNE), Middle Atlantic (MAT) and New Brunswick, Canada (NB) areas. Includes landings for Internal Waters Processing operations.

YEAR	GB	GOM[1]	SNE[2]	MAT[3]	NB[4]	TOTAL
1960	0	60237	261	152	34304	94954
1961	67655	25548	197	101	8054	101555
1962	152242	69980	131	98	20698	243149
1963	97968	67736	195	78	29366	195343
1964	131438	27226	200	148	29432	188444
1965	42882	34104	303	208	3346	80843
1966	142704	29167	3185	176	35805	211037
1967	218743	30191	247	524	30032	279737
1968	373598	40928	245	122	33145	448038
1969	310758	28336	2104	193	26539	367930
1970	247294	28070	1037	189	15840	292430
1971	267347	32631	1318	1151	12660	315107
1972	174190	37444	2310	409	32699	247052
1973	202335	21767	4249	233	19935	248519
1974	149525	29491	2918	200	20602	202736
1975	146096	31938	4119	117	30819	213089
1976	43502	49887	191	57	29206	122843
1977	2157	50348	301	33	23487	76326
1978	2059	48734	1730	46	38842	91411
1979	1270	63492	1341	31	37828	103962
1980	1700	82244	1200	21	13525	98690
1981	672	64324	749	16	19080	84841
1982	1378	32157	1394	20	25963	60912
1983	53	24824	72	21	11383	36353
1984	58	33958	79	10	8698	42803
1985	316	27157	196	13	27863	55545
1986	586	27942	632	20	27883	57063
1987	11	39179	376	87	27320	66973
1988		39382	1307	365	33421	74475
1989		52656	269	39	44112	97076
1990		62150	761	48	38778	101737
1991		50261	4007	402	24576	79246
1992		54411	716	4564	31968	91659

[1] Maine, New Hampshire, Massachusetts
[2] Rhode Island, Connecticut, New York
[3] New Jersey, Delaware, Maryland, Virginia
[4] NB landings for fixed gear only

in the winter. The abundance of herring during the winter in the mid-Atlantic region in recent years is a result of the recovery of the Georges Bank and Nantucket Shoals spawning stock(s). The IWP landings (U.S. fishermen supplying foreign processing ships anchored in state internal waters) began in Massachusetts in 1985, but have only become significant during the last four years (1989 to 1992) in Massachusetts, Maine, Rhode Island, New York, and New Jersey. Discards of Atlantic herring reported by observers aboard foreign processing ships operating off New Jersey are available for 1985 to 1991 (Table C2). There were no mackerel joint ventures in 1992.

AGE COMPOSITION

The estimated catches-at-age in numbers for the entire stock complex for 1967 to 1992 are given in Table C3. The 1967 to 1988 data were completely revised to correct for an error in the FORTRAN version of BIOSTAT (fish that were aged and measured were being double-counted) and are therefore not the same as used in the 1991 assessment. The effect of this error was minimal, however; the maximum percent change in the estimated numbers-at-age in the entire time series was only 2.6%.

The coastal U.S. catch-at-age estimates for 1989 and 1990 were recalculated to account for

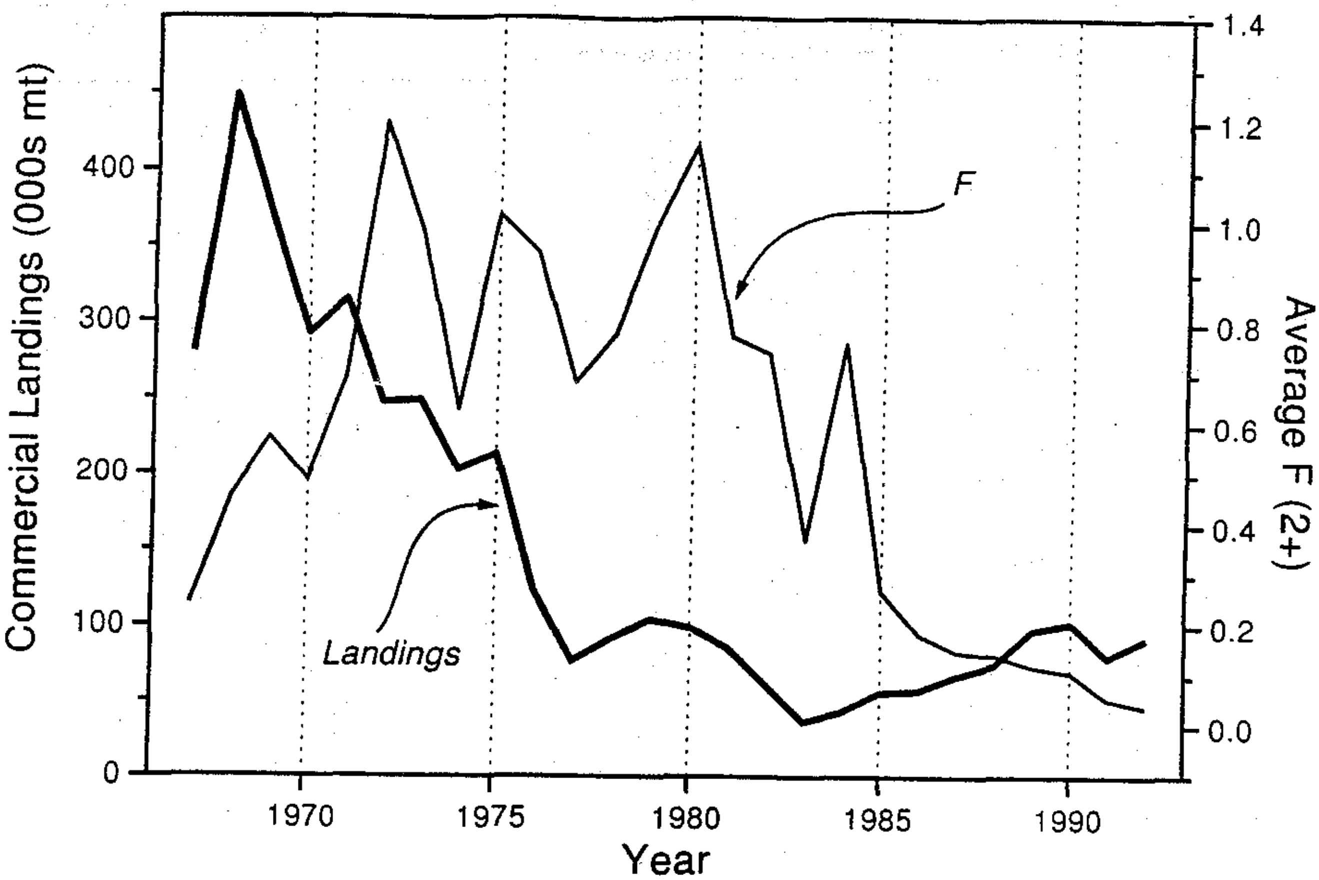

Figure C1. Trends in nominal catch (thousands of metric tons) and fishing mortality (average F, age 2+) for Atlantic herring, 1967-1992.

the same double-counting error as well as some other problems that became obvious in the process of reprogramming BIOSTAT in D-BASE and estimating catch-at-age for 1991 and 1992. These were:

1. Ages were sometimes missing for some length categories in the samples, especially for larger fish collected in Gloucester. Since all the age-length keys are based on fish that have been frozen and thawed prior to length measurement, and the Gloucester fish are measured when still fresh, a 3% shrinkage factor was applied to all the Gloucester length measurements. Remaining missing ages were assigned according to the most likely age composition for any given centimeter length category.

2. Sample data for some offshore catches in the central Maine coastal area in 1990 and 1991 had been assigned to the Massachusetts mobile gear category, whereas the catches had been included in the central Maine coast category. This problem was corrected. In the process, three new offshore Maine subareas were created in BIOSTAT to complement the Jeffreys Ledge subarea (which is combined with Massachusetts Bay for the purpose of calculating catches-at-age).

Table C2. Atlantic herring discards (metric tons) in the mackerel joint venture fishery in the Mid-Atlantic

Year	Discarded Catch (mt)
1985	16.8
1986	3.8
1987	132.9
1988	300.5
1989	742.4
1990	1395.0
1991	896.5
1992	0.0

3. In the process of rerunning BIOSTAT for 1989 to 1992, new decisions were made regarding the assignment of sample data from adjoining areas or months (for missing

Table C3. Combined catch at age (millions of fish) of Atlantic herring (1967-1992) for coastal United States, Georges Bank, and New Brunswick fixed gear fisheries

Age	1967	1968	1969	1970	1971	1972	1973
1	136.550	15.490	71.460	5.990	154.660	8.250	37.420
2	424.090	1392.430	581.790	494.400	233.400	1001.030	351.240
3	228.610	277.180	397.600	189.980	410.430	64.730	1301.350
4	208.760	180.550	234.320	492.870	327.900	165.16	294.010
5	130.530	397.240	300.730	296.160	333.260	261.730	76.870
6	270.320	266.920	309.600	151.770	221.840	209.470	47.340
7	389.360	464.730	216.850	128.080	135.930	126.160	36.180
8	50.180	356.110	215.250	79.170	69.380	55.570	19.600
9	11.550	25.110	130.010	50.750	26.390	32.220	4.8601
10	10.390	9.100	29.330	32.410	30.400	23.710	5.550
11	0.170	0.650	1.030	2.880	3.530	1.650	0.340
1+	1860.510	3385.510	2487.970	1924.460	1947.120	1949.680	2174.760

Age	1974	1975	1976	1977	1978	1979	1980
1	34.620	45.140	75.380	597.180	269.800	6.560	343.150
2	429.270	645.850	531.250	579.310	1222.480	1174.180	230.050
3	146.900	117.730	249.300	83.330	138.480	422.540	363.170
4	750.410	112.110	47.340	70.560	26.070	57.740	185.080
5	78.650	610.360	49.390	20.950	42.910	16.080	21.770
6	18.410	46.320	208.890	18.450	6.180	17.080	6.160
7	9.110	17.420	10.400	49.670	8.260	6.150	8.210
8	5.590	9.390	3.350	2.630	32.180	4.530	0.850
9	3.080	5.580	2.550	0.670	1.100	7.090	0.680
10	0.470	0.710	0.670	0.390	0.650	0.340	4.490
11	0.390	0.440	0.200	0.320	0.220	0.001	0.120
1+	1476.900	1611.050	1178.720	1423.460	1748.330	1712.291	1163.730

Age	1981	1982	1983	1984	1985	1986	1987	1988
1	61.710	52.700	32.810	18.880	30.200	40.680	50.990	79.280
2	1169.190	669.470	267.470	185.040	562.750	247.460	223.780	502.250
3	34.360	110.140	59.100	133.100	84.320	225.150	134.810	110.940
4	68.100	6.720	28.900	40.340	51.070	48.500	180.510	62.120
5	46.890	30.270	1.250	28.480	27.170	38.000	44.860	126.610
6	4.860	19.300	6.620	2.140	13.550	16.250	18.430	34.860
7	1.360	2.180	7.360	4.320	1.180	7.710	5.690	9.140
8	1.200	0.420	0.330	1.720	2.390	0.360	2.350	2.180
9	0.070	0.820	0.190	0.520	0.720	0.460	0.210	1.080
10	0.140	0.120	0.130	0.120	0.001	0.090	0.320	0.100
11	0.810	0.150	0.001	0.040	0.070	0.350	0.010	0.100
1+	1388.690	892.290	404.161	414.700	773.421	625.010	661.960	928.660

Age	1989	1990	1991	1992
1	27.060	12.590	5.540	0.800
2	460.210	571.050	461.780	561.020
3	166.030	220.560	180.440	234.920
4	108.150	89.360	101.700	102.120
5	81.340	37.990	65.300	85.590
6	180.690	43.170	33.270	48.470
7	29.270	82.480	23.290	24.630
8	8.380	28.530	21.440	15.480
9	2.200	14.710	9.750	8.350
10	0.150	5.690	4.960	2.720
11	0.250	0.310	0.150	0.040
1+	1063.730	1106.440	907.620	1084.140

sample data). In a few cases, small monthly catches (usually less than 50 mt) had to be omitted from the analysis because no appropriate substitute sample data were available.

For the first time, the catch composition of all significant domestic commercial landings south of Cape Cod, IWP landings, and reported mackerel JV discards were incorporated into the 1989 to 1992 catch-at-age estimates. Discards and Massachusetts IWP landings prior to 1989 have not been added to the catch-at-age matrix. Herring length frequency data, available from the mackerel JV and from New York and New Jersey IWPs, were converted to age frequencies based on age-length data from spring NMFS bottom trawl surveys. The IWP operations south of Cape Cod and the mackerel JVs take place in the first four months of the year when very little growth occurs, thus we felt justified in using the spring trawl survey age-length data to estimate the age composition of these catches. Missing mean weights for each centimeter length group (*i.e.*, for fish in the samples that were not weighed) were derived from a calculated length-weight regression formula for herring collected in Massachusetts Bay during January-April 1991.

Mean Weights-at-Age

Estimated mean weights-at-age for the whole year (mid-yr) are given in Table C4. Mid-year mean weights are calculated by dividing the derived tonnage at each age by the estimated numbers of fish at that age. The reduction in mean weights since 1987 continues to be reflected in the 1992 data; this reduced weight-at-age reflects a reduced growth rate that may be due to the rapidly increasing size of the stock in recent years.

STOCK ABUNDANCE INDICES

Research Vessel Survey Indices

Age-disaggregated NMFS spring bottom trawl survey abundance indices are given in Table C5 for 1968 to 1992. These estimates have been corrected for differences in the fishing power of the two survey vessels (NEFSC 1992), but have not been transformed or smoothed. Previous catch rate-at-age calculations failed to account for the fact that length measurements made at sea were in fork length, not total length. The net effect of converting fork length to total lengths was to "move" fish from the younger age groups into the older age groups, *i.e.*, to increase the catch rates for the older fish and decrease catch rates of the younger fish.

Stock abundance in 1992 was high at all ages, continuing the upward trend in the data from the extremely low values observed in the early 1980s (Table C5). The number of age 2 and 3 fish was especially high in 1992, indicating possible strong recruitment from the 1989 and 1990 year classes.

Larval Survey Indices

Larval surveys conducted by the NMFS since 1971 continue to provide a valuable indicator of spawning stock abundance on Georges Bank and Nantucket Shoals. The 1991 results are high (Table C5), as they were in 1989 and 1990, indicating that there may be more spawning in recent years than at the beginning of the time series. Results for the last three years are very consistent. These data were related to age 4+ spawning stock biomass in the VPA as an independent tuning index for determining fishing mortality rates in 1992.

Natural Mortality

The rate of instantaneous natural mortality (M) for the Atlantic herring coastal stock complex was assumed to be 0.20.

ASSESSMENT METHODOLOGY

Virtual Population Analysis

To tune the VPA for the Atlantic herring coastal complex for 1967 to 1992, ADAPT (Gavaris 1988, Conser and Powers 1990) was used. Spring bottom trawl indices for ages 2 to 6 and a larval index from NEFSC surveys for 1971 to 1991 were used in the tuning process (Table C5).

VPA estimates of stock numbers at ages 4, 5, and 6+ were "tuned" against bottom trawl survey abundance indices for these same ages for the purpose of estimating terminal fishing mortality rates. Stock sizes on ages 4 to 6 were estimated with the procedure because of relatively high CVs on younger ages. Weighted and unweighted

Table C4. Weight at age (mid-year) in kilograms for coastal U.S. fisheries, 1967-1992

Age	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	0.005	0.007	0.010	0.021	0.019	0.035	0.016	0.017	0.023	0.018	0.016	0.013
2	0.029	0.025	0.039	0.063	0.049	0.051	0.054	0.053	0.051	0.042	0.042	0.040
3	0.078	0.059	0.079	0.106	0.115	0.120	0.108	0.108	0.096	0.114	0.103	0.120
4	0.118	0.142	0.051	0.167	0.180	0.187	0.170	0.169	0.169	0.179	0.161	0.186
5	0.162	0.194	0.252	0.210	0.234	0.234	0.233	0.204	0.192	0.206	0.189	0.226
6	0.257	0.215	0.270	0.240	0.327	0.273	0.257	0.232	0.230	0.211	0.219	0.256
7	0.275	0.245	0.320	0.304	0.294	0.314	0.293	0.247	0.274	0.260	0.228	0.273
8	0.342	0.260	0.296	0.309	0.291	0.357	0.325	0.272	0.274	0.282	0.260	0.285
9	0.288	0.273	0.273	0.311	0.329	0.273	0.338	0.286	0.302	0.319	0.304	0.317
10	0.292	0.292	0.292	0.292	0.331	0.292	0.263	0.293	0.293	0.334	0.294	0.349
11	0.313	0.313	0.313	0.313	0.313	0.313	0.324	0.305	0.314	0.399	0.281	0.345

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	0.008	0.015	0.012	0.020	0.022	0.019	0.013	0.021	0.018	0.009	0.005	0.005
2	0.032	0.041	0.045	0.049	0.055	0.051	0.049	0.053	0.044	0.034	0.046	0.044
3	0.089	0.103	0.114	0.130	0.138	0.133	0.139	0.116	0.093	0.090	0.101	0.099
4	0.198	0.169	0.190	0.194	0.216	0.182	0.181	0.166	0.141	0.129	0.136	0.148
5	0.255	0.268	0.232	0.250	0.223	0.227	0.203	0.215	0.178	0.164	0.168	0.183
6	0.281	0.319	0.293	0.267	0.310	0.260	0.229	0.230	0.218	0.187	0.196	0.194
7	0.182	0.344	0.316	0.300	0.348	0.305	0.281	0.251	0.233	0.228	0.235	0.207
8	0.325	0.241	0.342	0.322	0.368	0.343	0.273	0.260	0.227	0.238	0.248	0.229
9	0.332	0.306	0.470	0.342	0.390	0.314	0.289	0.299	0.251	0.254	0.244	0.246
10	0.313	0.391	0.304	0.423	0.397	0.402	0.292	0.292	0.265	0.292	0.313	0.258
11	0.313	0.372	0.373	0.313	0.313	0.528	0.313	0.313	0.320	0.247	0.300	0.300

Age	1991	1992
1	0.005	0.005
2	0.053	0.047
3	0.087	0.090
4	0.133	0.129
5	0.166	0.154
6	0.193	0.179
7	0.214	0.202
8	0.225	0.219
9	0.229	0.226
10	0.243	0.269
11	0.300	0.300

ADAPT runs were completed and diagnostics were examined for both runs.

Yield and Spawning Stock Biomass per Recruit

Yield and spawning stock biomass per recruit analyses were performed using methods developed by Thompson and Bell (1934). The selection of the exploitation pattern used in the analysis (Age 1=0.011, Age 2=0.943, Age 3+=1.000) was influenced by the results of a separable VPA run for ages 1 to 8 herring over the years 1987 to 1992 assuming a reference age of 3. Catch and stock weights were assumed to be equal and were estimated as simple averages of August to September 1988 to 1992 sample data. The proportion of mature females used in the analysis was obtained from examination of samples.

ASSESSMENT RESULTS

Virtual Population Analysis

Estimates of numbers at age and spawning stock biomass for the Atlantic herring stock complex were computed using the ADAPT VPA tuning method (Conser and Powers 1990; Mohn

Table C5. Spring bottom trawl survey (BTS) number per tow of Atlantic herring (1968-1992) by age and weighted mean of larval herring abundance (1971-1991, number per 10 m^2) for Massachusetts Bay, Georges Bank, and Nantucket Shoals areas

	Index	1968	1969	1970	1971	1972	1973	1974
1.	BTS-Age 2	1.470	0.110	3.640	0.240	0.560	0.120	0.100
2.	BTS-Age 3	8.210	1.250	1.390	0.440	0.890	2.240	0.110
3.	BTS-Age 4	3.250	0.470	0.980	0.480	0.450	3.320	4.180
4.	BTS-Age 5	3.370	0.950	0.790	0.200	0.540	0.540	0.720
5.	BTS-Age 6	2.720	1.640	0.370	0.210	0.300	1.090	0.180
6.	Larval	-	-	-	89.700	81.400	355.200	304.500

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	0.050	0.860	0.170	0.200	2.530	0.120	0.020	0.390	0.190	1.830
2	0.150	0.260	0.150	1.900	0.390	1.400	0.020	0.060	0.030	0.380
3	0.110	0.060	0.370	0.310	1.310	3.550	0.490	0.050	0.070	0.290
4	1.190	0.110	0.130	0.280	0.780	0.660	1.290	0.060	0.010	0.130
5	0.110	0.300	0.070	0.040	0.230	0.080	0.180	0.040	0.050	0.010
6	55.900	2.200	19.200	2.400	6.000	1.900	29.700	18.200	3.700	2.300

	1985	1986	1987	1988	1989	1990	1991	1992
1	1.970	1.380	0.850	2.470	1.320	2.310	3.920	7.000
2	0.900	25.430	1.370	2.210	1.110	1.830	3.320	15.140
3	0.400	3.190	0.900	1.670	0.420	1.760	8.660	4.630
4	0.450	1.100	3.330	4.920	1.470	1.720	4.190	5.390
5	0.100	0.530	0.700	1.600	3.080	1.010	2.000	2.180
6	95.400	60.400	31.400	184.900	454.300	394.100	354.200	-

and Cook 1993) with six research survey indices. The consensus ADAPT run applied inverse-variance weighting to the tuning indices. The unweighted run produced similar, but less precise estimates of stock sizes and biomasses.

Fishing mortality (F) estimates at age for the whole time series as derived from the VPA are given in Table C6 and Figure C1. Fishing mortality for fully-recruited (age 2+) Atlantic herring increased from 0.24 in 1967 to 1.20 in 1972, and remained at high levels throughout the 1970s. Fishing mortality has decreased substantially throughout the 1980s to low levels in the early 1990s. In 1992, the fully-recruited fishing mortality was 0.04.

Estimates of precision and bias of fishing mortality rates from ADAPT are given in Table C7.

Bootstrapped estimates of the fully-recruited fishing mortality (F_{92}) in 1992 indicated that 80% confidence intervals for F_{92} were 0.026 to 0.054 (Figure C2). In comparison, $F_{0.1}$, F_{max}, and F_{20} were 0.19, 0.34, and 0.29. Thus, fishing mortality in 1992 was certainly below standard biological reference points. Furthermore, VPA results indicate that the fishing mortality rate for the Atlantic herring stock complex has been below F_{max} and F_{20} since 1985.

Spawning stock biomass (SSB) for the Atlantic herring stock complex decreased from 839,000 mt in 1967 to less than an average of 40,000 mt during 1976 to 1982 (Table C8, Figure C3). Since 1982, Atlantic herring SSB has increased at an exponential rate.

In 1992, the point estimate of Atlantic herring SSB (SSB_{92}) was 1.25 million mt and 80% confidence intervals for SSB_{92} were 930,000 mt to 2.0 million mt (Table C8, Figure C4). Thus, Atlantic herring spawning stock biomass in 1992 was likely to be more than 1.0 million mt, and has improved greatly from the very low levels observed from 1976 to 1982.

Recruitment (numbers of age 2 fish) for the Atlantic herring stock complex has been moderate (less than 2 billion) since 1983, following 12 years of low recruitment. However, VPA results indicate that the 1989 and 1990 year classes were the largest on record (19 and 21 billion) (Table C9, Figure C3). The size of these year

Table C6. Fishing mortality for coastal United States, Georges Bank, and New Brunswick fixed gear fisheries for 1967-1992

Age	1967	1968	1969	1970	1971	1972	1973	1974	1975
1	0.0288	0.0065	0.0385	0.0047	0.0224	0.0077	0.0419	0.0233	0.0499
2	0.1802	0.4516	0.3531	0.4032	0.2537	0.1973	0.5166	0.9140	0.7694
3	0.1493	0.1715	0.2220	0.1850	0.7001	0.1029	0.4252	0.4239	0.6942
4	0.1344	0.1688	0.2147	0.4721	0.5594	0.6899	0.9198	0.4671	0.6775
5	0.1307	0.4068	0.4687	0.4616	0.6899	1.3123	0.8320	0.6792	0.8954
6	0.2185	0.4289	0.6498	0.4597	0.7693	1.4383	0.9156	0.4775	1.2020
7	0.4070	0.7193	0.7582	0.6206	1.0173	1.6325	1.1330	0.4341	1.2287
8	0.3471	0.8235	0.9055	0.7049	0.8418	2.1341	1.5195	0.5062	1.1531
9	0.3656	0.2925	0.8442	0.5521	0.5392	1.3823	1.5885	1.1558	1.6268
10	0.2544	0.5529	0.6630	0.5172	0.7746	1.5334	0.9883	0.6166	0.9490
11	0.2544	0.5529	0.6630	0.5172	0.7746	1.5334	0.9883	0.6166	0.9490
	1976	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
1	0.0667	0.2027	0.1140	0.0178	0.1752	0.0395	0.0335	0.0244	0.0053
2	1.3301	1.0436	0.8250	1.0266	1.4673	1.5940	0.7646	0.2373	0.1864
3	0.7900	0.7612	0.7702	0.7791	1.1295	0.9387	0.6005	0.1322	0.1777
4	0.6777	0.5379	0.5726	0.8937	0.9972	0.6533	0.4650	0.3062	0.1253
5	0.7369	0.7422	0.7532	0.8728	1.0938	0.7536	0.6940	0.1444	0.5642
6	0.9298	0.6872	0.5050	0.7905	1.0556	0.7796	0.8334	0.3114	0.3929
7	1.0162	0.5897	0.7773	1.6024	1.2280	0.7038	1.0406	0.9315	0.3442
8	0.8386	0.7863	1.0100	1.5490	1.1067	0.5639	0.4866	0.4133	0.5781
9	1.2698	0.3868	0.9431	0.6345	1.1382	0.2277	1.0004	0.4251	4.2029
10	0.9150	0.6506	0.8200	0.8963	1.1562	0.7623	0.7665	0.4049	0.5254
11	0.9150	0.6506	0.8200	0.8963	1.1562	0.7623	0.7665	0.4049	0.5254
	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	
1	0.0114	0.0136	0.0109	0.0160	0.0051	0.0007	0.0003	0.0004	
2	0.2136	0.1214	0.0968	0.1420	0.1215	0.1424	0.0328	0.0365	
3	0.1211	0.1237	0.0898	0.0635	0.0636	0.0787	0.0609	0.0210	
4	0.0956	0.0948	0.1381	0.0543	0.0813	0.0441	0.0472	0.0444	
5	0.1164	0.0956	0.1192	0.1356	0.0935	0.0370	0.0411	0.0509	
6	0.5807	0.0945	0.0612	0.1280	0.2919	0.0657	0.0412	0.0388	
7	0.3918	0.7923	0.0433	0.0390	0.1508	0.2095	0.0458	0.0388	
8	0.3252	0.1969	0.5976	0.0209	0.0456	0.2155	0.0769	0.0388	
9	0.5111	0.0947	0.1685	0.6144	0.0264	0.1053	0.1058	0.0388	
10	0.1681	0.1074	0.0882	0.1129	0.1554	0.0883	0.0468	0.0388	
11	0.1681	0.1074	0.0882	0.1129	0.1554	0.0883	0.0468	0.0388	

classes is dependant on the results of 2 and 1 research survey cruises, respectively, and thus are thought to be of low precision.

Yield and Spawning Stock Biomass per Recruit

The results of the Y/R and SSB/R analysis are given in Table C10, with reference points of $F_{0.1}$=0.187, F_{20}=0.290, and F_{max}=0.342 (Figure C5).

SOURCES OF UNCERTAINTY

Stock structure, and in particular, the response of individual spawning components to intense localized fishing pressure, remains a potential source of uncertainty and concern for this assessment. Efforts to characterize the stock structure of this complex and its response to spatial patterns of fishing effort are encouraged.

Discards of herring from the mackerel fishery were included in this assessment. However,

Table C7. Precision and bias estimates of age-specific instantaneous fishing mortality rates (F) in 1992 for Atlantic herring[1]

Age	ADAPT Estimate	Boostrap Mean	Bootstrap St. Error	CV for ADAPT COLN
1	4.263E-4	4.731E-4	1.306E-4	0.31
2	3.655E-2	4.055E-2	1.120E-2	0.31
3	2.089E-2	2.542E-2	1.808E-2	0.87
4	4.439E-2	5.012E-2	2.885E-2	0.65
5	5.099E-2	5.347E-2	2.667E-2	0.52
6	3.876E-2	4.300E-2	1.188E-2	0.31
7	3.876E-2	4.300E-2	1.188E-2	0.31
8	3.876E-2	4.300E-2	1.188E-2	0.31
9	3.876E-2	4.300E-2	1.188E-2	0.31
10	3.876E-2	4.300E-2	1.188E-2	0.31
11	3.876E-2	4.300E-2	1.188E-2	0.31
Full	3.876E-2	4.300E-2	1.188E-2	0.31

Age	Bias Estimate	Bias Std. Error	Precent Bias	ADAPT Est. Corrected for Bias	CV for Corrected Estimate
1	4.673E-5	9.237E-6	10.96	3.796E-4	0.34
2	4.006E-3	7.919E-4	10.96	3.254E-2	0.34
3	4.522E-3	1.278E-3	21.64	1.637E-2	1.10
4	5.738E-3	2.040E-3	12.93	3.865E-2	0.75
5	2.486E-3	1.886E-3	4.88	4.850E-2	0.55
6	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
7	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
8	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
9	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
10	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
11	4.249E-3	8.398E-4	10.96	3.451E-2	0.34
Full	4.249E-3	8.398E-4	10.96	3.451E-2	0.34

[1] ADAPT estimates from final consensus run. Standard error, coefficients of variation (CV) and bias estimates are derived from 200 bootstrap replications.

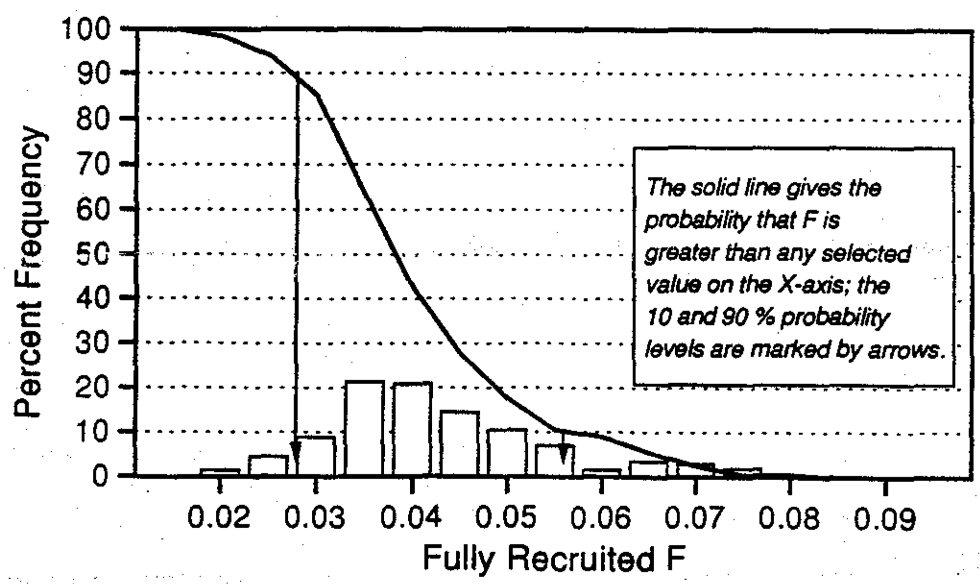

Figure C2. Precision of the estimates of fishing mortality for Atlantic herring derived from a statistical procedure known as bootstrap. The vertical bars give the range and probability of individual values within that range.

Table C8. Spawning stock biomass (thousands of metric tons) at the start of the spawning season - males and females for coastal United States, Georges Bank, and New Brunswick fixed gear fisheries, 1967-1992

Age	1967	1968	1969	1970	1971	1972	1973	1974
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	2.515	6.074	43.965	46.693	22.206	21.610	138.332	19.895
4	115.606	121.304	49.080	144.254	84.935	34.327	39.222	226.330
5	148.821	161.672	135.563	113.191	88.725	29.793	16.162	18.602
6	285.746	113.455	102.219	66.600	72.207	24.252	9.711	7.480
7	224.489	123.125	70.331	50.290	27.764	13.767	6.359	4.389
8	42.911	84.635	51.591	27.113	17.951	4.319	2.482	2.491
9	7.855	20.649	31.440	23.391	13.225	3.962	0.597	0.514
10	10.618	3.931	10.222	15.126	9.932	2.659	1.054	0.179
11	0.185	0.298	0.380	1.426	1.075	0.193	0.078	0.153
1+	838.745	635.142	494.791	488.083	338.020	134.882	213.997	280.033

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	8.435	17.872	3.160	2.824	14.444	2.907	0.863	11.346	32.973
4	21.923	9.792	17.040	6.550	9.265	20.822	15.312	2.337	17.751
5	96.284	10.681	4.120	9.909	3.481	3.674	11.108	8.547	1.769
6	5.882	34.484	4.618	2.599	4.619	1.299	1.394	4.640	5.776
7	2.554	1.881	15.537	2.216	0.401	1.513	0.477	0.441	1.999
8	1.506	0.844	0.662	6.433	0.556	0.127	0.593	0.232	0.250
9	0.589	0.415	0.452	0.268	2.962	0.124	0.130	0.199	0.148
10	0.158	0.179	0.140	0.208	0.087	1.024	0.043	0.051	0.109
11	0.103	0.063	0.108	0.069	0.000	0.026	0.300	0.046	0.001
1+	137.435	76.211	45.838	31.076	35.815	31.515	30.220	27.839	60.776

Age	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	45.986	60.336	65.185	19.729	59.289	88.656	31.063	46.60	283.552
4	53.428	89.358	77.200	159.800	138.379	166.356	251.930	257.879	249.903
5	9.341	43.772	79.380	61.827	140.672	135.694	176.965	248.456	242.997
6	1.213	4.335	36.742	61.454	46.894	106.892	119.301	146.792	210.888
7	3.325	0.725	1.857	28.812	50.329	41.730	73.428	102.415	120.932
8	0.828	1.752	0.430	0.721	23.465	42.894	27.277	58.536	82.403
9	0.007	0.337	1.349	0.285	0.359	19.209	31.826	19.548	45.869
10	0.076	0.002	0.226	0.895	0.239	0.276	15.461	24.205	17.785
11	0.033	0.118	0.941	0.034	0.202	0.439	0.976	0.902	0.291
1+	114.237	200.734	263.310	333.556	459.826	602.147	728.227	905.340	1254.621

discards of herring in the shrimp fishery are an unquantified source of mortality at this time and should be investigated.

Current SSB and stock size depend to some degree on estimates of the 1989 and 1990 year classes which appear to be very large. Future near-term estimates of these variables will depend heavily on the size of these cohorts. Until these year classes are estimated more precisely, it will be uncertain whether Atlantic herring SSB is closer to 1.0 or 2.0 million mt.

Weights-at-age used to estimate the age composition of the U.S. landings in this analysis were not weighted according to temporal or spatial variations in the landings and were not consistent with the New Brunswick weights-at-age, which are weighted by magnitude of monthly catches.

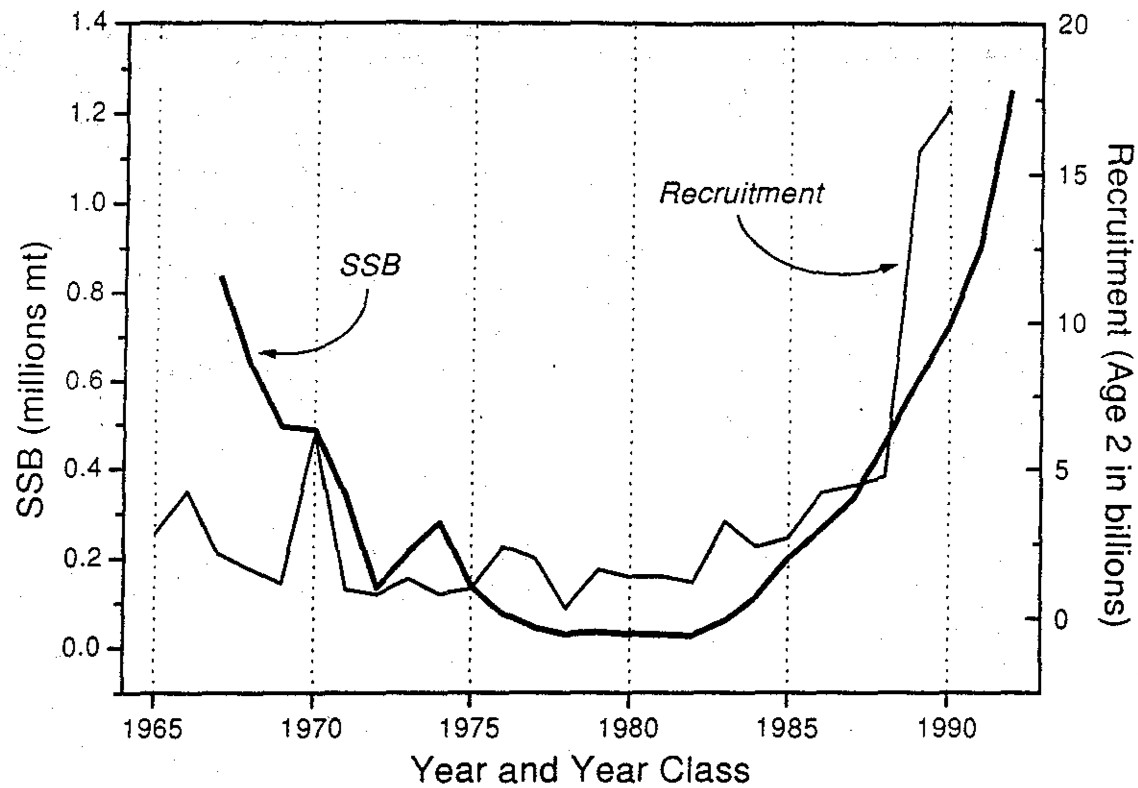

Figure C3. Trends in spawning stock biomass (millions of metric tons) and recruitment as numbers (in billions) of age 2 Atlantic herring, 1967-1992.

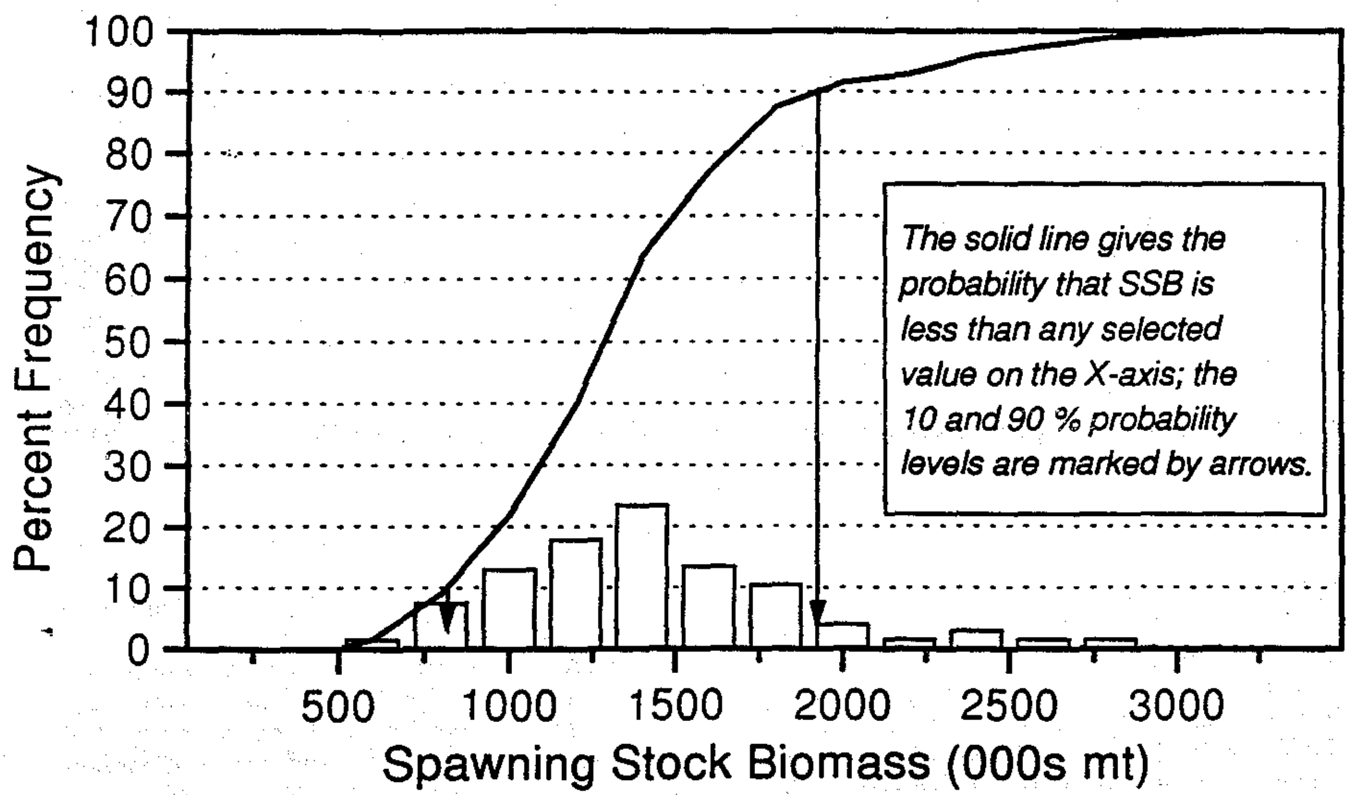

Figure C4. Precision of the estimates of spawning stock biomass (thousands of metric tons) for Atlantic herring derived from a statistical procedure known as bootstrap. The vertical bars give the range and probability of individual values within that range.

Table C9. Stock numbers (Jan 1) in millions of fish for coastal United States, Georges Bank, and New Brunswick fixed gear fisheries for 1967-1993

Age	1967	1968	1969	1970	1971	1972	1973
1	5323.340	2656.877	2090.365	1412.872	7716.750	1184.195	1008.596
2	2842.274	4234.826	2161.251	1646.786	1151.342	6177.998	962.072
3	1821.502	1943.325	2207.260	1243.057	900.923	731.450	4152.348
4	1835.179	1284.465	1340.257	1447.388	845.828	366.241	540.290
5	1177.255	1313.624	888.263	885.288	739.054	395.810	150.410
6	1521.853	845.746	716.067	455.136	456.836	303.540	87.238
7	1286.988	1001.392	450.919	306.128	235.307	173.297	58.981
8	189.118	701.389	399.365	172.968	134.745	69.658	27.729
9	41.686	109.432	252.027	132.207	69.978	47.542	6.750
10	51.127	23.679	66.875	88.705	62.321	33.414	9.770
11	0.832	1.673	2.319	7.802	7.133	2.265	0.588
1+	16091.155	14116.430	10574.969	7798.338	12320.217	9485.411	7004.773

Age	1974	1975	1976	1977	1978	1979	1980
1	1662.639	1024.818	1290.397	3597.392	2767.829	410.829	2359.726
2	791.910	1329.928	798.206	988.281	2404.944	2021.982	330.422
3	469.863	259.941	504.464	172.821	284.955	862.856	593.017
4	2222.145	251.771	106.295	187.444	66.094	107.999	324.117
5	176.321	1140.339	104.691	44.192	89.621	30.524	36.177
6	53.590	73.194	381.354	41.024	17.225	34.549	10.441
7	28.590	27.218	18.014	123.215	16.893	8.511	12.832
8	15.553	15.164	6.522	5.338	55.937	6.357	1.403
9	4.968	7.676	3.919	2.308	1.991	16.679	1.106
10	1.129	1.280	1.235	0.901	1.284	0.635	7.241
11	0.926	0.780	0.363	0.730	0.428	0.002	0.190
1+	5427.632	4132.110	3215.460	5163.647	5707.201	3500.923	3676.671

Age	1981	1982	1983	1984	1985	1986	1987
1	1758.949	1767.171	1504.825	3970.583	2955.043	3318.568	5179.172
2	1621.485	1384.268	1399.152	1202.359	3233.755	2392.059	2680.205
3	62.369	269.633	527.581	903.512	816.977	2138.377	1734.541
4	156.911	19.973	121.098	378.471	619.299	592.588	1547.031
5	97.897	66.849	10.272	72.997	273.365	460.829	441.286
6	9.921	37.724	27.342	7.279	33.995	199.228	342.911
7	2.975	3.725	13.422	16.395	4.023	15.572	148.410
8	3.077	1.205	1.077	4.329	9.514	2.226	5.773
9	0.380	1.433	0.606	0.583	1.988	5.627	1.497
10	0.290	0.248	0.432	0.325	0.007	0.976	4.191
11	1.655	0.305	0.003	0.107	0.498	3.784	0.131
1+	3715.908	3552.533	3605.810	6556.940	7948.465	9129.836	12085.148

Age	1988	1989	1990	1991	1992	1993
1	5516.156	5836.607	19314.886	21109.065	2074.415	0.000
2	4194.210	4444.511	4754.125	15802.299	17277.628	1697.664
3	1991.882	2979.474	3222.443	3375.641	12519.992	13638.094
4	1298.141	1530.432	2289.157	2438.742	2600.472	10037.938
5	1103.270	1006.619	1155.154	1793.347	1904.651	2036.684
6	320.703	788.719	750.551	911.385	1409.182	1481.951
7	264.076	231.027	482.254	575.437	716.075	1109.883
8	116.360	207.937	162.664	320.205	450.054	563.987
9	2.600	93.295	162.662	107.363	242.762	354.467
10	1.036	1.152	74.392	119.866	79.079	191.201
11	1.032	1.911	4.040	3.616	1.160	63.197
1+	14809.465	17121.684	32372.327	46556.966	39275.472	31175.067

Table C10. Yield and spawning stock biomass per recruit estimates for the Atlantic herring coastal stock complex

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.1 [Method of Thompson and Bell (1934)] 1-OCT-1991

Run Date: 25- 6-1993; Time: 09:18:13.62
SSB/R ANALYSIS - 1988-92, WTS AVG AUG-SEPT FROM SAMPLES

Proportion of F before spawning: .6700
Proportion of M before spawning: .6700
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:
==> YPRHER93.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Stock	Average Weights Catch
1	.0110	1.0000	.0000	.012	.012
2	.9430	1.0000	.0000	.047	.047
3	1.0000	1.0000	.3600	.111	.111
4	1.0000	1.0000	.9600	.161	.161
5	1.0000	1.0000	1.0000	.204	.204
6	1.0000	1.0000	1.0000	.239	.239
7	1.0000	1.0000	1.0000	.277	.277
8	1.0000	1.0000	1.0000	.281	.281
9	1.0000	1.0000	1.0000	.298	.298
10+	1.0000	1.0000	1.0000	.300	.300

Summary of Yield per Recruit Analysis for:
SSB/R ANALYSIS - 1988-92, WTS AVG AUG-SEPT FROM SAMPLES

Slope of the Yield/Recruit Curve at F=0.00: --> .7841
F level at slope=1/10 of the above slope (F0.1): -----> .186
Yield/Recruit corresponding to F0.1: -----> .0561
F level to produce Maximum Yield/Recruit (Fmax): -----> .342
Yield/Recruit corresponding to Fmax: -----> .0606
F level at 20 % of Max Spawning Potential (F20): -----> .289
SSB/Recruit corresponding to F20: --------> .1360

1

Listing of Yield per Recruit Results for:
SSB/R ANALYSIS - 1988-92, WTS AVG AUG-SEPT FROM SAMPLES

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	.8793	2.8398	.6801	100.00
	.032	.11356	.02067	4.9510	.7268	2.3072	.5365	78.87
	.065	.19931	.03430	4.5245	.6147	1.9123	.4324	63.57
	.097	.26636	.04346	4.1914	.5293	1.6095	.3544	52.11
	.130	.32023	.04968	3.9242	.4626	1.3713	.2945	43.30
	.162	.36446	.05389	3.7052	.4093	1.1801	.2475	36.39
F0.1	.186	.39234	.05608	3.5674	.3765	1.0621	.2190	32.20
	.195	.40144	.05671	3.5225	.3659	1.0240	.2099	30.87
	.227	.43282	.05855	3.3677	.3301	.8949	.1796	26.40
	.260	.45978	.05969	3.2350	.3002	.7867	.1547	22.74
F20%	.289	.48097	.06027	3.1310	.2773	.7038	.1360	20.00
	.292	.48320	.06031	3.1200	.2749	.6952	.1341	19.71
	.325	.50374	.06057	3.0194	.2533	.6172	.1169	17.18
Fmax	.342	.51357	.06059	2.9714	.2431	.5807	.1089	16.01
	.357	.52190	.06055	2.9308	.2347	.5502	.1024	15.05
	.390	.53807	.06034	2.8520	.2185	.4922	.0900	13.24
	.422	.55257	.05999	2.7818	.2044	.4418	.0795	11.69
	.455	.56563	.05954	2.7183	.1919	.3977	.0705	10.37
	.487	.57748	.05901	2.6612	.1810	.3589	.0627	9.22
	.520	.58826	.05843	2.6093	.1712	.3248	.0560	8.23
	.553	.59812	.05782	2.5621	.1624	.2945	.0501	7.36
	.585	.60718	.05720	2.5188	.1546	.2676	.0449	6.60
	.618	.61552	.05656	2.4791	.1475	.2437	.0404	5.94
	.650	.62324	.05592	2.4426	.1411	.2222	.0364	5.35

DISCUSSION

The sensitivity of the assessment to the natural mortality rate applied to all ages was discussed. Natural mortality rate was set at 0.2 for all ages and thus has exceeded fishing mortality rate in recent years. As a consequence of the decrease in fishing mortality rate relative to natural mortality, the precision of the VPA has also decreased. The appropriateness of the M used in the assessment was discussed and it was indicated that this rate was established from extensive research on herring populations in the U.S. and compared favorably to rates used for herring assessments elsewhere. It was felt the assessment could benefit from a sensitivity analysis of the assumed natural mortality rate.

It was noticed that the mean weights used in the VPA have been variable over time and that the most recent trend is toward lower weights at age. Weights are entered into the VPA as mid-year means, but it was questioned whether or not seasonal differences were adequately adjusted for when the yearly means are computed. It was pointed out that herring can grow at surprisingly rapid rates and that significant changes in weight can occur in time periods as short as a fortnight. It was speculated that the change in weight may reflect compensatory growth of the stock, which

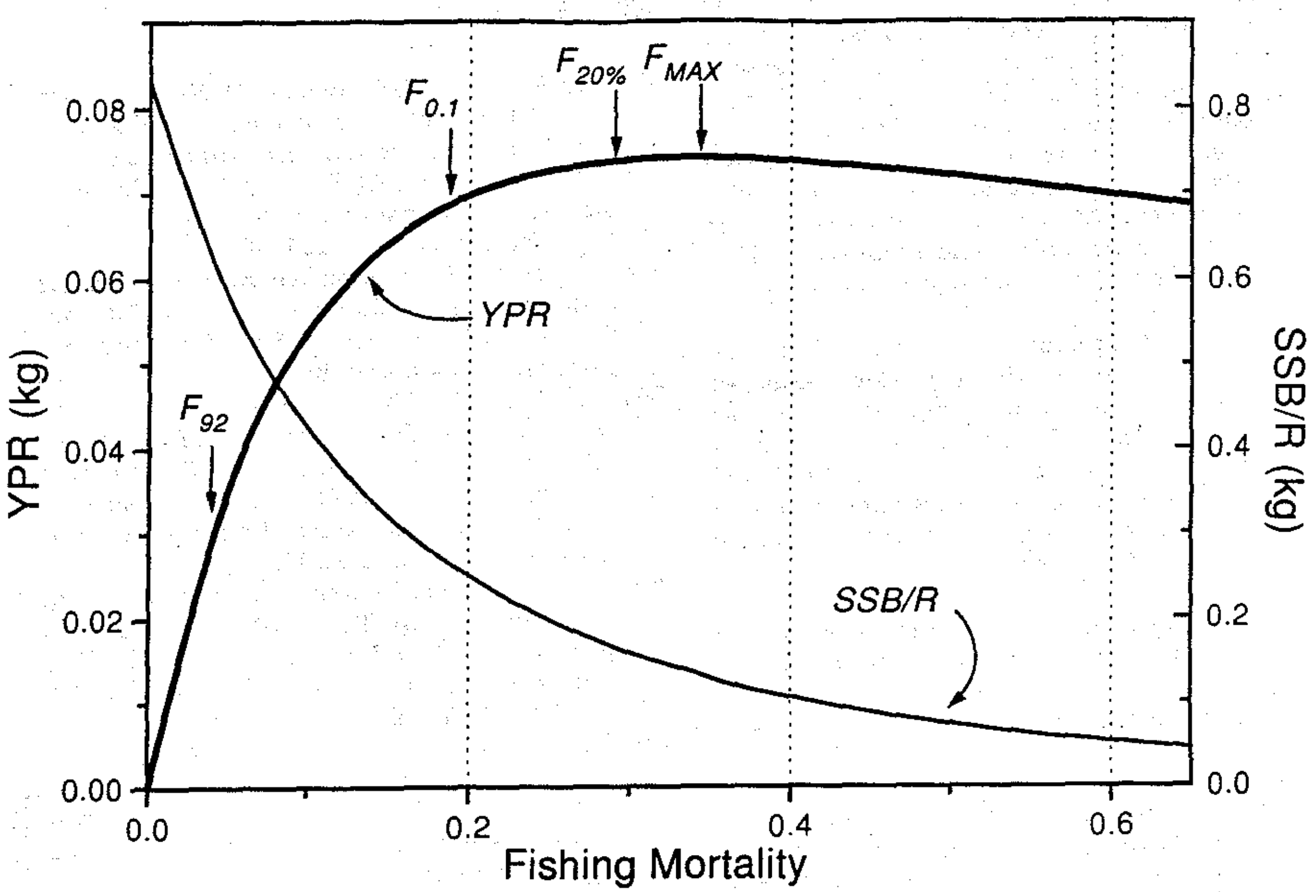

Figure C5. Yield and spawning stock biomass per recruit (kilograms) for Atlantic herring.

would be consistent with the overall pattern of results of the VPA. However, sampling problems in capturing the true trend in mean weights could not be totally discounted. A remedial measure to understand the trends in weight of the commercial data series would be to compare commercial fish weights to those taken on survey cruises by area and season.

The VPA currently consists of 10 true ages and a plus group beginning at age 11. It was pointed out that fishing mortality rates have been quite variable for older age fish reflecting the relatively low catches of these age groups. It was suggested that the number of ages in the VPA could be reduced. Though catch of older ages fish was now low, it has been higher in the past. Since there is an expectation that catch of older age herring will increase and that these ages can be adequately aged, it was agreed there was benefit to maintaining the catch at age matrix in its present configuration.

Other discussion points are captured by modification of report text or directly in the recommendation section.

RESEARCH RECOMMENDATIONS

- Although considered adequate, survey indices used to tune this assessment are variable. It is recommended that the use of transformations be examined with respect to ADAPT tuning. As long as fishing mortalities remain low, other simpler assessment models, such as surplus production or modified DeLury approaches, might be used to provide a similar level of precision.

- With the inclusion of Georges Bank catches from foreign fleets in the coastal stock complex, it is recognized that developing relationships with former Eastern Bloc fisheries agencies may enhance our understanding of this fishery. It is recommended that contacts with former fishing nations be pursued so that potential sources of foreign catch and logbook data (*i.e.* Eastern Bloc and former Soviet Union ICNAF data) might be made available to the Working Group.

- A perhaps unforeseen result of recent low catches and high stock biomasses for many of the pelagic species is that these stocks are becoming harder to assess with age-based methods. A dedicated pelagic survey utilizing hydroacoustic and trawling methods would provide another direct and independent means of estimating stock sizes for these increasing pelagic resources. This type of survey be pursued in future.

- The herring working group should investigate alternative methods of estimating mean weights-at-age used to determine the age composition of U.S. and Canadian landings from the coastal stock complex. Predicted weights and weighted estimates based on the temporal and spatial distribution of the catch are two possibilities.

- The frequency of assessment updates for this stock complex should be changed from every year to every two years, since the status of the stock is so optimistic and patterns in landings are not changing.

- The estimation of age 3 herring, the natural mortality rate assumed for all ages, the use of catch-per-unit-effort tuning indices, and the use of NEFSC fall bottom trawl survey tuning indices in the analytical assessment should be re-investigated.

- The SARC recommends the water displacement volume of the coastal stock complex be computed.

- Currently, scientific advice concerning the coastal stock complex includes an evaluation of the status of individual spawning components achieved by examining the abundance and distribution of small herring larvae. In this regard, the SARC noted the importance of the continuation of traditional larval surveys. Of equal concern is the current lack of information from certain spawning areas, such as Jeffreys Ledge. Because of planned changes in the NEFSC survey of larval fish populations, a retrospective analysis of herring larval and assessment data should be carried out to determine the role larval data plays in anticipating stock collapse and as a tuning index in the age-structured assessment.

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D. AMERICAN LOBSTER

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Examine selectivity of survey gear relative to pre-recruit and fully recruited lobsters and relative availability and incorporate these estimates to the DeLury analysis for the three stock areas. (See the section on estimates of stock size and fishing mortality, page 82.)

b. Estimate research vessel survey abundance indices of prerecruit and fully-recruited lobsters. (See the section on stock abundance indices page 81.)

c. Provide length-based cohort and DeLury model estimates of fishing mortality rates and stock sizes for the three stock areas. (See the section on estimates of stock size and fishing mortality, page 82.)

d. Initiate estimation of growth parameters appropriate to discontinuous growth models, specifically molt probability, and molt increment by sex, where feasible. (See the section on biological reference points, page 98.)

e. Calculate revised biological reference points including F_{max}, $F_{0.1}$, $F_{10\%}$, EPR, and F_{med} which are appropriate to the three stock areas. (See the section on biological reference points, page 98.)

f. Evaluate the status of lobster stocks relative to overfishing definitions and biological reference points. (See sections on estimates of stock size and fishing mortality, page 82; biological reference points, page 98; and discussion, page 104.)

INTRODUCTION

Overview

The American lobster, *Homarus americanus*, is distributed in the Northwest Atlantic from Labrador to Cape Hatteras from coastal regions out to depths of 700 m (Fogarty *et al.* 1982). Lobsters are locally abundant in coastal regions within the Gulf of Maine and off southern New England, and less abundant in more southerly areas. Coastal lobsters are concentrated in rocky areas where shelter is readily available, although occasional high densities occur in mud and other substrates suitable for burrowing. Offshore populations are most abundant in the vicinity of submarine canyons along the continental shelf edge. Tagging experiments in coastal waters suggest that small lobsters undertake rather limited movement with some evidence (Anthony and Caddy 1980) that larger individuals may travel extensively. In contrast, offshore lobsters show well defined shoalward migrations during the spring, regularly traveling 80 km (50 mi) with a few traveling as much as 300 km (186 mi). Lateral movements along the shelf edge have been demonstrated as well (Uzmann *et al.* 1977).

The lobster fishery is currently managed in the Exclusive Economic Zone under the New England Fishery Management Council's Lobster FMP (NEFMC 1991), and within territorial waters under various states' regulations. The primary regulatory measures used throughout the range are minimum carapace length (CL) and ovigerous female protection. Other regulations apply in specific states.

The current assessment attempts to address some of the shortcomings previously identified in SARC analyses (*e.g.* SARC 14). Several new aspects of the analysis include:

1. incorporation of three lobster stock assessment units encompassing the geographic range in U.S. waters,

2. extended and expanded research vessel trawl survey indices for prerecruit and fully-recruited lobsters for surveys conducted by NEFSC and the states of Massachusetts, Rhode Island and Connecticut,

3. improved estimates of the landings and catch size composition for defined stock areas,

4. calculations of biological reference points based on appropriate growth rates and other population dynamics parameters, as well as realistic accounting for various other protections on some components of the

stocks including egg-bearing females, v-notching and minimum/maximum size limits, and

5. improvements to the length-based cohort technique to include growth dynamics based on models other than von Bertalanffy and optional adjustments to the time schedule of removals within the year.

This assessment focuses primarily on evaluating the status of the female portion of the lobster stock, since the overfishing definition adopted by the New England Fishery Management Council is based on lifetime egg production per female recruit.

Definition of Stock Units for Assessment Purposes

Attempts to define the stock structure of the American lobster based on differences in morphological characteristics, parasite infestation, and biochemical and genetic markers have been equivocal. Differences between inshore and offshore lobsters based on parasite infestation have been used to infer stock differentiation (Uzmann 1970). However, studies using electrophoretic techniques and mitochondrial DNA (Barlow and Ridgeway 1971; Tracey et al. 1975) have shown low levels of genetic variability and little clear evidence of stock separation. Low sample sizes may have contributed to the lack of statistical significance in some of the studies. Examination of morphometric and meristic variables provides some evidence of differences between inshore and offshore populations (Saila and Flowers 1969) but levels of correct classification using discriminant functions were not high.

Mark-recapture studies (for example, Saila and Flowers 1968; Cooper and Uzmann 1971; Uzmann et al. 1977; Briggs 1985) demonstrate seasonal coastward movements of offshore lobsters during spring and a return migration in autumn. Lateral movements along the outer continental shelf between Georges Bank and Southern New England have also been noted. Reported movements for coastal lobsters are more limited (see Anthony and Caddy 1980), but this undoubtedly reflects both the smaller mean size and the relatively short time at large in many of the inshore studies. Studies of larger (>127 mm CL) inshore lobsters in the Gulf of Maine do show longer distance movements in a southwesterly direction.

Consideration of large-scale hydrographic factors suggests that areas within the Gulf of Maine may be connected by a common larval supply. Contribution of larvae to the Gulf of Maine from northeastern Georges Bank is possible based on considerations of larval drift. Similarly, it is probable that offshore lobsters from the southern New England region contribute larvae to the coastal regions in this area.

Life history parameters, particularly growth and maturation rates, differ markedly among regions, with sharp demarcations between coastal lobster populations in the Gulf of Maine, offshore lobsters in the Georges Bank-Southern New England area, and the warmer-water populations inshore south of Cape Cod. These life history differences have important implications for the determination of biological reference points such as yield per recruit and especially egg production per recruit. A single overall rate of growth, maturation schedule, and fecundity does not apply to all stock components. Likewise, because the nature of fishing patterns and regulations vary coastwide, some division of the resource into assessment areas is necessary. For assessment purposes, SARC 14 (NEFSC 1992) analyzed two separate lobster groups: (1) the Gulf of Maine (including inshore and offshore waters), and (2) Southern New England-Georges Bank offshore. With the addition of data for southern inshore areas, we analyzed three proposed stock units for assessment purposes in the current analysis: (1) Gulf of Maine, (2) Georges Bank and South - offshore (GBS-O), and (3) South of Cape Cod to Long Island Sound, inshore (SCCLIS-I). The geographic definitions of these three assessment units are illustrated in Figure D.1. It is recognized that there is some exchange of lobsters between the SCCLIS-I and the GBS-O regions. However, since biological rates are so different among the regions, the areas are initially evaluated separately. Lobsters occurring in nearshore oceanic waters south of Long Island, are assumed to be part of the GBS-O stock assessment unit. This reflects the fact that tagging data for statistical areas 613 and 612 have shown distinct inshore-offshore lobster movements (Briggs and Mushacke 1980; Briggs 1982; 1985), and size compositions of lobsters caught there more resemble the offshore than Long Island Sound. Likewise, lobster populations from New Jersey south appear to show affinities to the offshore canyons (Andrews 1980; Van Engel and Harris

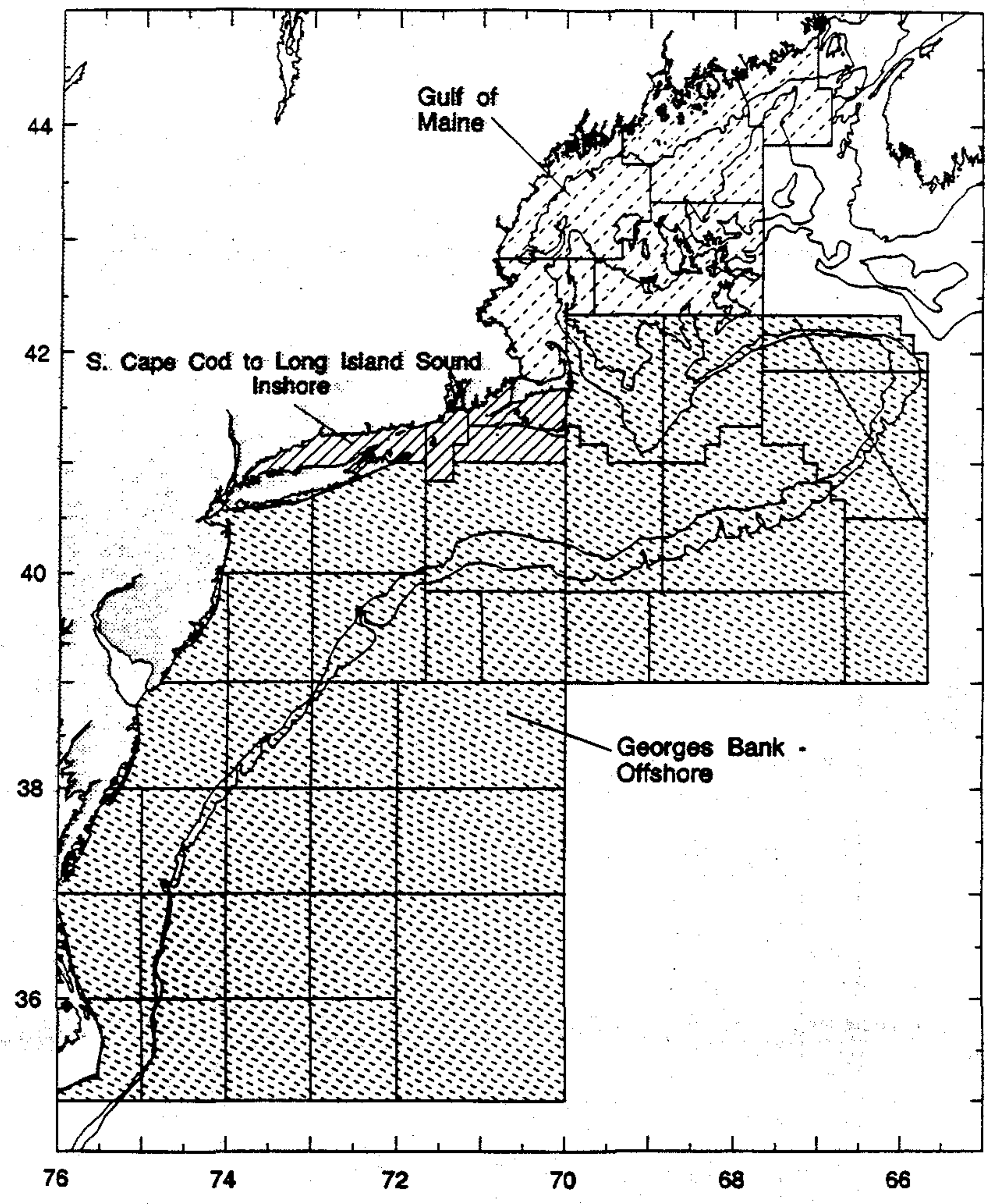

Figure D1. American lobster assessment areas off the northeast United States.

Table D1. Landings (metric tons) of American lobster by state, 1964-1992

Year	State				Total
	Maine	Massachusetts	Rhode Island	Other[1]	
1964	9713.1	2489.4	452.0	1260.6	13915.1
1965	8555.7	2884.9	816.5	1461.9	13718.9
1966	9033.8	2190.2	758.6	1417.2	13399.8
1967	7479.5	2154.9	884.9	1630.5	12149.9
1968	9299.6	2185.1	1393.8	1876.3	14754.8
1969	8997.1	2248.5	1926.1	2141.9	15313.6
1970	8242.9	2578.8	2356.6	2311.0	15489.3
1971	7964.5	2787.7	2444.3	2084.5	15281.0
1972	7374.0	3643.5	1524.5	2083.9	14625.8
1973	7731.2	2551.2	1257.9	1610.3	13150.6
1974	7465.2	2387.4	1549.9	1544.6	12947.1
1975	7714.6	3054.5	1672.6	1256.9	13698.5
1976	8618.9	3111.0	1548.0	1126.0	14403.9
1977	8385.8	3281.8	1583.8	1160.8	14412.2
1978	8677.6	4322.7	1280.1	1350.0	15630.4
1979	10039.6	4333.1	1038.3	1501.4	16912.4
1980	9970.4	4501.7	1086.6	1321.8	16880.5
1981	10265.7	5089.6	848.8	1546.4	17750.5
1982	10310.4	5965.2	1439.6	1827.8	19543.0
1983	9968.5	5634.2	2319.9	2406.7	20329.3
1984	8865.9	6668.7	2385.9	2748.0	20668.5
1985	9128.7	7391.5	2331.5	2464.9	21316.7
1986	8937.9	6830.1	2571.0	2443.6	20782.6
1987	8957.6	6857.0	2411.8	2599.3	20825.8
1988	9860.7	7197.0	2158.7	3019.2	22235.6
1989	10600.1	7005.4	2597.2	3626.3	23828.9
1990	12731.8	7735.9	3292.3	3822.6	27582.6
1991	13965.7	7497.2	3377.1	4248.6	29088.6
1992	12170.3	6882.7	3086.8	3189.5	25329.3

[1] "Other" = New Hampshire + Connecticut + New York + New Jersey + Delaware + Maryland + Virginia

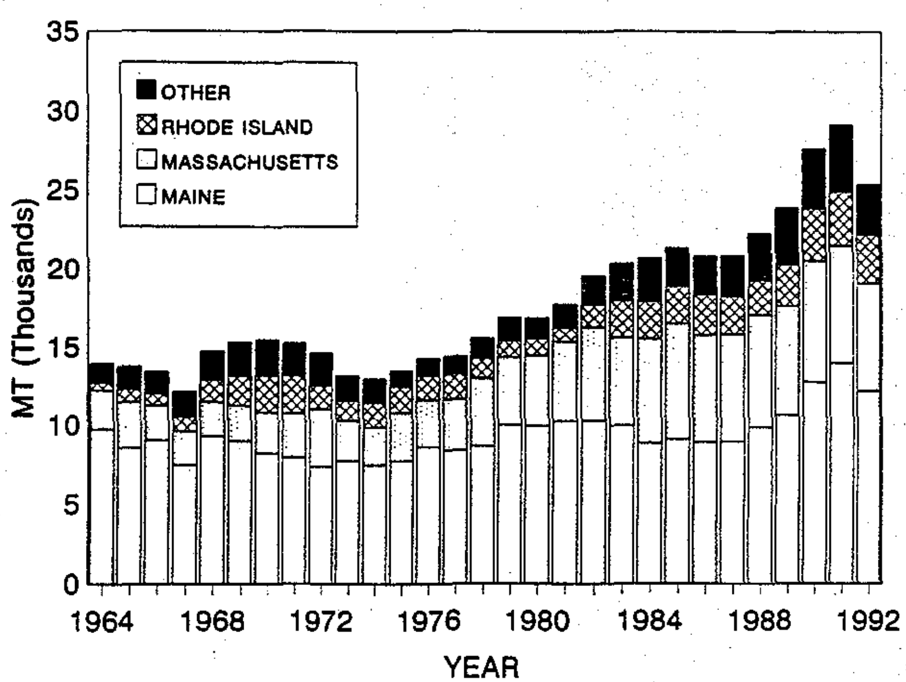

Figure D2. American lobster landings (thousands of metric tons) by state, 1964-1992.

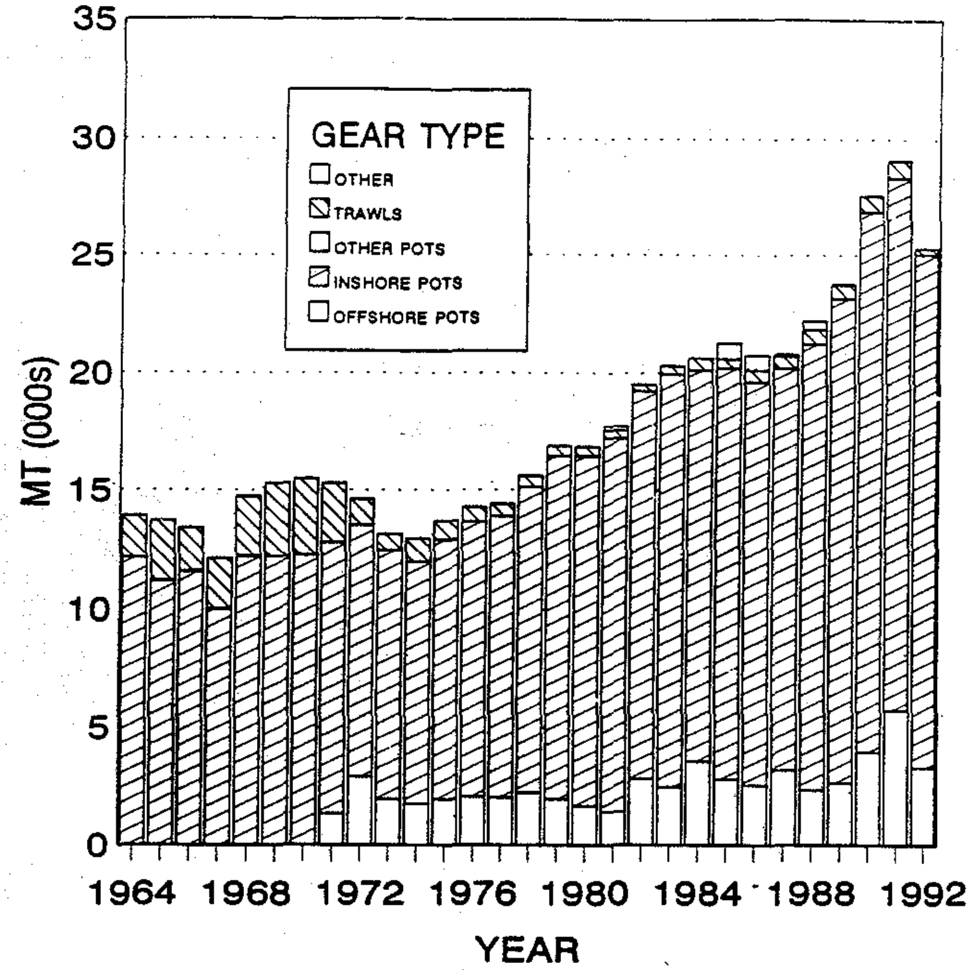

Figure D3. American lobster landings by gear type, 1964-1992.

1980). Initially, the two southern areas were analyzed separately. However, in light of the interchange between areas, a combined assessment for the southern areas was also attempted.

Some exchange of lobsters occurs among the Gulf of Maine and GBS-O stocks units based on movement of tagged lobsters northward from outer Cape Cod. However, on balance, the proposed division of stock units separates the bulk of animals with divergent population dynamics parameters, and defines predominant nearshore fisheries (Gulf of Maine) from predominant offshore fisheries (Georges Bank and South).

DESCRIPTION OF THE FISHERY

Total lobster landings increased steadily from the mid-1960s to early 1990s (Table D1; Figure D2). Landings peaked at 29,089 mt in 1991 and declined 13% in 1992, to 25,329 mt. Landings declined in 1992 (based on preliminary NMFS annual canvass statistics) in all major lobster-producing states: Maine:- 13%; Massachusetts: -8%; Rhode Island: -9%; and all other states: -25%. Reductions in lobster landings in 1992 are probably related to reduced resource availability (either due to lower stock abundance or reduced catchability), since LPUE declined in many areas (see section on stock abundance, page 81), while total effort increased. Similarly, a number of autumn research vessel trawl survey indices declined in 1992, coincident with the decline in landings and LPUE.

Landings by gear type are plotted in Figure D3. Inshore pots account for the predominance of landings (86% in 1992), with offshore pots (13%) accounting for the bulk of the remainder. Trawl landings of lobster accounted for less than one percent of 1992 landings, but in previous years trawls generated higher proportions of reported landings. Trawl landings represented a significant fraction of the fishery in the during the 1960s. The offshore pot fishery developed beginning in 1971. This segment of the fishery has exhibited relatively stable landings, while inshore pots have shown dramatically increasing landings since 1974 (a near doubling of inshore pot landings).

Trends in annual landings for the three nominal assessment areas (1979 to 1992) are given in Figure D4 and Table D2. The Gulf of Maine assessment area accounted for an average of 65% of landings, while the GBS-O area contributed 21%, and the SCCLIS-I region generated an average of 14% of landings. In recent years a higher fraction of landings has been derived from the Gulf of Maine (71%) and a lower fraction from GBS-O.

Calculations involving the DeLury and length cohort population models (Conser and Idoine 1992; Jones 1974) require that catch in numbers be estimated quarterly for each assessment area. Since overfishing definitions for the resource currently involve only egg production per recruit calculations, we focused on estimating fishing mortality and stock sizes for females. Thus, catches in numbers only for the female component of the resource were estimated. Since autumn trawl surveys were used to calibrate DeLury stock depletion models, the annual landings were shifted to a 'survey year' basis. This procedure involved combining the Q4 landings of year i with Q1+Q2+Q3 of years i+1. Thus, for example, research vessel survey data for autumn 1991 and autumn 1992 were calibrated to landings in numbers for Q4 of 1991 and Q1+Q2+Q3 of 1992.

Catches in numbers and weight for female lobsters by survey year and assessment area are given in Table D3. These estimates are based on catches expanded by sex and size from appropriate port and sea sampling. Estimation of catch numbers was problematical for all assessment areas, owing to the very uneven catch sampling for size composition and sex ratios among the states and NMFS. Catch numbers for inshore areas of the Gulf of Maine were estimated separately for Maine and Massachusetts. New Hampshire inshore catch in numbers was estimated assuming size and sex ratio data for Massachusetts catches in statistical area 514 were applicable. Offshore catches for the Gulf of Maine (area 515) were expanded based on Canadian sea sampling data from the Crowell Basin area, because of the lack of appropriate U.S. sampling data.

Catch numbers for the GBS-O area were expanded from NMFS commercial sampling data (1979 to 1990). Rhode Island offshore sea sampling data were used for 1991 and 1992. Catch in numbers for the SCCLIS-I area were estimated from Connecticut, Rhode Island, and Massachu-

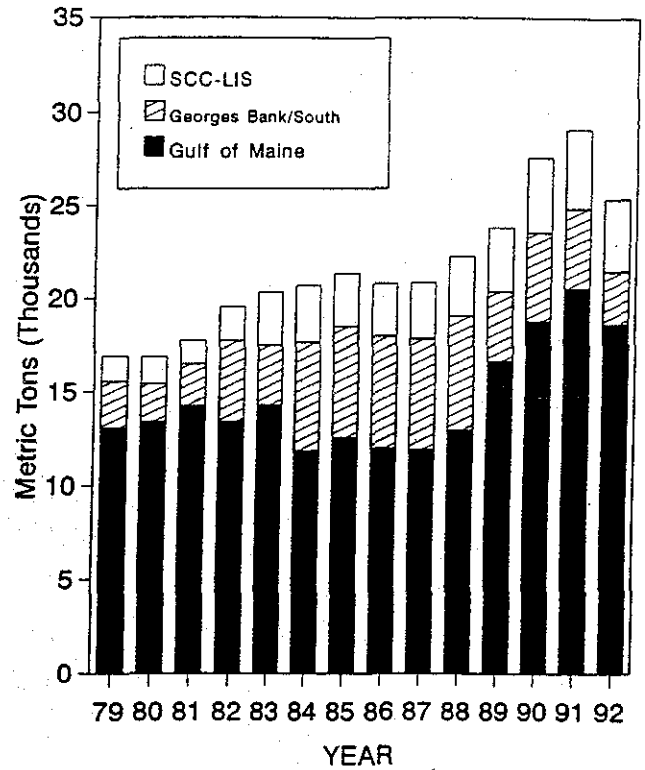

Figure D4. American lobster landings by stock assessment area, 1979-1992.

Table D2. Landings (metric tons) of American lobster by assessment area, 1979-1992[1]

Year	Gulf of Maine	GBS-O	SCCLIS-I
1979	13065.591	2489.013	1357.782
1980	13404.982	2020.271	1455.244
1981	14241.436	2256.589	1252.477
1982	13418.038	4330.993	1794.007
1983	14317.816	3196.447	2815.072
1984	11854.116	5824.708	2989.652
1985	12579.900	5925.656	2811.095
1986	11996.198	5999.249	2787.144
1987	11932.364	5926.847	2966.545
1988	12949.185	6128.339	3158.039
1989	16654.892	3691.004	3430.047
1990	18782.806	4714.370	4085.390
1991	20531.931	4274.615	4282.077
1992	18649.506	2782.533	3897.305

[1] GBS-O - Georges Bank and South-Offshore assessment area
SCCLIS-I - South of Cape Cod to Long Island Sound-Inshore assessment area

Table D3. Estimated landings of female lobsters in numbers (millions of lobsters) and weights (metric tons), by assessment area, for survey years 1979-1991 (Q4 year i + Q1, Q2, Q3 in year i+1)[1]

Year	Gulf of Maine		GBS-O		SCCLIS-I	
	Number	mt	Number	mt	Number	mt
1979	-	-	0.95	690	1.79	981
1980	12.28	6765	1.09	1203	1.39	758
1981	12.29	6875	1.42	1733	1.72	945
1982	12.52	6935	2.02	1493	3.21	1775
1983	10.74	5867	3.45	1997	3.44	1890
1984	12.40	6680	4.92	2575	3.49	1913
1985	12.83	6813	6.86	2611	3.48	1895
1986	11.36	6148	5.95	2865	3.40	1857
1987	11.43	6186	6.23	3036	3.54	1969
1988	13.63	7479	5.14	1900	4.10	2316
1989	14.90	8302	5.10	1707	4.48	2530
1990	17.10	9554	2.80	2399	4.75	2666
1991	14.57	8166	1.77	1559	4.47	2474

[1] GBS-O = Georges Bank and South-Offshore assessment area
SCCLIS-I = South of Cape Cod to Long Island Sound-Inshore assessment area

setts size/sex ratio data. New York catches were expanded using Connecticut sampling. Similarly, Rhode Island landings prior to 1990 were not sampled for biological characteristics. Thus, Buzzards Bay (Massachusetts) sampling data were used to estimate numbers of females caught from total Rhode Island landings.

STOCK ABUNDANCE INDICES

Research Vessel Trawl Survey Indices

Indices of relative stock abundance were computed from various trawl survey time series developed by NEFSC and the states of Massachusetts, Rhode Island, and Connecticut. These data were used both as relative indices of stock abundance and as tuning indices for the DeLury population models. Indices were developed for two size categories from the data: (1) fully-recruited individuals (81 mm carapace prior to 1988, 82 mm CL in 1988, and 83 mm CL in 1988-1992), and (2) prerecruit indices. Prerecruits are defined as the molt group likely to become legal size during the 12-month period between successive surveys. In the case of surveys for the Gulf of Maine and SCCLIS-I areas, the prerecruit size group was 11 mm CL below the legal size:

through 1987:	70-80 mm CL
1988:	71-81 mm CL
1989-1992:	72-82 mm CL

For the GBS-O area, faster growth rates result in a prerecruit size group 14 mm below legal size:

through 1987:	67-80 mm CL
1988:	68-81 mm CL
1989-1992:	69-82 mm CL

Indices are presented separately for pre-recruit and fully-recruited sizes.

Gulf of Maine Assessment Area

Indices of relative abundance for lobsters in the Gulf of Maine assessment area are available from two sources. The NEFSC bottom trawl survey series begins in 1963, however methods used for length determinations are inconsistent prior to 1970, and sex determinations for lobsters were not made prior to 1979 (Table D4; Figure D5). The survey is conducted with roller-rigged Yankee-36 bottom trawl. The predominance of stations is located in relatively deep waters, owing to the extremely rough bottom conditions in nearshore waters of the Gulf of Maine.

The relative abundance of lobsters in the NEFSC series increased substantially over the period 1970 to 1991 and especially since 1983. The relative abundance of both size classes of each sex declined substantially from 1991 to 1992, consistent with declines in regional CPUE.

The state of Massachusetts has conducted autumn bottom trawl surveys since 1978 (Table D5; Figure D6). Indices used for Gulf of Maine analyses were calculated from sampling conducted north of Cape Cod. The surveys are conducted with the trawl sweep comprised of 3.5 in. 'cookies'; thus it is likely more efficient at sampling lobsters than the NEFSC sampling gear. Differences in mean sizes between the NEFSC and state of Massachusetts surveys are due to a combination of differences in gear selection and habitats sampled in the two programs. However, neither sampling gear is particularly effective in sampling hard bottom lobster habitats.

Abundance indices for both sexes and size groups increased throughout the late-1970s to the mid-1980s. Abundance declined between 1986 and 1988, and subsequently increased to time-series highs in 1990. Abundance has decreased sharply since 1990.

Georges Bank and South Offshore Assessment Area

The only trawl survey time series available for this region is the NEFSC offshore survey (Table D6; Figure D7). The entire region from Georges Bank to Cape Hatteras, with the exception of NEFSC offshore stratum 5 in coastal Rhode Island waters, was included in the strata set for analysis of this assessment area. Indices reported in SARC 14 included only Georges Bank and Southern New England. The addition of more southern strata results in lower apparent abundance of pre-recruits relative to fully-recruited animals, and has important implications for assessment results for this area.

The abundance of recruit-sized lobsters has varied without trend since the mid-1970s. Conversely, the abundance of prerecruits has increased steadily over the time period. Unlike the Gulf of Maine, abundance did not appreciably change between 1991 and 1992.

South of Cape Cod to Long Island Inshore Assessment Area

Two sets of trawl survey abundance indices are available for this area. The state of Rhode Island has conducted an inshore trawl survey since 1979 (Table D7; Figure D8). The survey is conducted in Narragansett Bay, and in Block Island and Rhode Island Sound waters. Survey gear is a three-quarter scale high-rise bottom trawl equipped with a 'cookie' sweep. Abundance indices for lobsters increased substantially since the early 1980s. The 1992 index for females was near the time-series high, while the index for males declined to a five-year low.

The State of Connecticut has conducted a trawl survey of Long Island Sound since 1986 (Table D8; Figure D9). Abundance indices for both sexes and size groups increased steadily since 1987, declines in prerecruit indices occurred between 1991 and 1992.

Although the State of Massachusetts bottom trawl survey extends west of Nantucket, survey catches are generally very small, and thus a reliable index of stock abundance for lobsters can not be calculated from these data.

Landings Per Unit of Effort Indices

A variety of effort and LPUE series are available from the individual states. Trends in total nominal fishing effort for Maine (numbers per trap haul), Massachusetts (numbers per trap haul), and New York (number of traps) and Connecticut (number of trap hauls) are given in Table D9. In all cases, nominal inshore effort has increased substantially in recent years.

The LPUE series for the Gulf of Maine and SCCLIS-I assessment areas are given in Figures D10 and D11. The LPUE indices in the Gulf of Maine region generally increased from the mid-1980s until 1991. For both Maine and Massachusetts, LPUE declined dramatically in 1992. The LPUE indices for the southern inshore area have generally trended downward since the early 1980s. The only significant decline between 1991 and 1992 was for Rhode Island.

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Two alternative approaches to calculating stock sizes and fishing mortality rates have been used in previous assessments: DeLury population modeling, and length cohort analyses. Comparative analyses using both techniques were undertaken for the Gulf of Maine assessment area. Length cohort analyses (LCAs) were not undertaken for the two southern stock areas due to the lack of adequate time series data.

DeLury Model Analyses

A DeLury population estimation model for American lobster assessments was first intro-

Table D4. Estimates of relative lobster stock abundance for the Gulf of Maine stock area from autumn NEFSC bottom trawl surveys in the Gulf of Maine, 1970-1992, delta-distributed mean catch-per-tow for females

Year	Numbers		Mean	
	Prerecruits	Fully-Recruited	Prerecruits	Fully-Recruited
1970[1]	0.000	0.026	000.0	2590.1
1971	0.000	0.096	000.0	1761.6
1972	0.000	0.113	000.0	2065.9
1973	0.005	0.081	354.1	1661.2
1974	0.018	0.099	354.1	977.7
1975	0.000	0.071	000.0	979.6
1976	0.005	0.183	347.6	993.6
1977	0.068	0.430	352.9	992.6
1978	0.020	0.152	345.8	1171.4
1979	0.038	0.094	350.8	827.4
1980	0.041	0.393	346.9	815.4
1981	0.004	0.106	347.6	982.9
1982	0.117	0.064	342.7	739.6
1983	0.236	0.330	356.6	659.5
1984	0.102	0.194	357.1	908.8
1985	0.269	0.567	353.8	842.3
1986	0.305	0.311	336.9	683.8
1987	0.091	0.228	351.9	1015.7
1988[2]	0.373	0.270	374.3	750.2
1989[3]	0.289	0.314	368.0	876.2
1990	0.419	0.304	395.0	758.3
1991	0.457	0.355	391.4	717.3
1992	0.196	0.164	368.7	863.4

[1] Fully-recruited ≥81 mm carapace length, prerecruits = 70-80 mm (1970-1987)
[2] Fully-recruited ≥82 mm carapace length, prerecruits = 71-81 mm (1988)
[3] Fully-recruited ≥83 mm carapace length, prerecruits = 72-82 mm (1989-1992)

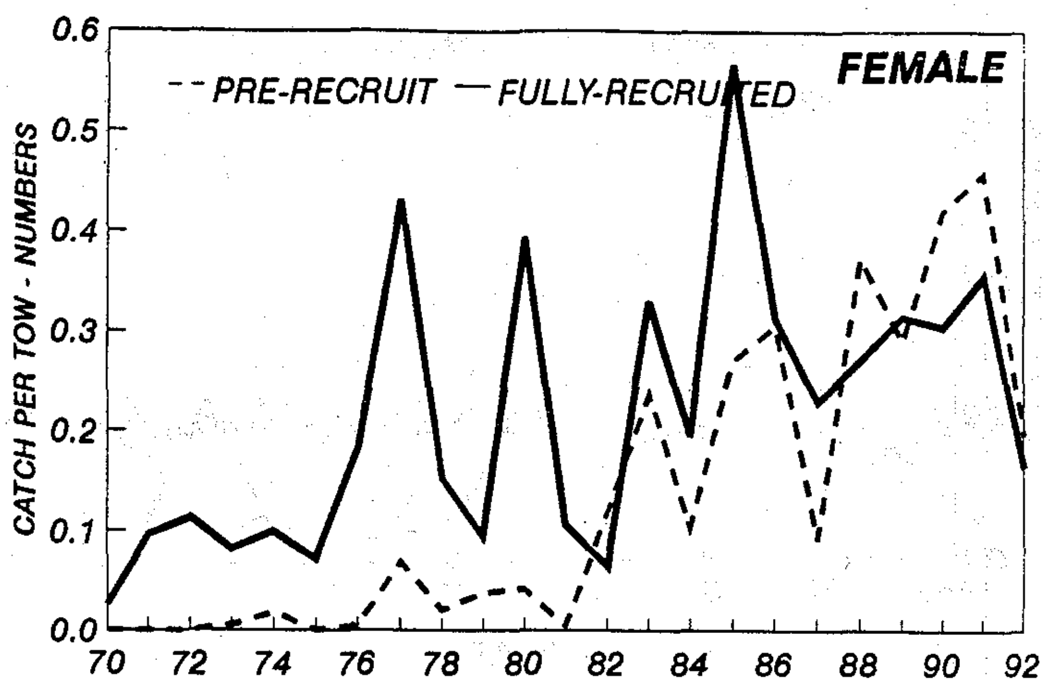

Figure D5. Research vessel trawl survey indices of female lobsters in the Gulf of Maine assessment area, 1970-1992. Data are given for prerecruit and fully-recruited sizes (see text for definitions), and are from NEFSC surveys.

Table D5. Indices of relative lobster stock abundance for the Gulf of Maine stock area from Massachusetts autumn bottom trawl surveys north of Cape Cod, 1978-1992, delta-distributed mean catch-per-tow for females

Year	Numbers		Mean Animal Weight (g)	
	Prerecruits	Fully-Recruited	Prerecruits	Fully-Recruited
1978[1]	1.13	0.65	349.5	586.7
1979	3.92	1.52	349.8	585.4
1980	1.78	0.96	349.4	586.4
1981	2.83	1.04	349.7	585.0
1982	2.30	1.84	349.4	567.5
1983	4.35	1.64	351.7	573.0
1984	2.49	1.49	346.4	585.0
1985	4.68	2.25	347.3	579.1
1986	1.98	0.61	341.7	543.3
1987	0.53	0.37	368.3	662.6
1988[2]	1.26	0.29	349.5	532.3
1989[3]	1.64	0.55	373.7	577.8
1990	7.46	2.30	366.4	560.6
1991	3.56	0.56	371.1	527.0
1992	2.69	0.77	361.2	583.7

[1]Fully-recruited ≥81 mm carapace length, prerecruits = 70-80 mm (1978-1987)
[2]Fully-recruited ≥82 mm carapace length, prerecruits = 71-81 mm (1988)
[3]Fully-recruited ≥83 mm carapace length, prerecruits = 72-82 mm (1989-1992)

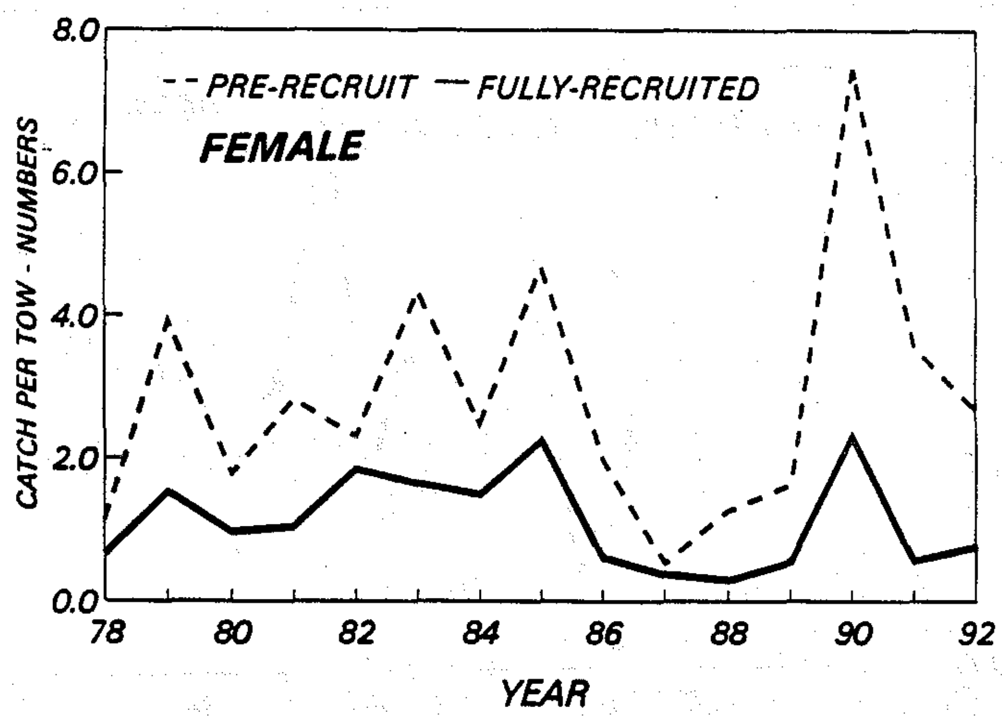

Figure D6. Research vessel trawl survey indices of female lobsters in the Gulf of Maine assessment area, 1978-1992. Data are given for prerecruit and fully-recruited sizes (see text for definitions), and are from State of Massachusetts surveys.

Table D6. Indices of relative lobster stock abundance (mean-catch-per-tow of females) for the Georges Bank and South offshore stock area from NEFSC autumn bottom trawl surveys for Georges Bank and south, 1970-1992.

Year	Numbers		Mean Animal Weight (g)	
	Prerecruits	Fully-Recruited	Prerecruits	Fully-Recruited
1970[1]	0.036	0.424	300.2	1593.3
1971	0.032	0.325	304.9	2493.3
1972	0.115	0.688	307.0	1314.3
1973	0.055	0.447	308.6	1947.2
1974	0.055	0.197	290.2	1563.8
1975	0.093	0.284	298.0	1289.8
1976	0.079	0.280	290.5	959.0
1977	0.095	0.451	295.1	1249.2
1978	0.078	0.318	307.2	1128.4
1979	0.094	0.330	300.0	1102.2
1980	0.082	0.317	289.2	1326.7
1981	0.124	0.340	283.8	1077.6
1982	0.131	0.359	293.9	1096.4
1983	0.127	0.285	295.0	1177.4
1984	0.119	0.322	310.1	825.4
1985	0.173	0.249	305.1	1155.9
1986	0.173	0.312	296.4	854.6
1987	0.099	0.212	303.0	1033.0
1988[2]	0.101	0.322	321.1	1024.5
1989[3]	0.169	0.330	312.8	1126.1
1990	0.213	0.347	309.9	945.8
1991	0.100	0.406	309.7	1137.2
1992	0.188	0.339	327.1	1175.1

[1]Fully-recruited = ≥81 mm carapace length, prerecruits = 67-80 mm (1970-1987)
[2]Fully-recruited = ≥82 mm carapace length, prerecruits = 68-81 mm (1988)
[3]Fully-recruited = ≥83 mm carapace length, prerecruits = 69-82 mm (1989-1992)

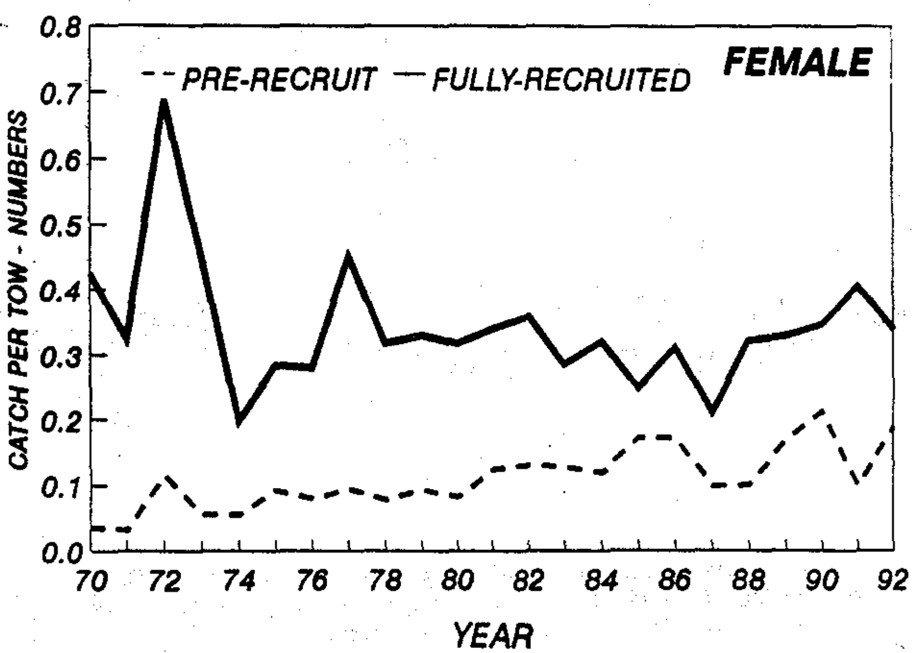

Figure D7. Research vessel trawl survey indices of female lobsters in the Georges Bank and South offshore assessment area, 1970-1992. Data are given for prerecruit and fully-recruited sizes (see text for definitions), and are from NEFSC surveys.

Table D7. Indices of relative lobster stock abundance for the South of Cape Cod-Long Island Sound Inshore stock area from Rhode Island bottom trawl surveys for 1979-1992, delta-distributed mean catches-per-tow for females

Year	Numbers		Mean Animal Weight (g)	
	Prerecruits	Fully-Recruited	Prerecruits	Fully-Recruited
1979[1]	0.096	0.024	318.4	475.3
1980	0.638	0.071	342.5	611.7
1981	0.640	0.091	343.6	488.1
1982	0.206	0.012	336.4	511.1
1983	0.290	0.094	360.4	511.9
1984	0.491	0.212	350.2	579.4
1985	0.631	0.015	346.0	568.2
1986	0.400	0.037	342.4	458.1
1987	1.527	0.330	338.8	532.2
1988[2]	0.951	0.219	362.8	607.5
1989[3]	1.383	0.285	353.4	483.7
1990	1.102	0.155	374.7	543.7
1991	0.768	0.193	367.4	526.7
1992	1.328	0.251	400.4	555.3

[1]Fully-recruited ≥81 mm carapace length, prerecruits = 70-80 mm (1979-1987)
[2]Fully-recruited ≥82 mm carapace length, prerecruits = 71-81 mm (1988)
[3]Fully-recruited ≥83 mm carapace length, prerecruits = 72-82 mm (1989-1992)

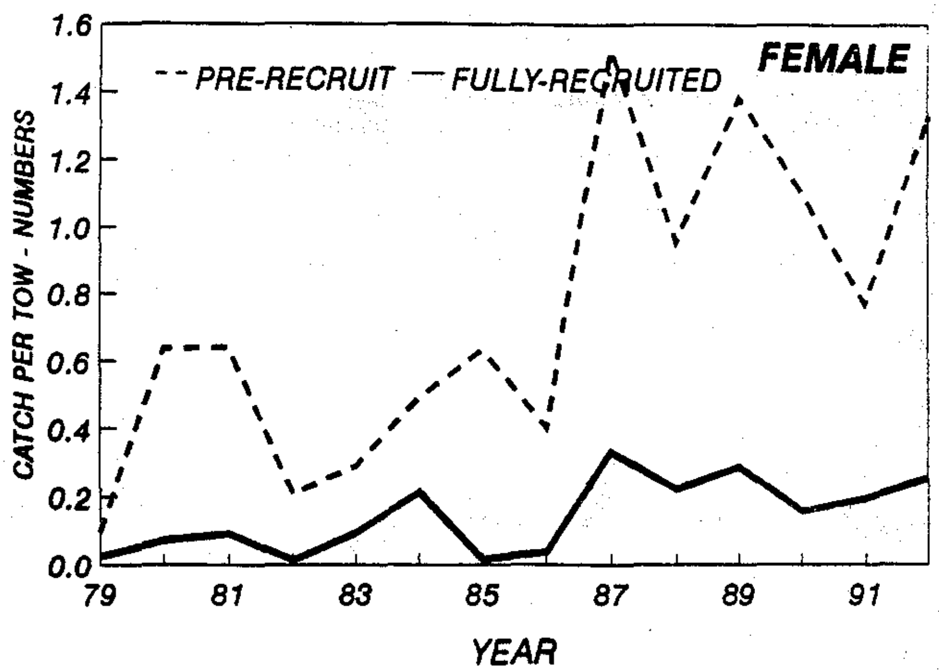

Figure D8. Research vessel trawl survey indices of female lobsters in the South Cape Cod-Long Island Sound inshore assessment area, 1979-1992. Data are given for prerecruit and fully-recruited sizes (see text for definitions), and are from State of Rhode Island surveys.

Table D8. Indices of relative lobster stock abundance for the South of Cape Cod-Long Island Sound inshore stock area from Connecticut bottom trawl surveys of Long Island Sound, 1986-1992, geometric mean catch-per-tow for females

Year	Numbers		Mean Animal Weight (g)	
	Prerecruits	Fully-Recruited	Prerecruits	Fully-Recruited
1986[1]	1.2985	0.5363	371.7	521.6
1987	1.4280	0.5410	379.4	516.1
1988[2]	0.8879	0.4172	379.9	545.5
1989[3]	0.9289	0.2408	384.9	507.7
1990	1.3311	0.3932	384.4	523.7
1991	1.6775	0.3395	392.2	511.5
1992	1.3964	0.4540	396.8	518.7

[1] Fully-recruited ≥81 mm carapace length, prerecruits = 70-80 mm (1986-1987)
[2] Fully-recruited ≥82 mm carapace length, prerecruits = 71-81 mm (1988)
[3] Fully-recruited ≥83 mm carapace length, prerecruits = 72-82 mm (1989-1992)

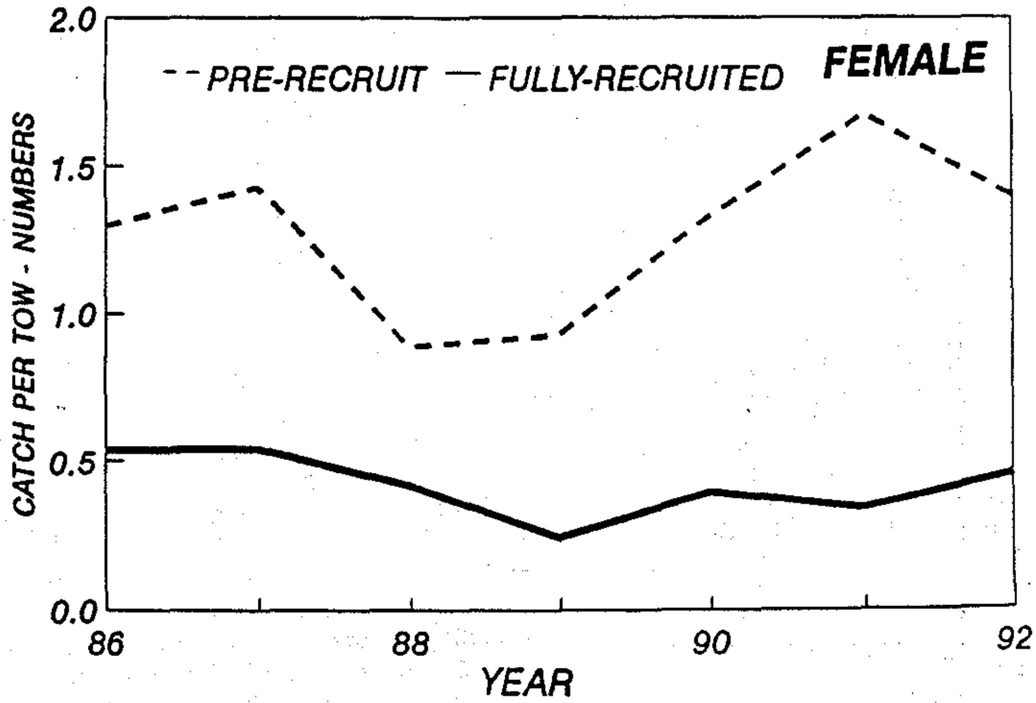

Figure D9. Research vessel trawl survey indices of female lobsters in the South Cape Cod-Long Island Sound inshore assessment area, 1986-1992. Data are given for prerecruit and fully-recruited sizes (see text for definitions), and are from State of Connecticut surveys.

duced at SARC 14 (Conser and Idoine 1992). This method utilizes a two life-stage model, with the population divided into prerecruits and fully-recruited sizes. Research vessel bottom trawl survey indices and annual catch in numbers are used to estimate stock sizes and fishing mortality rates.

The DeLury model was fit to survey and landings data for the three stock areas. Trial runs for the Gulf of Maine region indicated that survey data for 1980 and later gave most consistent results, thus the analysis was not extended back in time. Two DeLury runs for the Gulf of Maine region evaluated the effects of assuming that selectivity of prerecruits was 1.0 and 0.5 of that of fully-recruited sizes (Tables D10 to D12). In the absence of data to firmly establish the relative selection of the two size groups, the two runs were combined using bootstrap techniques to generate a combined estimate of fishing mortality and stock size giving equal probability to the two sets of runs (Table D13; Figure D12). Bootstrap estimates of average fishing mortality rates for the last three years (1989 to 1991), as

Table D9. Trends in total pot fishing effort (numbers of traps, in thousands), by state, 1964-1992

Year	Maine[1]	Massachusetts[1]	Connecticut[2]	New York
1964	754	104.8		
1965	789	113.3		
1966	776	120.9		
1967	715	130.7		
1968	747	141.7		
1969	805	141.5		
1970	1180	152.3		
1971	1278	162.3		
1972	1448	175.6		
1973	1172	169.7		
1974	1790	157.0		
1975	1771	211.1		
1976	1754	222.3		
1977	1739	218.0		19.1
1978	1723	257.5		20.1
1979	1810	291.5	1192	18.4
1980	1846	278.1	1277	21.8
1981	1825	299.4	1178	24.7
1982	2143	319.1	1000	23.2
1983	2340	334.9	1627	31.6
1984	2175	354.9	1973	44.8
1985	1766	375.2	1859	51.6
1986	1595	399.8	1737	44.0
1987	1909	427.0	2066	54.0
1988	2053	433.4	2294	57.8
1989	2001	430.5	2583	60.6
1990	2094	385.2	3069	73.1
1991	2015	398.0	3009	83.5
1992	2000	N/A	3200	N/A

[1] Data for 1992 for Maine and Massachusetts are preliminary.
[2] Connecticut data expressed in trap hauls

Table D10. Indices of prerecruit and fully-recruited stock size (numbers per tow from NMFS autumn bottom trawl surveys) and total landings (millions) in the Gulf of Maine assessment area by survey years (Q4 year i + Q1, Q2, Q3 of year i+1)

Survey Year	Indices of Abundance: Recruits	Indices of Abundance: Fully-Recruited	Total Landings
1980	0.0410	0.3930	12.288031
1981	0.0040	0.1060	12.286778
1982	0.1170	0.0640	12.520628
1983	0.2360	0.3300	10.745529
1984	0.1020	0.1940	12.401634
1985	0.2690	0.5670	12.832394
1986	0.3050	0.3110	11.362626
1987	0.0910	0.2280	11.430961
1988	0.3730	0.2700	13.633450
1989	0.2890	0.3140	14.903986
1990	0.4190	0.3040	17.100721
1991	0.4570	0.3550	14.572636
1992	0.1960	0.1640	

well as distribution statistics are given in Table D14 and Figure D13.

Fishing mortality rates increased 45% from 1983 to 1991 (Table D13; Figure D12). The average fishing mortality rate for the stock for 1989 to 1991 is computed to be 0.65 (Table D14). Distribution statistics around this point indicate 80% CIs of 0.47 to 0.87. There is a 78% probability that F exceeds the $F_{10\%}$ EPR level of 0.52 (Figure D13).

Trial DeLury runs were made for the GBS-O assessment area assuming selectivity of prerecruits at 1.0 and 0.5 of that for fully-recruited animals (Tables D15 to D17). These runs indicated very low fishing mortality rates, particularly in light of SARC 14 results indicating an average F of 0.69 for the Georges Bank and Southern New England offshore region. These revised results included survey indices from Georges Bank through Cape Hatteras. When this larger survey area is included, the ratio of prerecruits to fully-recruited numbers per tow declines significantly, perhaps indicating a dearth

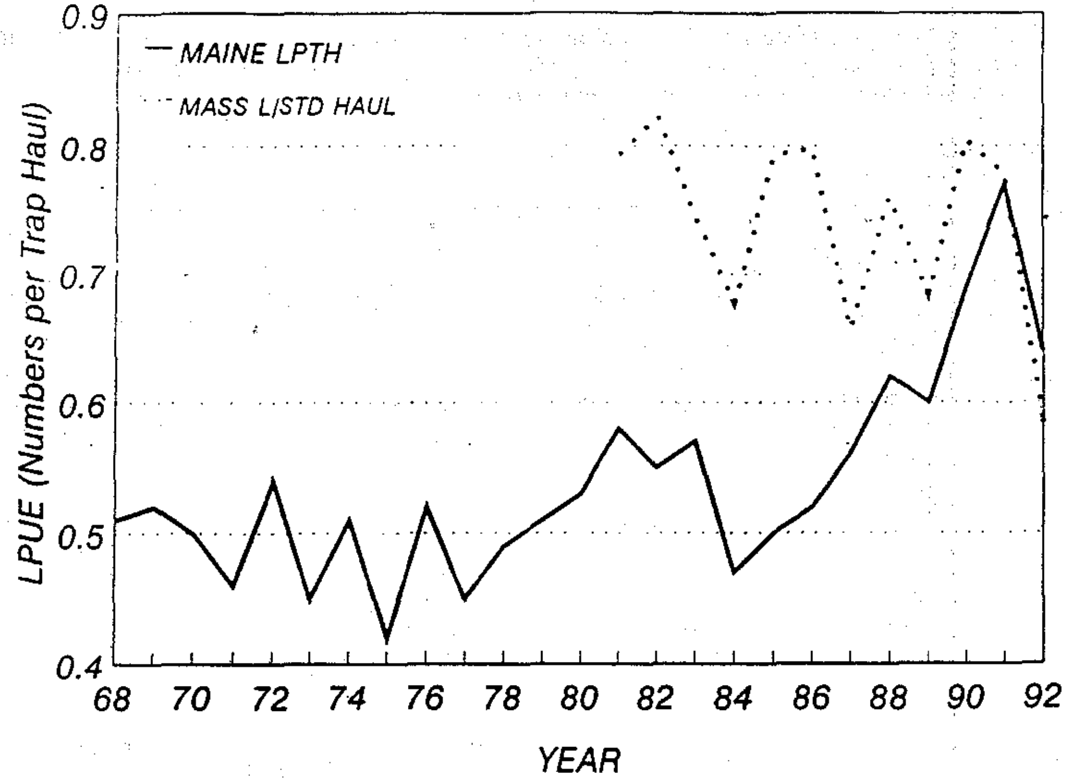

Figure D10. Landings per unit effort (LPUE) for Gulf of Maine lobster populations. Data are catch per trap haul (Maine) and catch per standardized haul (Massachusetts.)

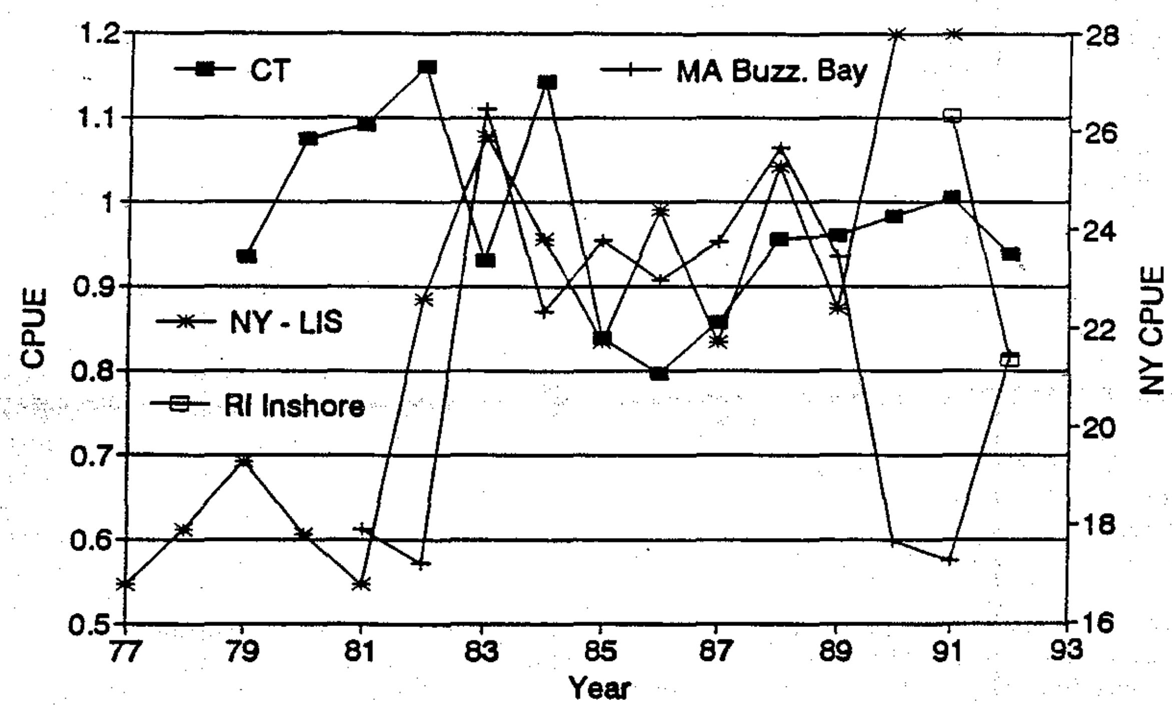

Figure D11. Catch per unit effort (CPUE) for South of Cape Cod-Long Island Sound lobster populations. Massachusetts index is in numbers per trap haul, New York is pounds per trap per year.

Table D11. Estimates of stock size (numbers) fishing and total mortality rates and biomasses of Gulf of Maine lobster (females), based on DeLury model run assuming selectivity of prerecruits and fully-recruited animals to NMFS survey gear is equal

Recruits =Size Class 1
Fully-Recruited =Size Class 2+

Survey Year	Stock Size Estimates (millions-Oct 1) Recruits	Fully-Recruited	F on Size 1+	F on Size 1	F on Sizes 2+
1980	3.394	28.880	0.50	0.16	0.54
1981	0.340	17.664	1.10	0.33	1.11
1982	22.767	5.429	0.44	0.30	1.02
1983	21.268	16.395	0.31	0.15	0.52
1984	10.685	24.893	0.31	0.12	0.39
1985	18.863	23.616	0.43	0.19	0.63
1986	19.737	24.975	0.40	0.17	0.59
1987	7.444	27.011	0.42	0.15	0.50
1988	24.800	20.390	0.43	0.21	0.71
1989	19.537	26.494	0.48	0.20	0.68
1990	25.287	25.814	0.52	0.24	0.80
1991	24.204	27.512	0.51	0.23	0.76
1992	16.486	28.125			

Survey Year	Biomass Estimates (mt, Oct. 1) Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	Catch Biomass During Survey Year (mt)
1980	1177	23548	24726	23898	6765
1981	118	17362	17480	17397	6875
1982	7802	4015	11818	6330	6935
1983	7584	10813	18397	13062	5867
1984	3816	22623	26438	23754	6680
1985	6674	19892	26565	21871	6813
1986	6650	17078	23727	19050	6148
1987	2620	27435	30055	28213	6186
1988	9283	15297	24580	18051	7479
1989	7189	23214	30403	25347	8302
1990	9989	19575	29563	22538	9554
1991	9473	19734	29207	22544	8166
1992	6078	24283	30362	26086	

of prerecruits in survey tows from Hudson Canyon south. The result of this change is that fully-recruited stock sizes are increased, and Fs decline. Based on the average of the two current DeLury runs, average Fs for the last three years are about 0.3. These estimates should be considered tentative, given the difficulty in resolving the spatial components of this offshore area. The bulk of the GBS-O landings come from a restricted portion of this area. If semidiscrete stock units exist, for example in southern canyon areas, there is a danger that the smaller stock units could experience substantially higher mortality rates than expressed in the overall analysis. Fishing mortality rates calculated at SARC 14 for Georges Bank and Southern New England offshore are consistent with an hypothesis of smaller stock units. In the absence of definitive stock identification studies, a cautious approach to exploiting the offshore region is warranted.

DeLury runs for the SCCLIS-I, using the Rhode Island trawl survey indices, assumed equal selectivity of prerecruits and fully-recruited sizes (Tables D18 and D19). Total apparent fishing mortality rates were very high for this assessment area (average F for 1989 to 1991 = 1.47), reflecting the intensive nearshore fishery, and emigration to offshore waters.

Survey indices and landings data were combined in several DeLury runs to examine the implications for an integrated inshore/offshore assessment (as in the case of the Gulf of Maine area). Three runs of the combined assessment were: (1) combined landings, and the NEFSC

Table D12. Estimates of stock size (numbers), fishing and total mortality rates, and biomasses of Gulf of Maine lobster (females), based on DeLury model run assuming selectivity of preprecruits equal to 0.5 that of fully-recruited animals to NMFS survey gear.

Recruits =Size Class 1
Fully-Recruited =Size Class 2+

Survey Year	Stock Size Estimates (millions-Oct 1) Recruits	Fully-Recruited	F on Size 1+	F on Size 1	F on Sizes 2+
1980	3.593	23.594	0.54	0.18	0.60
1981	0.343	14.300	1.77	0.53	1.80
1982	19.472	2.262	0.78	0.62	2.10
1983	16.896	9.058	0.57	0.31	1.05
1984	11.743	13.319	0.59	0.26	0.89
1985	15.818	12.524	0.69	0.34	1.13
1986	16.497	12.904	0.60	0.30	1.00
1987	7.402	14.528	0.84	0.29	0.97
1988	20.394	9.442	0.69	0.40	1.34
1989	16.677	13.497	0.76	0.37	1.25
1990	20.657	12.718	0.82	0.43	1.45
1991	18.537	13.289	0.78	0.39	1.32
1992	16.221	13.216			

Survey Year	Biomass Estimates (mt, Oct. 1) Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	Catch Biomass During Survey Year (mt)
1980	1246	19239	20485	19609	6765
1981	119	14055	14174	14091	6875
1982	6673	1673	8346	3652	6935
1983	6025	5974	11999	7761	5867
1984	4193	12104	16297	13348	6680
1985	5596	10549	16145	12209	6813
1986	5558	8823	14381	10472	6148
1987	2605	14756	17361	15529	6186
1988	7633	7083	14717	9348	7479
1989	6137	11826	17963	13647	8302
1990	8160	9644	17803	12064	9554
1991	7256	9532	16788	11685	8166
1992	5981	11411	17391	13185	

offshore survey indices, assuming equal selectivity of the two size classes; (2) combined landings and the NEFSC offshore survey indices, assuming selectivity of prerecruits is 0.5 that of fully-recruited sizes; and (3) combined landings and Rhode Island survey indices. Results of these runs were intermediate to the area-separate analyses. Fishing mortality rates were higher than when NMFS survey indices were used for the offshore area alone, and lower than if the Rhode Island survey is applied only to inshore landings. Each survey is indexing a segment of the population, and more analysis of the results is required to interpret the merits of each approach. Interestingly, both the Rhode Island and NMFS surveys index recruitment at approximately the same levels, however fully-recruited stock sizes are higher in the case of the NMFS survey used as a tuning index, and fishing mortality rate estimates are unrealistically high (likely due to emigration). Thus, DeLury results should be interpreted cautiously. More effort devoted to integrated inshore/offshore assessments of the southern region is clearly needed.

Length-Cohort Analyses

Lobster landings from the Gulf of Maine assessment area (Maine, New Hampshire, and Massachusetts) and biological information (*e.g.* sex ratios, size frequencies, and weights) from commercial sampling in Canada, Maine, and Massachusetts were used to estimate 1981 to

Table D13. Estimates of the fishing mortality rate (F) for all legal-sized female lobsters in the Gulf of Maine assessment area, based on bootstrap combinations of DeLury runs assuming selectivity of prerecruit-sized lobsters to NMFS survey gear = 1.0 and 0.5 that of fully-recruited sizes (equal probability)[1]

Survey Year	DeLury Estimate	Bootstrap Std. Error	CV for DeLury SOLN
1980	0.5226	0.0535	0.10
1981	1.4333	0.3948	0.28
1982	0.6087	0.2061	0.34
1983	0.4406	0.1334	0.30
1984	0.4518	0.1594	0.35
1985	0.5590	0.1379	0.25
1986	0.5045	0.1188	0.24
1987	0.5837	0.2219	0.38
1988	0.5636	0.1849	0.33
1989	0.6212	0.1940	0.31
1990	0.6700	0.2034	0.30
1991	0.6440	0.2015	0.31

Survey Year	Minimum	Percentiles 10	25	Median	75	90	Maximum
1980	0.3184	0.4517	0.4906	0.5263	0.5594	0.5841	0.6347
1981	0.5430	0.9661	1.1425	1.4299	1.6448	1.9346	2.5665
1982	0.2083	0.3602	0.4582	0.5946	0.7237	0.8703	1.6168
1983	0.1550	0.2836	0.3460	0.4178	0.5180	0.6245	0.9257
1984	0.1198	0.2484	0.3387	0.4389	0.5447	0.6698	1.0841
1985	0.2773	0.3984	0.4604	0.5458	0.6402	0.7268	1.1511
1986	0.2611	0.3684	0.4107	0.4911	0.5754	0.6724	0.9225
1987	0.1384	0.3427	0.4414	0.5557	0.7010	0.8834	1.7270
1988	0.2112	0.3622	0.4421	0.5497	0.6469	0.7839	1.2979
1989	0.0793	0.3862	0.4870	0.6143	0.7372	0.8498	1.3022
1990	0.2794	0.4348	0.5284	0.6395	0.7833	0.8921	1.5413
1991	0.1505	0.4117	0.5033	0.6183	0.7799	0.9026	1.3047

[1]Number of bootstrap replications is 200. The distribution of bootstrap estimates of annual Fs are given intable.

1992 total landings of females by size for a series of modified length-based cohort analyses for the Gulf of Maine (statistical areas 511 to 515, Figure D1).

Port sampling data from eastern, central, and western Maine regions (cluster sampling methodology described by Krouse *et al.* 1991) were used to describe landings from statistical areas 511, 512, and 513, respectively. Biological estimates from the fourth quarter of the previous year were used to characterize first quarter landings. Monthly sea sampling data from Cape Ann, Beverly/Salem, Boston Harbor, and Cape Cod Bay (sampling design reported by Estrella and Cadrin 1992) were used to describe area 514 landings.

Maine and Massachusetts commercial lobster sampling did not adequately sample offshore lobster and there were only a few recent NMFS sea sampling trips in the Gulf of Maine. Therefore, area 515 landings were characterized by four sea sampling trips conducted by Canada Department of Fisheries and Oceans in Crowell Basin (D. Pezzack, personal communication).[1] Landings for 1981 to 1983 were described by a 1982 trip, 1984 to 1985 landings by a 1985 trip, 1986 to 1987 by a 1987 trip, and 1989 to 1992 by a 1991 trip.

A key assumption in the application of length-based estimators of mortality is a stable size structure. Interannual variations in growth rates, recruitment, and fishery management measures all result in departures from a stable age and size structure. Somerton and Kobayashi (1990) illustrated potential pitfalls in length-based models and recommended use of a three-year running average to approximate stability in length frequencies. A truly stable structure probably never exists, but the relevant issues are the magnitude of the departures, their implications for mortality estimation, and the detectability of nonstable size structures. Statistical detectabil-

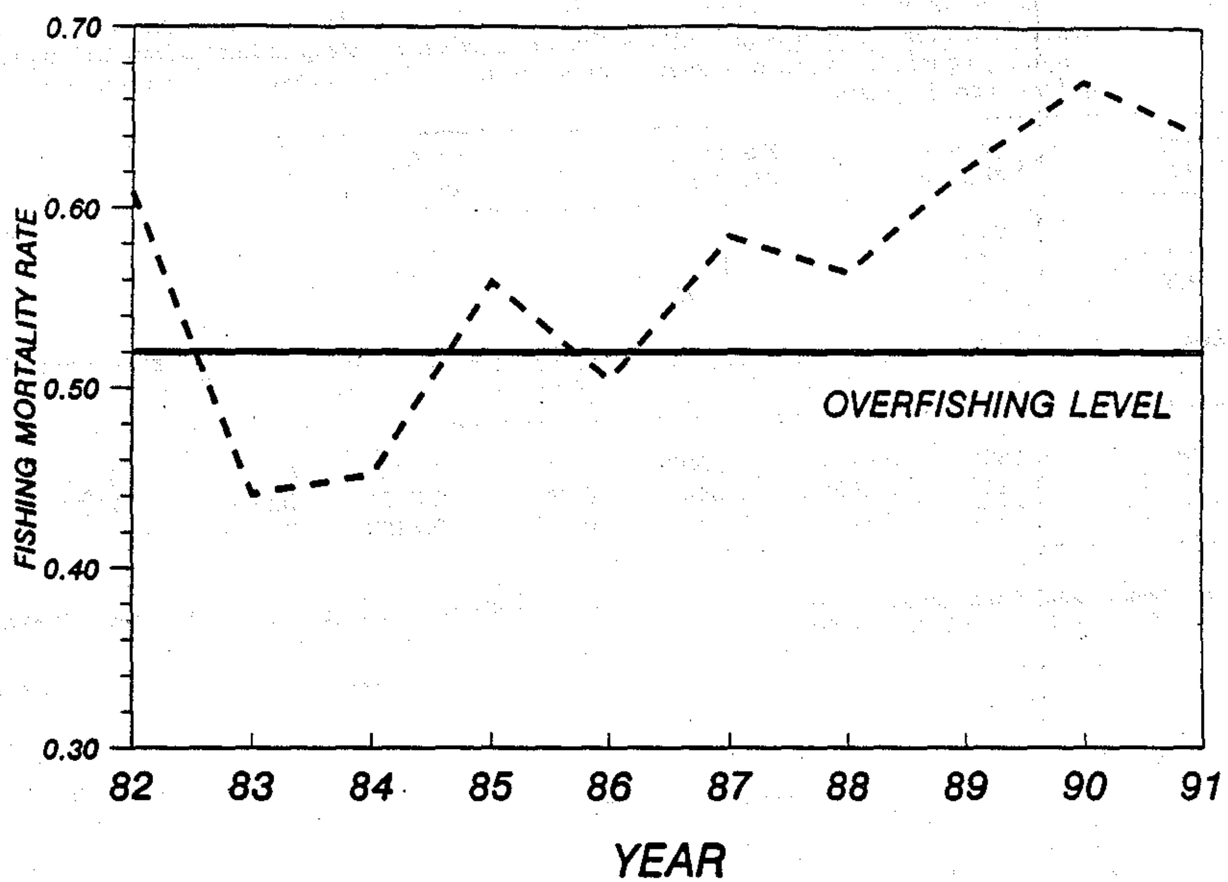

Figure D12. Calculated fishing mortality rates for female American lobster for the Gulf of Maine assessment area, 1982-1991. Results are from combined analyses assuming the relative selectivity of prerecruit-sized lobsters is 1.0 and 0.5 that of fully-recruited sizes.

ity of interannual changes in length frequencies was examined for the Gulf of Maine landings for 1981 to 1992.

Length frequencies of the catch are estimated from sample data appropriately weighted by catches in the sampling stratum. Annual catches were summarized in 5 mm intervals with the minimum size determined by the minimum legal size. Legal minimum carapace lengths were 81 mm from 1981 to 1987, 81.8 mm in 1988, and 82.6 mm since then. Total catches ranged from 1.2 to 1.8 million lobsters over this period. Usual goodness of fit tests based on contingency tables or cumulative density functions were considered inappropriate measures of statistical significance. Catch estimates by length class are not independent and the large number of "observations" in such a comparison ensures statistical significance, irrespective of the true state of nature.

Measures of central tendency and dispersion of the annual length frequencies exhibit no apparent temporal trend. Mean lengths decreased about 2 mm between 1981 and 1986, increased about .5 mm in 1987 and 1988, and declined again over 1989 to 1992. Changes in mean carapace length spanned a range of less than 2 mm over the past decade (Figure D.14). Standard deviation of catch lengths varied by less than 1.5 mm in the same period. Initial attempts to fit statistical distributions to annual length frequencies were not successful but more work is necessary. Parameterization of single or composite probability density function would permit examination of interannual changes in length frequencies. In view of the small changes in the 1981 to 1992 sample moments, such changes probably would have minor consequences for mortality estimation. High underlying rates of total mortality (>1) and within-year variations in growth into the fishable population would tend to dampen variations in prerecruit abundance.

In the absence of raw length sample data, the

Table D14. Calculation of average fishing mortality of all legal-sized female lobsters in the Gulf of Maine assessment area, for three combinations of years based on bootstrap estimates from DeLury runs assuming equal probability of selectivity of prerecruits to NMFS survey gear is 1.0 and 0.5 that of fully-recruited sizes[1]

Survey Year	DeLury Estimate	Bootstrap Std. Error	CV for DeLury SOLN
1991	0.6440	0.2015	0.31
1990-91	0.6570	0.1745	0.27
1989-91	0.6451	0.1603	0.25

Survey Year	Minimum	Percentiles 10	25	Median	75	90	Maximum
1991	0.1505	0.4117	0.5033	0.6183	0.7799	0.9026	1.3047
1990-91	0.2149	0.4536	0.5445	0.6423	0.7570	0.8916	1.2176
1989-91	0.2078	0.4670	0.5311	0.6374	0.7367	0.8742	1.1886

[1] Distributions of bootstrap estimates are given below. Estimates are given for the last year (1991), the last two years (1991 and 1990) and the last three years (1991, 1990 and 1989).

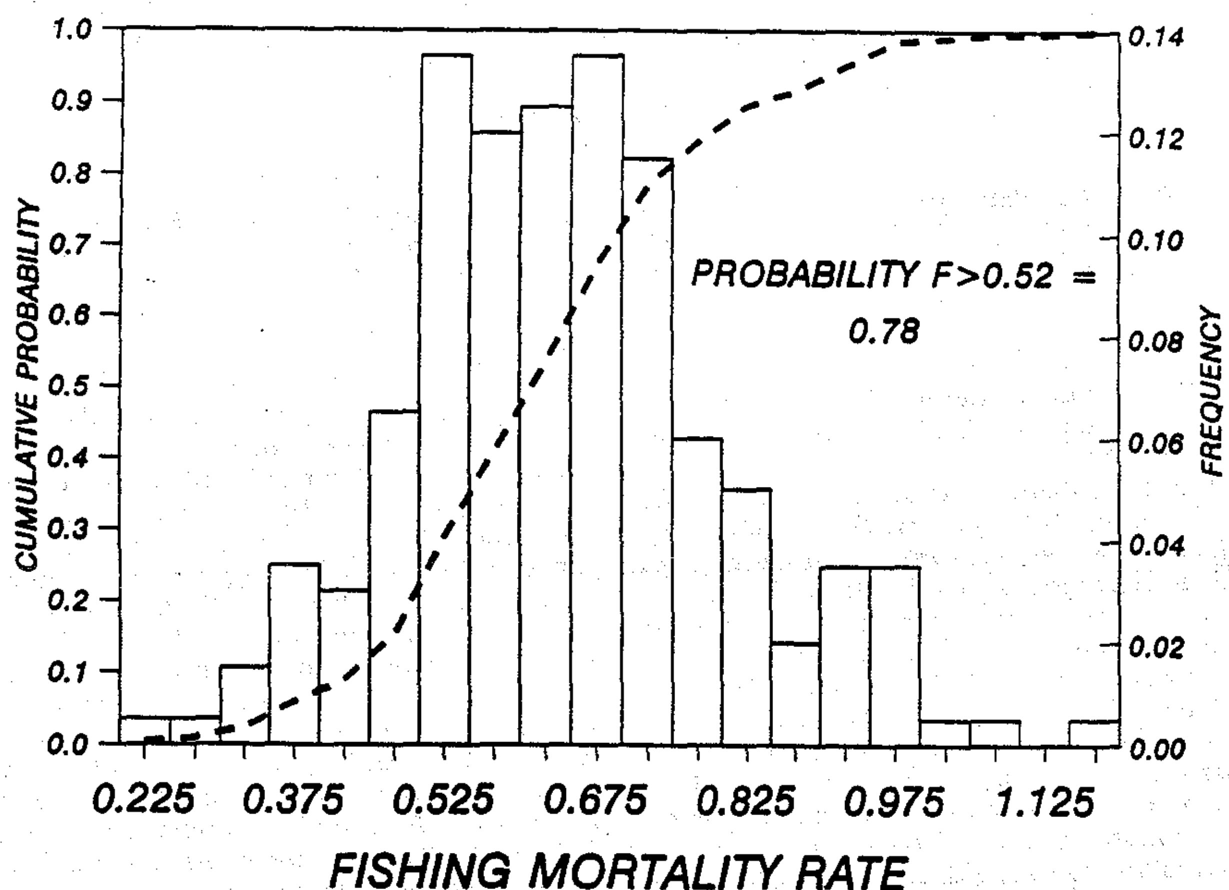

Figure D13. Bootstrap estimates of average fishing mortality rates (1989-1991) for female lobsters in the Gulf of Maine assessment area. The probability that F exceeds the reference overfishing level is 0.78.

Table D15. Indices of prerecruit and fully-recruited stock size (numbers per tow from NMFS autumn bottom trawl surveys) and total landings (millions of female lobsters) in the Georges Bank and South offshore assessment area by survey years (Q4 year i + Q1, Q2, Q3 of year i+1)

Survey Year	Indices of Abundance		Total Landings
	Recruits	Fully-Recruited	
1979	0.0940	0.3302	0.949159
1980	0.0816	0.3169	1.090160
1981	0.1243	0.3403	1.415728
1982	0.1311	0.3588	2.025416
1983	0.1268	0.2849	3.451745
1984	0.1194	0.3218	4.918873
1985	0.1728	0.2485	6.859152
1986	0.1735	0.3122	5.949321
1987	0.0989	0.2121	6.231778
1988	0.1007	0.3223	5.135940
1989	0.1693	0.3303	5.095941
1990	0.2133	0.3467	2.803984
1991	0.0996	0.4064	1.771617
1992	0.1883	0.3392	

sample sizes that would be necessary to detect significant changes (a = 0.01) in length frequency distributions between years were evaluated. This analysis utilized the two-sample Kolmogorov-Smirnov test and assumed that the magnitude of the maximum difference (D_{max}) in cumulative distributions between years would be observed in the sample data. The annual sample size necessary to detect a change is $(2.3/D_{max})^2$. Examination of one- and two-year differences revealed that at least 2000 length measurements would be required in most years. The issue of the appropriate sampling stratification (*e.g.* division, quarter, *etc.*) was not resolved.

To minimize the effects of variable annual recruitment, three-year running average relative length frequencies were applied to estimated annual number of females landed, as recommended by Somerton and Kobayashi (1990). For example, the length frequency used for the 1991 analysis was derived by applying the 1990 to 1992 mean relative size class frequency to the 1991 estimate of total female landings.

Table D16. Estimates of stock size (numbers) fishing and total mortality rates and biomasses of Georges Bank and South offshore lobster (female), based on DeLury model run assuming selectivity of prerecruits and fully-recruited animals to NMFS survey gear is equal

Recruits =Size Class 1
Fully-Recruited =Size Class 2+

Survey Year	Stock Size Estimates (millions-Oct 1)		F on Size 1+	F on Size 1	F on Sizes 2+
	Recruits	Fully-Recruited			
1979	4.213	13.275	0.08	0.03	0.09
1980	3.644	14.639	0.09	0.03	0.10
1981	5.248	15.119	0.12	0.04	0.14
1982	5.374	16.410	0.15	0.06	0.19
1983	5.452	16.888	0.20	0.07	0.25
1984	5.228	16.500	0.28	0.10	0.34
1985	8.134	14.814	0.36	0.14	0.47
1986	8.113	14.552	0.31	0.12	0.41
1987	5.371	15.098	0.32	0.12	0.39
1988	5.237	13.428	0.29	0.11	0.37
1989	8.189	12.589	0.28	0.11	0.38
1990	9.490	14.267	0.14	0.06	0.19
1991	4.525	18.693	0.10	0.03	0.11
1992	8.879	19.033			

Survey Year	Biomass Estimates (mt, Oct. 1)				Catch Biomass During Survey Year (mt)
	Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	
1979	1264	14632	15896	15006	690
1980	1054	19421	20475	19733	1203
1981	1490	16292	17781	16734	1733
1982	1579	17992	19571	18460	1493

[1] D. Pezzack, Department of Fisheries and Oceans-Canada, P.O. Box 55, Halifax, NS B3J 2S7.

Table D16. Continued.

Survey Year	Biomass Estimates (mt, Oct. 1) Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	Catch Biomass During Survey Year (mt)
1983	1609	19892	21501	20369	1997
1984	1621	13619	15240	14100	2575
1985	2482	17124	19605	17860	2611
1986	2405	12436	14841	13149	2865
1987	1627	15597	17224	16079	3036
1988	1682	13757	15438	14255	1900
1989	2562	14177	16739	14937	1707
1990	2941	13493	16434	14366	2399
1991	1402	21257	22659	21673	1557
1992	2904	22366	25270	23228	

Table D17. Estimates of stock size (numbers) fishing and total mortality rates and biomasses of Georges Bank and South offshore lobster (female), based on DeLury model run assuming selectivity of pre-recruits 0.5 that of fully-recruited lobsters to NMFS survey gear

Recruits =Size Class 1
Fully-Recruited =Size Class 2+

Survey Year	Stock Size Estimates (millions-Oct 1) Recruits	Fully-Recruited	F on Size 1+	F on Size 1	F on Sizes 2+
1979	3.111	4.957	0.17	0.07	0.23
1980	2.700	6.178	0.18	0.07	0.23
1981	3.732	6.685	0.22	0.09	0.29
1982	3.866	7.595	0.27	0.11	0.35
1983	4.164	7.916	0.38	0.15	0.50
1984	4.216	7.504	0.56	0.22	0.75
1985	7.238	6.045	0.72	0.35	1.17
1986	6.957	5.853	0.62	0.30	1.01
1987	5.772	6.226	0.69	0.31	1.04
1988	4.988	5.456	0.65	0.29	0.98
1989	6.497	4.940	0.59	0.29	0.99
1990	6.716	5.727	0.29	0.14	0.47
1991	3.507	8.429	0.19	0.07	0.24
1992	7.350	8.900			

Survey Year	Biomass Estimates (mt, Oct. 1) Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	Catch Biomass During Survey Year (mt)
1979	933	5464	6397	5741	690
1980	781	8196	8978	8428	1203
1981	1059	7204	8263	7518	1733
1982	1136	8327	9463	8664	1493
1983	1228	9324	10553	9689	1997
1984	1307	6194	7502	6582	2575
1985	2208	6988	9196	7643	2611
1986	2062	5002	7064	5614	2865
1987	1749	6432	8181	6951	3036
1988	1602	5590	7191	6065	1900
1989	2032	5563	7595	6166	1707
1990	2081	5417	7498	6034	2399
1991	1086	9586	10672	9908	1557
1992	2404	10458	12862	11172	

Table D18. Indices of prerecruit and fully recruited stock size (numbers per tow from Rhode Island bottom trawl surveys) and total landings (millions of female lobsters) in the South of Cape Cod-Long Island Sound inshore assessment area, presented for survey years (Q4 year i + Q1, Q2, Q3 of year i+1).

Survey Year	Indices of Abundance		Total Landings
	Recruits	Fully-Recruited	
1979	0.0960	0.0240	1.785189
1980	0.6380	0.0710	1.387242
1981	0.6400	0.0910	1.715388
1982	0.2060	0.0120	3.206920
1983	0.2900	0.0940	3.436386
1984	0.4910	0.2120	3.494189
1985	0.6310	0.0150	3.477153
1986	0.4000	0.0370	3.397401
1987	1.5270	0.3300	3.538575
1988	0.9510	0.2190	4.099118
1989	1.3830	0.2850	4.479324
1990	1.1020	0.1550	4.746186
1991	0.7680	0.1930	4.470257
1992	1.3280	0.2510	

The Pope (1972) cohort analysis model assumes that catch is removed from the population at mid-year:

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

where:
N: cohort size,
t: time (y),
M: natural mortality, and
C: landings.

The annual recruitment schedule for Gulf of Maine lobster provides evidence that majority of lobster landings in the Gulf of Maine are taken in the later months of the year. Accordingly, a modified model,

$$N_{t+1} = (N_t e^{-0.7M} - C_t)\, e^{-0.3M}$$

was used that assumes removal in mid-August. Sensitivity of estimates to this adjustment are reported next.

A length-based approach to cohort analysis (Jones 1974) used von Bertalanffy growth parameters to estimate the average time to grow from one length to a larger length (Nt):

$$N_{l+\Delta l} = (N_l e^{-0.5M\Delta t} - C_{l,l+\Delta l})e^{-0.5M\Delta t}$$

where

$N_{l+\Delta l}$ = the number of animals growing from length l to length $l+_{\Delta l}$.

Estrella and Cadrin (1991) reported that estimates of instantaneous fishing mortality (F) for Gulf of Maine lobster using the Jones model were very sensitive to growth parameter estimates. A more appropriate estimation of lobster growth based on growth increment and molt probability (as in Fogarty and Idoine 1988) was employed to estimate Nt for 5 mm size classes.

The modified length-based cohort analyses used 0.8 as a terminal estimate of total instantaneous mortality (Z, from SAW-14 DeLury analysis), and 0.1 instantaneous natural (M, from Thomas 1973). Length frequencies, estimated number in sea, F at size, and weighted average F for 1981 and 1992 are listed in Table D20. Annual estimates of weighted Fs are plotted in Figure D15.

Sensitivity of estimates to input parameters was assessed using the 1991 running average run (Table D21). The possible bias of underestimating offshore landings was assessed by removing area 515 landings from the 1991 analysis. The result was fewer large lobster and an increase in estimated weighted average F of 0.04.

Increasing terminal F to 2.5 or decreasing it to 0.2 had no appreciable effect on weighted average F. Increasing M to 0.15 caused a proportional decrease in weighted average F. Using catch at mid-year, increased weighted average F by 0.25.

The implementation of LCA for American lobster populations was improved significantly with the inclusion of length increments from the molt increment data, rather than assuming van Bertalanffy growth. The method produces estimates of fishing mortality substantially greater than the 1+ group Fs from DeLury methods. However, when compared to 2+ group DeLury estimates, the two sets of Fs are more comparable. In particular, if the assumption of differential selectivity of prerecruits and fully-recruited sizes (ratio of 0.5) holds, then the estimated of F produced by LCA and DeLury are nearly identical (LCA average for 1990 to 1992 = 1.36; DeLury (S_R=0.5) average F for 1989 to 1991 (survey years, size group 2+) = 1.34. Nevertheless, given the relatively poor catch sampling of offshore catches in the Gulf of Maine and the lack of definitive analysis of trawl selection of various size classes of lobsters, these comparisons are considered provisional. Because of the relative stationarity of length compositions over time, an intensive experiment to collect better offshore

Table D19. Estimates of stock size (numbers), fishing and total mortality rates, and biomasses of South of Cape Cod-Long Island Sound inshore lobster (females), based on DeLury model run assuming prerecruits and fully-recruited lobsters have equal selectivity to survey gear

Recruits =Size Class 1
Fully-Recruited =Size Class 2+

Survey Year	Stock Size Estimates (millions-Oct 1)		F on Size 1+	F on Size 1	F on Sizes 2+
	Recruits	Fully-Recruited			
1979	1.908	0.160	1.80	1.52	5.13
1980	1.829	0.309	1.36	1.01	3.42
1981	1.321	0.496	3.02	1.83	6.18
1982	3.634	0.080	1.83	1.74	5.88
1983	3.816	0.537	1.37	1.06	3.57
1984	2.606	1.003	3.59	2.17	7.30
1985	3.643	0.090	2.69	2.54	8.57
1986	4.441	0.230	1.12	1.00	3.38
1987	4.860	1.380	1.20	0.79	2.66
1988	4.356	1.697	1.26	0.76	2.55
1989	4.467	1.558	1.59	0.99	3.33
1990	5.149	1.109	1.50	1.06	3.56
1991	4.814	1.266	1.31	0.88	2.97
1992	7.951	1.478			

Survey Year	Biomass Estimates (mt, Oct. 1)				Catch Biomass During Survey Year (mt)
	Recruits	Fully-Recruited	Total Biomass	Exploited Biomass	
1979	608	76	684	256	981
1980	626	189	816	375	758
1981	454	242	696	376	945
1982	1222	41	1264	404	1775
1983	1376	275	1650	683	1890
1984	913	581	1494	852	1913
1985	1261	51	1312	425	1895
1986	1521	105	1626	556	1857
1987	1647	734	2381	1223	1969
1988	1580	1031	2611	1500	2316
1989	1579	754	2332	1222	2530
1990	1930	603	2533	1175	2666
1991	1768	667	2435	1191	2474
1992	3183	821	4004	1765	

length composition data could yield valuable insights into inshore/offshore distributions.

BIOLOGICAL REFERENCE POINTS

Biological reference points used in the assessment and management of lobster populations are based on yield and egg production per recruit analyses. The overfishing definition for American lobster adopted by the New England Fishery Management Council specifies that the resource will be considered overfished when the egg production per recruit is reduced to 10% of the unexploited state throughout the range (NEFMC 1991). The method used in the current assessment is based on the size-structured model described by Fogarty and Idoine (1988). Basic components of the model include size-specific annual molt probabilities, molt increments, egg bearing proportions, fecundities and weights. Growth is determined by the combination of the annual molt probability and increment. The analysis was carried out individually for each of the three assessment areas. For the purposes of the present analysis, several modifications were made to the original formulation to account for regulations specific to lobster fisheries in the Gulf of

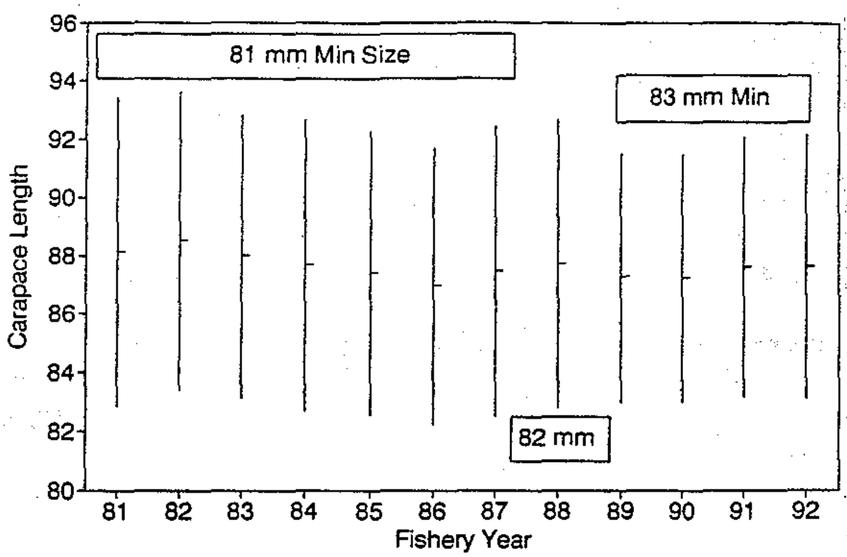

Figure D14. Mean ± one standard deviation of size frequencies from female American lobsters landed from the Gulf of Maine assessment area, 1981-1992.

Table D20. Results of length-based cohort analyses for female lobsters from the Gulf of Maine assessment area for 1981 and 1992

1981

Length Group	Number Landed	Number In Sea	Mean Number	F/Z	ZDT	FDT	Z	DT	F
141-145	0.100E+01	0.126E+01							
136-140	0.100E+01	0.276E+01	0.192E+01	0.669	0.781	0.522	0.302	2.275	0.202
131-135	0.500E+01	0.919E+01	0.535E+01	0.777	1.204	0.935	0.448	2.098	0.348
126-130	0.700E+01	0.191E+02	0.136E+02	0.703	0.734	0.516	0.337	1.921	0.237
121-125	0.639E+04	0.725E+04	0.122E+04	0.885	5.936	5.251	0.867	1.743	0.767
116-120	0.266E+05	0.381E+05	0.186E+05	0.861	1.661	1.429	0.717	1.566	0.617
111-115	0.315E+05	0.786E+05	0.560E+05	0.780	0.723	0.564	0.455	1.388	0.355
106-110	0.110E+06	0.208E+06	0.133E+06	0.847	0.975	0.826	0.654	1.211	0.554
101-105	0.162E+06	0.405E+06	0.296E+06	0.823	0.665	0.548	0.566	1.033	0.466
96-100	0.451E+06	0.920E+06	0.628E+06	0.876	0.820	0.718	0.803	0.856	0.703
91-95	0.257E+07	0.368E+07	0.199E+07	0.931	1.387	1.292	1.455	0.679	1.355
86-90	0.472E+07	0.876E+07	0.586E+07	0.930	0.866	0.805	1.419	0.501	1.319
81-85	0.438E+07	0.135E+08	0.110E+08	0.919	0.435	0.400	1.227	0.324	1.127
TOTAL	0.125E+08		0.200E+08					Wtd. Ave. F	1.215

1992

Length Group	Number Landed	Number In Sea	Mean Number	F/Z	ZDT	FDT	Z	DT	F
138-143	0.484E+03	0.618E+03							
133-138	0.874E+04	0.179E+04	0.110E+04	0.747	1.062	0.794	0.396	2.187	0.296
128-133	0.112E+04	0.348E+04	0.254E+04	0.665	0.666	0.443	0.298	2.009	0.198
123-128	0.108E+05	0.164E+05	0.834E+04	0.832	1.552	1.291	0.596	1.832	0.496
118-123	0.356E+05	0.593E+05	0.334E+05	0.829	1.283	1.064	0.586	1.654	0.486
113-118	0.186E+05	0.894E+05	0.733E+05	0.619	0.411	0.254	0.262	1.477	0.162
108-113	0.707E+05	0.179E+06	0.129E+06	0.787	0.696	0.547	0.469	1.300	0.369
103-108	0.972E+05	0.306E+06	0.237E+06	0.769	0.534	0.410	0.433	1.122	0.333
98-103	0.178E+06	0.526E+06	0.406E+06	0.807	0.543	0.439	0.519	0.945	0.419
93-98	0.177E+07	0.244E+07	0.125E+07	0.927	1.533	1.421	1.369	0.767	1.269
88-93	0.627E+07	0.912E+07	0.507E+07	0.938	1.319	1.238	1.620	0.590	1.520
83-88	0.734E+07	0.171E+08	0.127E+08	0.925	0.626	0.579	1.326	0.412	1.226
Total	0.158E+08		0.119E+08					Wtd. Ave.	1.326

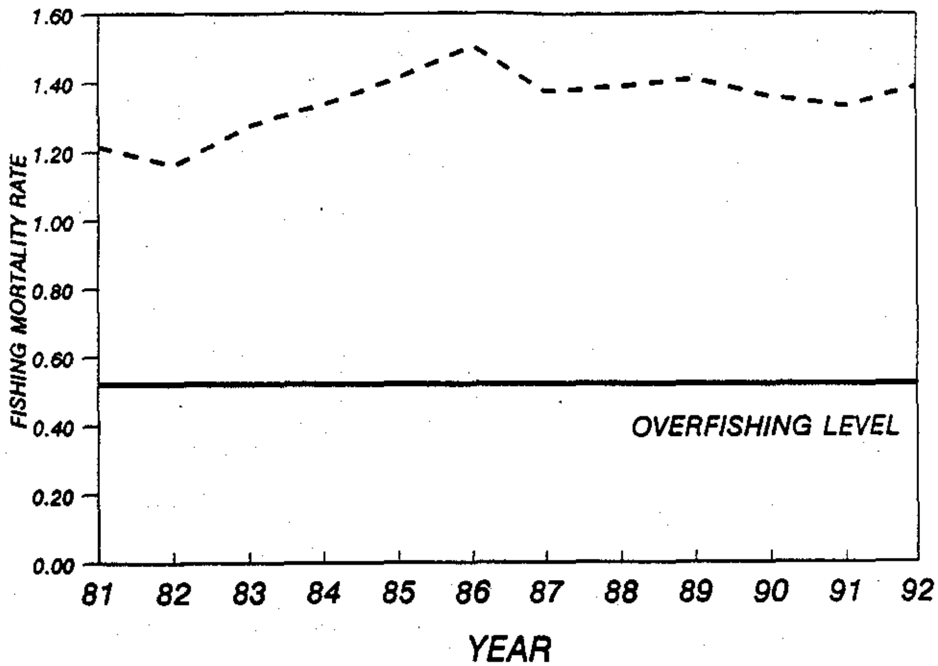

Figure D15. Calculated fishing mortality rates for female American lobster from the Gulf of Maine assessment aream 1981-1992. Results are annual, estimated from length-cohort analyses.

Table D21. Estimated fishing mortality rates for female lobsters from the Gulf of Maine assessment area, based on length cohort analyses, presented for single year and running averages of three-year intervals[1]

Year	1-Year Runs Runs	3-Year Runs Runs
1981	1.215	
1982	1.162	1.213
1983	1.276	1.249
1984	1.337	1.338
1985	1.415	1.412
1986	1.504	1.428
1987	1.376	-
1988	1.391	-
1989	1.411	-
1990	1.360	1.366
1991	1.333	1.337
1992	1.326	

Sensitivity Runs(using 1991 data only):

(1). Remove landings at size from area 515:F=1.379

(2) Set M = 0.15: F = 1.286

(3) Set Terminal F = 2.5: F = 1.337

(4) Set Terminal F= 0.2: F = 1.336

(5) Set t = 0.5: F = 1.591

[1] Sensitivity runs are summarized in the table. Three-year average runs do not include 1988, the only year in which a 82 mm minimum size limit was in effect.

Maine including the practice of v-notching and the use of maximum legal size limits. V-notching is practiced traditionally in Maine but is not mandatory. Accordingly, we have used the fraction of landings in the Gulf of Maine attributable to Maine alone (71%) to adjust the analyses and have explored a range of levels of v-notching (0, 50 and 100%).

The results of the analyses of Fogarty and Idoine (1988) for female lobsters were expressed in terms of the nominal fishing mortality rate. Since a significant portion of this resource is protected from exploitation at various points in the individual's life history (including berried and v-notched, and minimum and maximum sizes), the vulnerable portion of the population changes, and thus the actual mortality on the population diverges from the nominal rate. For comparison with fishing mortality rates actually imposed on the population(s) (such as those calculated by the DeLury analyses), it will be necessary to express the biological reference points in terms of the realized fishing mortality rates after adjustment for those regulations which remove some females from the fishable population. Nominal fishing mortality gives the catch, whereas the realized fishing mortality gives the landings after the catch is decremented for egg bearing, v-notch, and lobsters the maximum size. We assumed that those female lobsters that are berried are in

Table D22. Parameters used for calculating biological reference points for three assessment areas for female American lobster

Parameter		**Assessment Area**		
		Gulf of Maine	**Georges Bank and South**	**South of Cape Cod to Long Island Sound**
Molt Probability[1]	α	-8.08127	-6.867	-13.39
	β	0.076535	0.058	0.1459
Molt Increment (mm)		11	14	11
Fecundity[2]	α	0.0010178	0.00658	0.0005046
	β	3.58022	3.1569	3.7580
Proportion[3] Mature	α	18.3270	18.256	9.720
	β	-0.1957	-0.18299	-0.1032
Proportion V-Notched		1.0; 0.5; 0.0	0.0	0.0
Min/Max Size (mm)		83/127	83/NA	83/NA
Proportion Max Size		0.71	0.0	0.0
Length/Weight[4]	α	0.001167	0.000833998	0.001365
	β	2.9194	2.972	2.88726
M		0.1	0.1	0.1

[1] Logistic model: $P_t = 1/[1 + \exp(\alpha + \beta CL)]$
[2] Power Function: $f = \alpha CL^{\beta}$
[3] Logistic model: $M_t = 1/[1 + \exp(\alpha + \beta CL)]$
[4] Power Function: $W = \alpha CL^{\beta}$

this condition for a nine month period; that v-notching is performed only on those that are berried and that the v-notch mark was no longer discernible after two molts. The realized rates will necessarily be lower than the nominal fishing mortality rates in these simulations. Realized rates were calculated on an annual basis by iteratively solving the catch equation for F based on the deaths due to fishing (catch) and the population size at the beginning of the period. These annual Fs were weighted (by population size) over the lifetime of the cohort, and the weighted average was considered to be the realized fishing mortality rate.

Parameter inputs were required for the probability of annual molting, molt increment, fecundity, the proportion mature, length-weight relationships and natural mortality rates. The parameters used in the analyses for each of the three assessment regions are provided in Table D22. Parameter inputs for the Georges Bank and south offshore region are derived from Fogarty and Idoine (1988). Estimates of molt probability for the Gulf of Maine region were based on tagging studies in the Gulf of Maine and Scotian Shelf (D. Pezzack, personal communication). Molt probability information for the SCCLIS-I region were based on unpublished tagging studies conducted by the Rhode Island Department of Environmental Management. Information on length-weight relationships and fecundity for the Gulf of Maine and for SCCLIS-I was based on studies conducted by the Massachusetts Division of Marine Fisheries. In addition to results reported here, the Subcommittee also evaluated the sensitivity of these results to alternative assumptions of natural mortality rates.

Biological reference points, including the fishing mortality rate resulting in maximum yield recruit (F_{max}) and the level of fishing mortality resulting in reduction to 10% of the maximum egg production per recruit ($F_{10\%}$) were calculated for each of the three assessment areas. The relationships between yield and egg production per recruit and fishing mortality rate are provided in Figures D16 to D18 and Table D23. Calculated

F_{max} and $F_{10\%}$ EPR values for female lobsters from the Gulf of Maine assessment areas, under various assumptions of fractions of egg-bearing lobsters caught that are v-notched by Maine fishermen are given below (F values are realized rates for the stock, nominal F values resulting in the realized rates are given in parentheses):

Percent V-Notched	F_{max}	$F_{10\%}$ EPR
100	0.26 (0.43)	0.55 (0.78)
50	0.29 (0.41)	0.52 (0.67)
0	0.31 (0.39)	0.50 (0.59)

For the Gulf of Maine, the key run of yield and egg-production per recruit assumed a 50% v-notching rate. The 50% v-notching rate is a measure of the proportion of egged females that are actually v-notched by Maine fishermen. Since v-notching is not mandatory, this was assumed to be a reasonable level for the region. As stated

Table D23. Summary of estimated biological reference points ($F_{10\%}$ EPR, F_{max}) and current estimates of fishing mortality for three assessment areas for American lobster

Area	$F_{10\%}$ EPR	F_{max}	Average F (1989-1991)
Gulf of Maine	0.52	0.29	0.65
Georges Bank and South	0.44	0.15	0.24-0.51[1]
South of Cape Cod to Long Island Sound	0.68	0.38	1.47

[1] Averages for 1988-1990, assuming two levels of selection of prerecruits to survey gear.

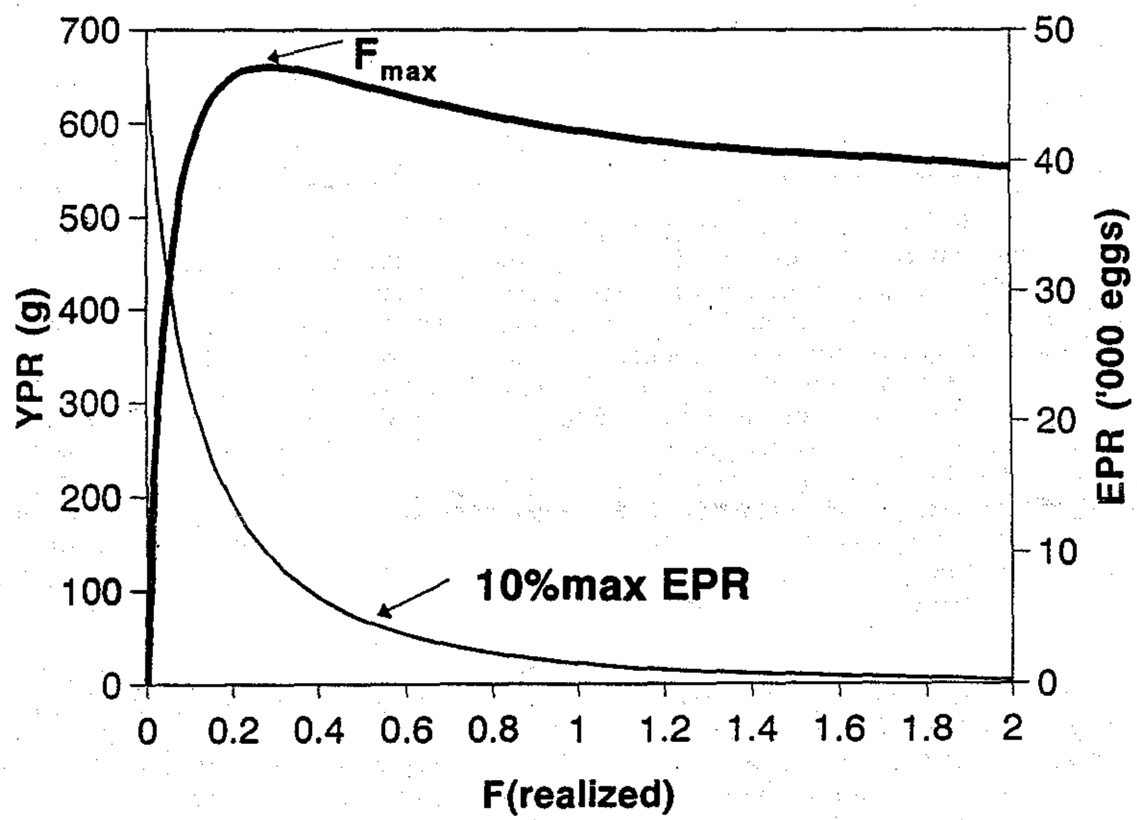

Figure D16. Calculated yield and egg production per recruit for female American lobsters from the Gulf of Maine assessment area assuming a 50% v-notching rate by Maine fishermen.

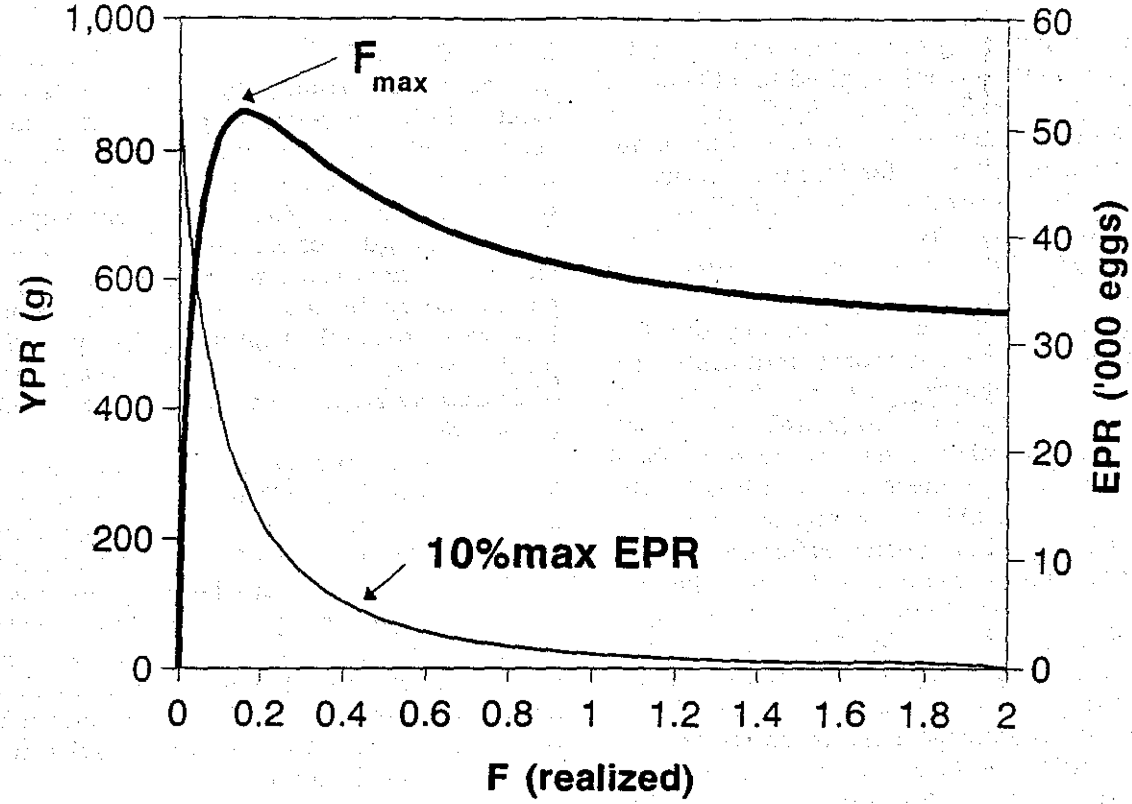

Figure D17. Calculated yield and egg production per recruit for female American lobsters from the Georges Bank and South-Offshore assessment area.

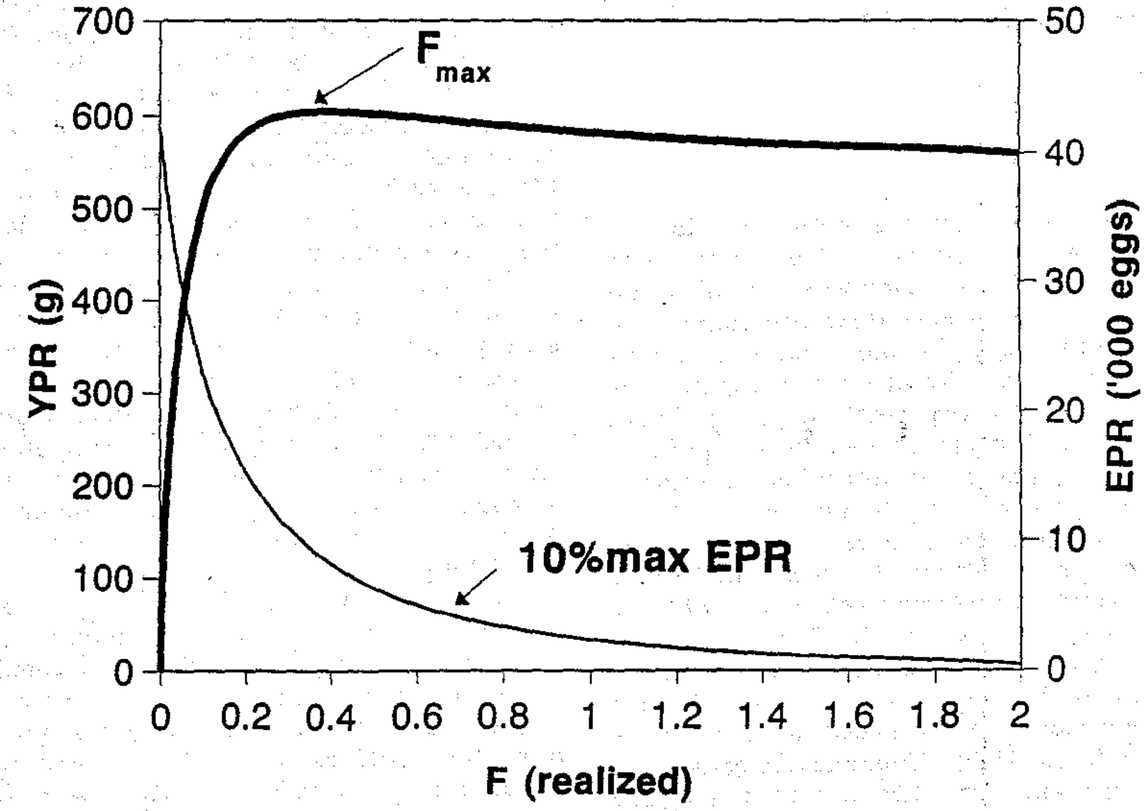

Figure D18. Calculated yield and egg production per recruit for female American lobsters from the South of Cape Cod to Long Island Sound-Inshore assessment area.

above, the v-notching and maximum size (127 mm CL) protections were applied to 71% of the animals, since these programs apply only to the state of Maine (which averages 71% of the landings in the Gulf of Maine for this time period).

For the GBS-O region, the $F_{10\%}$EPR level is 0.44 and for the inshore southern New England region is 0.68. The F_{max} levels are: Georges Bank = 0.15, SCCLIS-I = 0.38.

Differences in the resultant biological reference points from the last assessment (SARC 14) are due to the following reasons. The Gulf of Maine $F_{10\%}$ dropped from 1.0 (SARC 14) to 0.52. This is due to several reasons. The current model utilizes growth parameters better suited for the Gulf of Maine, and allows for only 50% v-notching. Additionally, the biological reference point in this study is explicitly calculated as a realized F, not nominal. The differences in the Georges Bank values are small. The SARC 14 value of 0.44 was a nominal value based on a combination of molting and hardshell natural mortalities. Additionally, the average molt increment was reexamined and found to be 14 mm as opposed to the 15 mm value use last time. The SCC-LIS values are new analyses, and were not attempted last time. Provisional growth parameters, given the lack of specific knowledge of molt probability were used for this area. Therefore, the calculated reference points for the SCCLIS-I area are provisional.

DISCUSSION

Recent annual landings of American lobster are at record high levels. The increases in landings during this period are a result of an apparent increase in recruitment, combined with increasing fishing effort, particularly in the inshore pot fisheries. Total lobster landings declined by 13% during 1992, with significant reductions occurring in all major lobster-producing states. Reductions in Gulf of Maine landings were accompanied by significant declines in inshore CPUE and research vessel trawl survey indices for prerecruit and fully-recruited sizes. Relative abundance indices elsewhere did not decline as drastically as in the Gulf of Maine.

Fishing mortality rates on the female component Gulf of Maine stock, based on DeLury population modeling, increased nearly 50% between 1983 and 1991. This trend is consistent with increases in total fishing effort in the region. The average calculated fishing mortality rate of the Gulf of Maine stock over the period 1989 to 1991 is 0.65 (80% CI = 0.47 to 0.87). The major source of uncertainty in DeLury estimates is related to the selection of prerecruits and fully-recruited sizes by the survey gears. Estimates of fishing mortality based on length cohort analysis of the integrated (inshore + offshore) population is 1.3. Length cohort analyses estimates are similar in magnitude to fishing mortality rates calculated by the DeLury method for the portion fully-recruited at the beginning of the year. Based on the overfishing definition of F=0.52, the Gulf of Maine stock is considered to be overfished (Table D23).

Calculated apparent fishing mortality rates for the South of Cape Cod to Long Island inshore assessment area were extremely high throughout the period (Average F = 1.47 during 1989 to 1991). Abundance and landings in this area increased significantly in recent years, with the exception of 1992. These Fs may be overestimated if a net emigration is occurring. Nevertheless, under any reasonable emigration scenario, this component of the resource is substantially overfished (Table D23).

Calculated fishing mortality rates for the GBS-O assessment area were 0.24 to 0.51 for the three year average, 1988 to 1990 (under two assumptions of size selection by the R/V trawl survey). These calculated values are near the overfishing definition for the offshore GBS-O stock of 0.44 (Table D23). Given that there is some movement of inshore southern lobsters to the offshore stock, F is likely underestimated by assuming a separate offshore component. Combined assessments of the two southern areas were attempted, but are greatly dependent on which research vessel survey series are used for calibration. The inshore Rhode Island survey results in very high Fs, while the NMFS offshore survey produces lower Fs. In the absence of definitive stock identification studies, a cautious approach to exploiting the offshore region is warranted. Since the inshore component is clearly overfished, and the offshore component is at or near the overfishing definition, the southern resource in aggregate is considered to exceed the overfishing level.

Biological reference points of F_{max} and $F_{10\%}$ EPR (F level producing 10% of the maximum level of egg production per recruit) were recalculated for the three assessment areas, based on updated biological information, and incorporating protections such as egg-bearing, v-notching and maximum size limits for the Gulf of Maine stock. The most likely level of $F_{10\%}$ EPR for the Gulf of Maine stock is 0.52, and F_{max} is 0.29. Reference fishing mortality rates for the SCCLIS-I area are: $F_{10\%}$ EPR = 0.68; F_{max} = 0.38. Reference levels for the GBS-O areas are: $F_{10\%}$ EPR = 0.44; F_{max} = 0.15 (Table D23).

The Gulf of Maine stock currently generates about 71% of annual landings, while the SCCLIS-I assessment area contributes about 14%. Since both of these stock components (contributing 85% of the landings) are determined to have fishing mortality rates in excess of the overfishing level, and the Georges Bank-Southern New England offshore is near the overfishing level, the aggregate resource is determined to exceed the reference overfishing level.

SARC COMMENTS

Recent increases in landings to record levels in 1991, followed by substantial declines in 1992 have been observed in southeast Canadian waters (-20%, D. Pezzack, pers. comm. 1993), and in the United States. Factors responsible for similar trends in landings over the whole area are poorly understood, but need further evaluation.

Examination of diagnostics from DeLury model fits for the Gulf of Maine stock indicate some patterning in residuals, perhaps indicating some misspecification of the model. The influences of environmental factors on catchability and other potential causes of this behavior should be examined in more detail. Similarly, there was concern that variations in prerecruit abundance didn't necessarily correlate well with fluctuations in fully-recruited stock abundance in the trawl survey catch.

The lack of definitive stock identification information (particularly for the area from Georges Bank south) confounds the process of providing region-wide management advice. Clearly, nearshore resources are overfished, and offshore southern resources are near the overfishing definition. Although limited tagging data suggest offshore movements, exploitation rates inshore are so high that few tagged animals are alive long enough to be captured offshore. Alternative methods, such as biochemical studies, could potentially help in resolving the question of southern stock definition.

RESEARCH RECOMMENDATIONS

- Results of these analyses have emphasized the need to resolve the question of stock identification, particularly as related to inshore/offshore components south of Georges Bank. Appropriate genetic studies are highly recommended and a compilation and analysis of existing tagging data should be undertaken prior to any new tagging studies.

- The biological characteristics of catches and landings are sampled very unevenly over the range of the species. In particular, sampling in offshore areas is minimal and enhanced sea sampling and/or port sampling of offshore catches is urgently needed.

- Estimates of biological reference points for the Gulf of Maine stock are partly influenced by the assumed level of v-notching undertaken by area fishermen. No adequate estimate of the proportional compliance with this voluntary measure now exists. Results of a credible study will reduce uncertainty in biological reference points and is so recommended. Sensitivity analyses under three widely varying assumptions of the rate of v-notching by Maine fishermen, indicate that calculations of EPR reference points are relatively insensitive to v-notching.

- More precise and accurate DeLury model estimates of stock sizes and fishing mortality rates can be made if the question of the relative selectivity of prerecruit and fully-recruited sizes to the bottom trawl survey gear is resolved. Appropriate field studies of lobster availability and research vessel gear selectivity are considered a priority.

- This assessment only considered the female segment of the lobster populations. Similar analyses should be extended to male components.

- The inclusion of multiple survey indices in DeLury population models is important for refining estimates of stock size and F, and should be explored.

- Combined analyses of inshore and offshore southern stocks produced intermediate results, and were sensitive to which research vessel survey series (Rhode Island inshore or NEFSC offshore) was used for DeLury modeling. Quantitative methods for combining assessment results and reference points for multiple stock areas are necessary for providing region-wide assessment advice for the American lobster resource throughout its range.

- Length cohort analyses should be extended to the two southern stock areas, contingent upon adequate length sampling data.

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G. TILEFISH

TERMS OF REFERENCE

The following term of reference was addressed:

- Review data possibilities for developing overfishing definitions.

REVIEW OF DATA POSSIBILITIES FOR OVERFISHING DEFINITION

Limited stock assessment data are available for the development of an overfishing definition for tilefish. The most promising approach to date appears to be based on a nonequilibrium surplus production-type model applied to a CPUE time series constructed from information from the longline fishery from 1973 to the present. Results to date must be interpreted cautiously, however.

Data quality appears inadequate to support development of an overfishing definition for tilefish based on direct estimates of minimum SSB and/or stock-recruitment data unless fairly arbitrary criteria are used. A VPA developed by Turner (1986) is based on only six years of catch data. There are also no recent age data or length data collected to update the VPA. This precludes reasonable fitting of stock-recruitment relationships, and estimates of F_{med} (or similar points) would be based on a small ten-year-old data set. In addition, unless tilefish sampling were increased and aging undertaken, there would be no way to evaluate the current situation relative to an overfishing definition in terms of either SSB or F.

The use of the yield per recruit model to produce estimates of F_{max} is a possibility. The major uncertainties and drawbacks are the changes in life history parameters detected by Turner (1986) between the 1977 to 1981 period and 1982, which resulted in different values of F_{max}. The decrease in the population abundance (based on CPUE) since 1982 suggests that life history parameters may have also changed in recent years. The consequence would be a potential error in the biological reference point. The problem of measuring the current F relative to the biological reference point still exists. Increased monitoring and sampling would be required to collect the appropriate information.

The Southern Demersal Subcommittee and the SARC reviewed the applicability of a nonequilibrium surplus production model to tilefish. The model, as implemented in the computer software package ASPIC by Prager (1991), represents a modification of the Schaefer (1954, 1957) model whereby the requirement for equilibrium conditions is relaxed and ancillary information can be incorporated to calibrate stock abundance. Unfortunately, this latter capability cannot be used with tilefish as no fishery-independent sources of information exist. Fishery independent surveys, routinely conducted by NEFSC since 1963, fail to sample the deep offshore regions where tilefish are caught by commercial longline gear, due to trawl gear configuration, including roller gear. Despite the high total landings of tilefish in the last two decades, sampling of the commercial fishery is intermittent and suitable length or age composition information does not exist. Reliable effort data are available however, and this information permits application of the surplus production model. In view of the overall paucity of existing data, and the long period that would be required to obtain relevant new information, the Subcommittee and the SARC noted that some form of surplus production model is the only feasible method for assessing stock status in the near-term.

APPLICATION OF A SURPLUS PRODUCTION MODEL

Catch and effort data from the longline fishery are available for 1973 to 1982 from logbook data maintained by fishermen from Barnegat, N.J. (Turner 1986); and for 1977 to 1992 from the NEFSC weighout data base, which included Montauk, N.Y. (the second principal tilefish port) in addition to Barnegat, N.J. Because the two original series were recorded in different units, a single series was constructed in four steps:

1. Effort data from 1977 to 1992 collected under the NEFSC weighout system were standardized using a general linear model (GLM) incorporating year and individual vessel effects.

2. Those annual effort data were raised, to reflect effort associated with regional land-

ings not reported under the weighout system.

3. That raised effort series was then related to the 1973-1982 (Barnegat, N.J.) series by a significant linear regression of points from the 1977-1982 period of overlap between the two series.

4. The 1973-77 period of the Barnegat, N.J. series was rescaled to units of the 1977 to 1993 series based on the linear regression relationship (Table G1, Figure G1).

The Southern Demersal Committee and the SARC reviewed one application of a nonequilibrium form of the surplus production model (Prager 1991) to tilefish. Based on estimated parameters from this model formulation, maximum sustainable yield (MSY) is estimated at around 1200 mt, substantially lower than previously estimated (2500 mt; Turner 1986) (Table G2). Fishing mortality rate at MSY was estimated to be approximately 0.11 at MSY (Table G2). Current biomass levels are at about 40% of the level producing MSY (Figure G2). Fishing mortality rates are currently about three times larger than F_{MSY} (Table G2, Figure G2). Relative levels of F (F_{1992}/F_{MSY}) and biomass (B_{1992}/B_{MSY}) are more accurately estimated by this model than absolute values of F_{1992}, F_{MSY}, B_{1992} or B_{MSY} alone.

The known life history aspects of tilefish however, warrant caution in interpretation of results. Tilefish are long-lived and the age structure of the population may induce lags in the response to fishing mortality. More complicated surplus production models might be applied, but the extra parameters required would likely reduce the generality of the conclusions in view of the 18 years of data available. Little is known about the variability of tilefish recruitment, but the model results suggest a maximum instantaneous rate of population biomass increase (r) on the order of 0.22 per year. The model fit is particularly imprecise for r, which may indicate a flat likelihood surface. As the predicted F_{MSY} is simply half of r, the Southern Demersal Subcommittee and the SARC suggested caution interpreting this model output.

The SARC felt additional caution was warranted in light of the number of parameters being estimated in the model version presented. If the number of parameters estimated is too large, parameter estimates may become correlated with each other, and lead to inaccurate parameter estimates and artificially good model fits. Additional exploration of model behavior was recommended (*e.g.*, the effect of estimating more parameters from auxiliary data and fewer parameters from the model).

A number of alternative approaches were considered to refine and verify the model results. Cross-validation of the model, perhaps by dividing the catch and effort time series into geographical regions, may assist in validation of this aspect of model performance. Simulation comparisons with age structured populations may also offer insights on the suitability of surplus production models to long-lived species. Another approach suggested was to compare tilefish life history parameters with predictive relationships derived from other species.

CONCLUSIONS

The only data currently available to develop an overfishing definition for tilefish are catch and effort data from the longline fishery. Estimates of F_{max} are outdated, and new data on mean weight, maturity, and partial recruitment at age are needed before F_{max} (or $F_{0.1}$ or $F_{\%MSP}$) can be recalculated. Data on the age and length structure of catch would also be needed to monitor fishing mortality rates. The catch and effort data can currently be used to estimate F_{MSY} and B_{MSY}, but the results will not be as precise or accurate as F_{max}-type estimates. Fishing mortality should be reduced at least 50% to rebuild stock size and increase yield, based on the first results from an MSY (surplus production) model. Caution should be used when interpreting those results, because questions about precision and accuracy of model results are still being investigated.

MAJOR SOURCES OF UNCERTAINTY

- The interview coverage of the fishery is very low, making effort estimates uncertain.
- The instantaneous rate of population biomass increase (r) is imprecisely estimated in this formulation. This imprecision leads to corresponding imprecision in F_{MSY}.
- The life history of tilefish indicates that longevity, and hence potential age structure, in the population may induce lags in response to fishing mortality. This may ultimately make surplus production models less suitable than age structured models.

Table G1. Results of effort standardization for tilefish 1973-1992 based on GLM with year and vessel effects (1977-1992) and rescaled logbook data (1973-1976)

Year	Total longline catch (mt)	Weighout std. CPUE	Total[1] adj. effort	Turner CPUE (1986)	Rescaled CPUE	Total[2] std. effort
1973	371			0.206	6.54	56.7
1974	553			0.135	4.37	126.5
1975	599			0.096	3.18	188.5
1976	1019			0.114	3.73	273.3
1977	1751	3.96	441.6	0.125		441.6
1978	3091	4.31	716.8	0.132		716.8
1979	3390	3.50	967.9	0.100		967.9
1980	3587	3.03	1184.1	0.091		1184.1
1981	3231	2.85	1132.5	0.090		1132.5
1982	1886	1.80	1049.1	0.051		1049.1
1983	1779	1.37	1297.2			1297.2
1984	1919	1.00	1927.8			1927.8
1985	1909	0.98	1948.3			1948.3
1986	1693	1.16	1461.8			1461.8
1987	3029	1.60	1887.5			1887.5
1988	1328	1.10	1206.6			1206.6
1989	437	0.81	537.5			537.5
1990	852	0.86	996.0			996.0
1991	1164	0.73	1599.2			1599.2
1992	1477	0.82	1799.6			1799.6

[1] Total adjusted effort 1977-1992 = total longline catch/weighout standardized CPUE.
[2] Total standardized effort 1973-1976 = total longline catch/rescaled CPUE, where rescaled CPUE is based on linear relationship between weighout standardized CPUE and Turner (1986) logbook CPUE, 1977-1982. CPUE is days fished, calculated as hours fished per longline set X number of sets/ 24 hours.

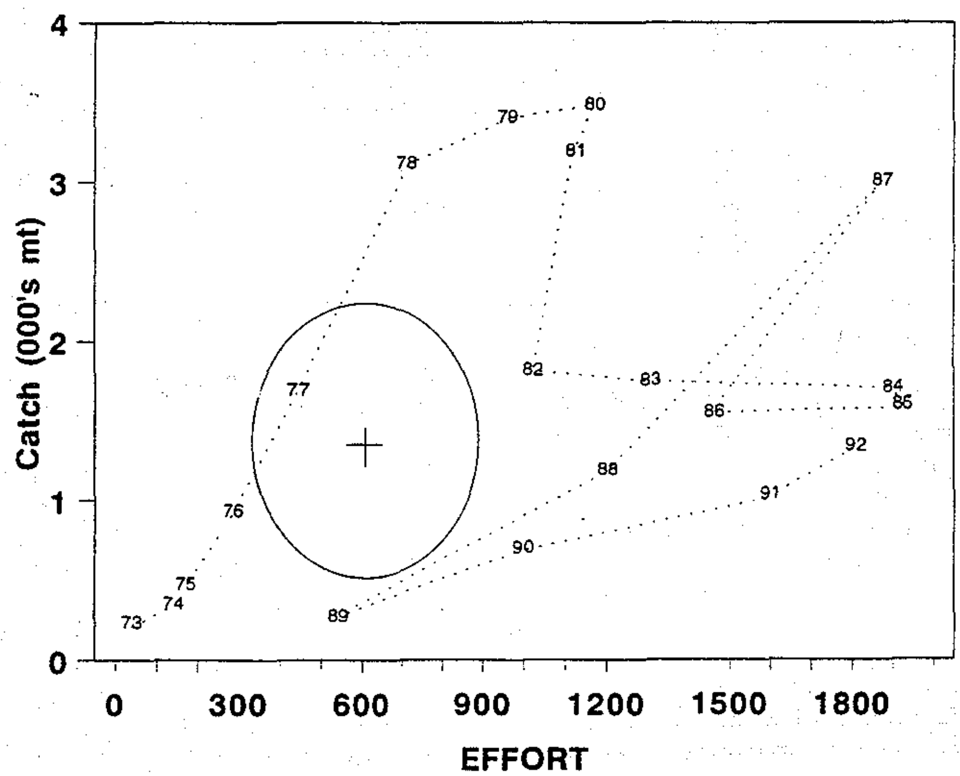

Figure G1. Catch and standard effort for tilefish longline fishery. 1973-1992. MSY and F_{msy} indicated within ellipse designating 95% CI.

Table G2. Nonequilibrium surplus production model (ASPIC) for tilefish 1973-1992, using standardized effort data[1,2]

Parameter	Estimate	Bootstrap Median	Nonparameter SE	Nonparameter CV
MSY	1,218 mt	1,345 mt	478.1	35.55%
SS @ MSY	11,020 mt	11,350 mt	2944	25.94%
F @ MSY	0.111	0.119	0.068	57.15%
f @ MSY	599.6	590.6	144.1	24.40%
B_1	25,090 mt	21,570 mt	8351	38.72%
K	22,040	22,700	5889	25.94%
r	0.221	0.238	0.136	57.15%
q	0.00018	0.0002	0.00007	34.74%

[1] Variability estimates based on bootstrap method using 101 trials. B1 equals initial biomass estimate, K equals carrying capacity of habitat, r equals the intrinsic rate of increase for the population, and q equals the catchability coefficient.
[2] The basic surplus-production model is:

$$dB_t/dt = rB_t - r/KB^2_t - qf_tB_t$$

where: B_t = biomass at time t; r = intrinsic rate of population increase; K = the carrying capacity.

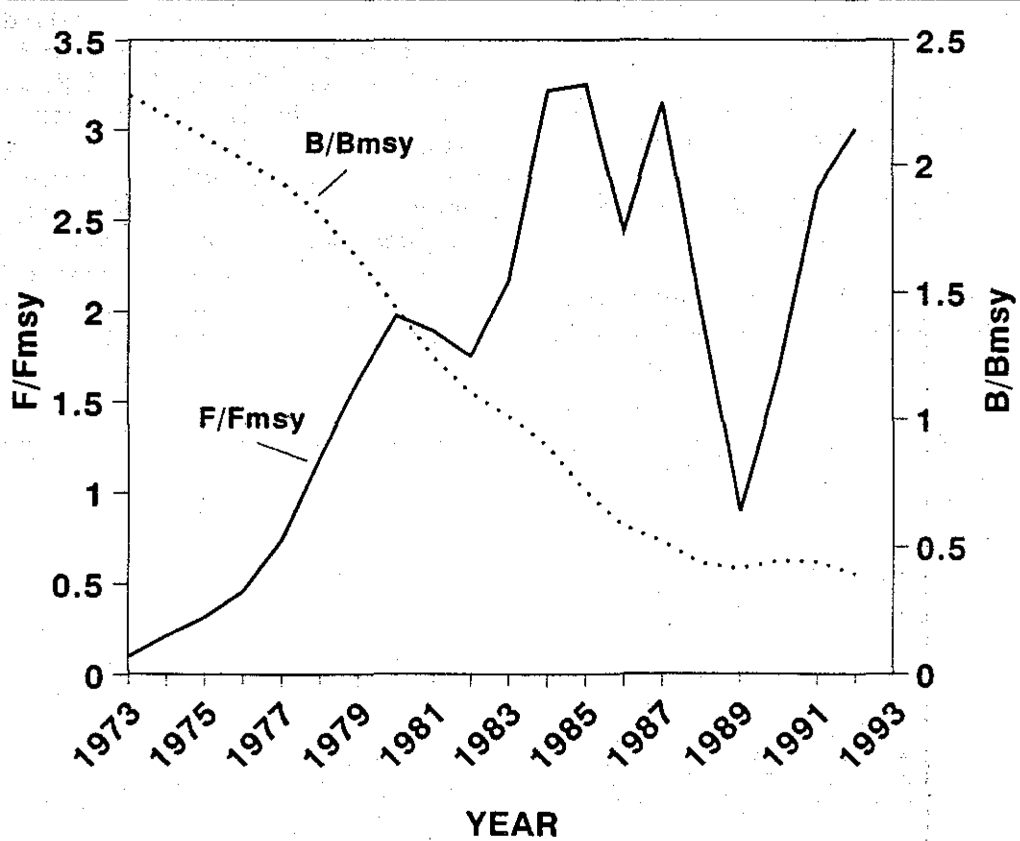

Figure G2. Ratios of estimated F/F_{msy} and Biomass/Biomass at MSY in the tilefish longline fishery, as determined from the surplus-production model.

- No information is currently available on number of hooks and hook spacing over time, which leads to uncertainty in estimating effort.

- If parameter estimates are correlated with each other (because too many parameters were estimated), parameters (*e.g.*, MSY, F_{MSY}, B_{MSY}) may not be accurate and may appear artificially precise.

RESEARCH RECOMMENDATIONS

- Incorporate auxiliary data to estimate parameters such as B_1 or r independent of the model.

- Incorporate effect of hook number and line length in estimates of CPUE if feasible and data are available.

- Collect data on age, maturity, and size composition from the fishery, to estimate mean weight at age, maturity at age and exploitation pattern, monitor fishing mortality rate, and evaluate changes in stock production rates.

- Encourage state and university participation in collection of biological data (*e.g.*, as noted above), if possible.

- Increase interview rate in tilefish fishery to improve accuracy of CPUE estimates.

- Investigate alternative appropriate surplus production formulations.

- Verify model results by cross-validating, *e.g.*, fitting model using only part of the data.

- Evaluate suitability of surplus production models for long-lived species by simulation. Compare results of surplus production models with age-structured population models.

- Compare tilefish life history parameters with predictive relationships derived from other species to investigate accuracy of r estimate.

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SARC ASSESSMENT METHODS SUBCOMMITTEE CANDIDATE TERMS OF REFERENCE

The following candidate terms of reference include explicit suggestions tabled during the SARC 16 Meeting (June 21-25, 1993); several items that by implication must be examined to address assessment issues raised at SARC 16; and suggestions that have arisen during previous SARC meetings. Although these terms of reference were prepared by the chairman of the Assessment Methods Subcommittee based on discussions at this meeting, the SARC did not review the draft due to lack of time.

The complexity and the amount of work needed to address these items varies greatly. The Methods Subcommittee meetings are likely to be about five days in duration. Although some preliminary studies may be carried out prior to Subcommittee meetings (depending upon the available time of Subcommittee members), it is likely that much of the intensive computing work will be done at the meetings. In this environment, it is unlikely that more than two issues can be addressed during a typical Subcommittee meeting. Some items are sufficiently substantive that they will need to be addressed as sole topics during a five-day Subcommittee meeting.

1. POTENTIAL BIASES IN SARC ASSESSMENT RESULTS

- Biases in the methods employed - ADAPT, DeLury, Production Models, *etc.*
- Biases due to database limitations, *e.g.* missing discards and/or recreational catches.
- As appropriate, examine using:
  Bootstrap methods
  Simulation modeling
  Retrospective analysis
- Emphasize the management implications (if any) of potential biases, *e.g.* effect on current F and SSB estimates; on estimates of overfishing definitions (*e.g.* $F_{20\%}$); on estimated catches and F's in projection years, *etc.*

2. METHODS FOR MEDIUM-TERM STOCHASTIC PROJECTIONS

Consider the methods and the assumptions needed to carry out medium term (5 to 10 year), stochastic projections. Discuss software development issues that will allow straightforward linkage with currently used tuning methods, such as ADAPT. Discuss the statistical and graphical methods that may best summarize and display results.

3. MULTIPLE INDICES OF ABUNDANCE WITHIN THE DELURY MODEL

Although multiple indices of abundance are used routinely in ADAPT, only indices from a single survey (recruit and fully-recruited) have been used in the DeLury models.

The Methods Subcommittee should investigate procedures for incorporating abundance from multiple sources into the DeLury model (*e.g.* from NMFS surveys, state surveys, CPUE data). Procedures for appropriately weighting the various indices are critical in this endeavor.

4. CPUE-BASED INDICES OF ABUNDANCE FOR VPA TUNING

Current usage of CPUE-based indices of abundance for VPA tuning is problematic because:

- The indices are based on total catch-at-age data. An inherent correlation results when using them with a regression-based tuning method, such as ADAPT.
- The basic data used are landings per unit effort rather than catch in number per unit effort. In many cases, it is necessary to make tenuous assumptions regarding identical size composition among fishery components and across years in order to use these data as indices of age-specific stock size in number.

The Methods Subcommittee should investigate the estimation of catch-at-age by fleet component, and the development of CPUE indices (in number) from the better sampled fleet components.

5. CALIBRATION OF RECRUITMENT INDICES

Calibration of recruitment indices and historical VPA estimates in ADAPT (using the default option) differs from that done with methods used in the ICES arena. The primary difference is the assumption of a linear relationship (the ADAPT default option) *vs* the assumption of a log-linear relationship in the ICES methods. A secondary difference is the usage (in the ICES methods) of shrinkage toward the mean.

The Methods Subcommittee should examine these two calibration models using retrospective analysis, and provide guidance on their usage within ADAPT.

6. EFFECTS OF OUTLIERS IN SURVEY DATA

Investigate the effect of outliers in survey catch per tow data on ADAPT results (*e.g.* the effect on current F and SSB; on F's and catches in the projection years). If these outliers bias management-related results, suggest methods for reducing their effect (*e.g.* objective methods for outlier identification; the use log or other transformation in developing indices, *etc.*)

7. SENSITIVITY OF ADAPT RESULTS TO MULTIPLE INDICES

Develop quantitative measures of the effect of individual indices on ADAPT results (*e.g.* the effect on current F and SSB; on F's and catches in projection years).

8. EXTENDING THE TIME SERIES OF STOCK-RECRUITMENT DATA

Most age-structured assessments reviewed by the SARC provide recruitment and SSB results (from VPA) for the most recent 10 to 15 year period. However, survey indices are available for nearly 30 years. A longer time series of stock-recruitment data would be useful in developing overfishing definitions.

The Methods Subcommittee should investigate procedures for extending the stock-recruit data using calibration and smoothing techniques.

OTHER BUSINESS

UPCOMING MEETINGS

The chairman, Dr. Vaughn Anthony, reminded the participants that the SAW Steering Committee scheduled the 16th SAW Plenary Meeting for 29 July 1993 at the Air Port Ramada in East Boston, Massachusetts. It will be a one-day meeting for the purpose of presenting and finalizing the Advisory Report on Stock Status. Future Plenary meetings will be held in conjunction with planned Mid-Atlantic and New England Fishery Management Councils, or Atlantic States Marine Fisheries Commission meetings.

The SAW Steering Committee also set the timing for SAWs 17 and 18. The committee planned to hold the SAW-17 SARC meeting during 29 November - 3 December 1993 and the Plenary the day before the January 1994 meeting of the Mid-Atlantic Fishery Management Council. The SAW-18 SARC meeting is scheduled for 20 - 24 June 1994 and the Plenary the day before the July meeting of the New England Fishery Management Council.

THE SARC PROCEDURE

The work of the subcommittees, the heavy meeting agenda, and the way SARC carries out its business under the current (new) SAW structure was discussed.

The superb job done by subcommittees in preparing documents for the SARC meeting was noted, as were the excellent presentations by subcommittee chairs, and the consistently good assessments. In addition to subcommittee reports, SARC members found the detailed species assessment documents to be useful as well.

As this was the first meeting held under the "new" SAW structure, some growing pains were experienced within the SARC procedure. Discussion of the role of the SARC versus the role of its subcommittees indicated that it was not clear where the responsibilities of the subcommittees end and those of the SARC begin. A major question was the detail of the SARC review. Should the SARC be concerned with the details already reviewed by subcommittees? In spite of the subcommittees' work, some indicated that it was important for the SARC to have the opportunity to review the assessments from "another perspective". The chairman made it clear that the responsibility of the SARC was to peer-review the assessments. The detail required should vary from group to group.

In discussion of the "heavy" (12 species/stocks) agenda, it was suggested that the steering committee set the number of species that can realistically be reviewed at a one week meeting, since allowing the subcommittees the flexibility to select the terms of reference to meet in the case of second and third priority species, clearly did not work. Each group felt that they should do everything indicated, regardless of priority. As management responsibilities increase, however, a much shorter list of species to review may not be an option, affirming the need to improve the SARC's efficiency.

The chairman noted that the development of new draft advisory report sections consumed much meeting time, which prevented the review of analyses for additional species. Once the first advisory report for each species has been established, however, the development of subsequent advisory documents should be easier and faster.

Specific suggestions from participants to improve the SARC procedure included the following:

- The SARC should clearly outline the duties of its subcommittees (the terms of reference were not enough).

- As a major role of the SARC is the development of scientific advice for fisheries management, the responsibility for the production of the advisory report should lie within the SARC; not with outside rapporteurs. (Rapporteurs for this SARC meeting were chosen as follows: (1) the SAW chairman asked each subcommittee to name a rapporteur from the subcommittees who would draft the SARC report with the subcommittee chairman; (2) Dr. T.P. Smith was asked by the SARC chairman to serve as rapporteur for the entire advisory report, assisted by the rapporteurs of for species of the SARC report; and (3) the intent of the procedure was to promote continuity across all advisory reports.)

- Rapporteurs should be members of the SARC so as to sort out the advice and record **their** (SARC's) ideas directly. Advice should be generated by SARC members only, as token approval of outside rapporteurs' reports would be misleading to managers.

- To assure a thorough, efficient, review, SARC members should be assigned the responsibility for certain areas of the agenda (*i.e.*, thoroughly review one or two species) prior to the meeting. This would result in a better level of assimilation in certain areas on the part of SARC members, who would thus be better prepared to lead relevant discussions.
- To further save time at the meeting, SARC members should bring a draft advisory report on their assigned species to the meeting, a report which would be modified according to consensus.
- Changes in advisory report drafts should be noted on overheads to make it easier for participants to follow.
- SARC member rapporteurs could draft reports outside the meeting hours so that they would not be distracted from participation at the meeting.
- There should be a single rapporteur (editor) for all advisory reports to assure continuity from stock to stock.