Northeast Fisheries Science Center Reference Document 94-22

Report of the 18th Northeast Regional Stock Assessment Workshop (18th SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, MA 02543-1026

December 1994

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The correct citation for the document is: NEFSC [Northeast Fisheries Science Center]. 1994. Report of the 18th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NOAA/NMFS/NEFSC: Woods Hole, MA. *NEFSC Ref. Doc.* 94-22.

Reports of the 18th Northeast Regional Stock Assessment Workshop (18th SAW)

CRD 94-15	Bluefish assessment, 1994 report of the SARC Pelagic/Coastal Subcommittee
CRD 94-16	Assessment of summer flounder (*Paralichthys dentatus*), 1994 report of the SAW Summer Flounder Working Group by SAW Summer Flounder Working Group
CRD 94-17	Assessment of Gulf of Maine-Georges Bank witch flounder stock for 1994 by S. E. Wigley and R.K. Mayo
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CRD 94-25	Assessement of Georges Bank Cod Stock for 1994 by F. Serchuk, R. Mayo, and L. O'Brien

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MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) Meeting of the 18th Northeast Regional Stock Assessment Workshop (18th SAW) was held at the Northeast Fisheries Center, Woods Hole, Massachusetts during 20 - 24 June 1994. SARC Chairman was Dr. Vaughn Anthony (NEFSC). Members of the SARC were from a number of fisheries organizations and academia within the region, one state agency in North Carolina, and two Biological Stations in Canada (Table 1). In addition to SARC members, about 50 other individuals also participated in the meeting (Table 2). The agenda for the meeting is presented in Table 3.

OPENING

After introductions, Dr. Vaughn Anthony indicated that the SARC is a fairly rigid group, one that will provide peer review of assessments as well as other related materials which will be brought before the group. During the week, the SARC would carefully complete peer review of single species assessments, designate any material for publication, list research needs for the next assessment, produce the "Consensus Summary of Assessments" document (SARC Report), draft an "Advisory Report on Stock Status" (Advisory Report), review past Terms of Reference for the Assessment Methods Subcommittee, and recommend new items for the Assessment Methods Subcommittee to consider.

The SARC process, and resulting documentation, as well as responsibilities of the subcommittee chairs, rapporteurs, SARC leaders, and the editor of the Advisory Report were carefully reviewed. Edited drafts of the Advisory and SARC reports were to be provided to SARC leaders after the meeting for final review, to assure that the reports include all points agreed to by the SARC. To insure that all procedures and timing were well understood, the Chairman tabled a packet of the overheads used in this presentation.

AGENDA AND REPORTS

The SARC agenda included six species/stocks and the report of the Assessment Methods Subcommittee. The SARC reviewed analyses for bluefish, summer flounder, witch flounder, spiny dogfish, Georges Bank yellowtail flounder, and Georges Bank cod. A chart of U.S. commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 1.

The SARC prepared a Consensus Summary of Assessments report, which includes recommendations for future research on the species. The report is based on the analyses submitted in the form of Subcommittee Reports, which were developed in a series of Subcommittee meetings (Table 4). Material from these reports form the basis of the SARC Report. In addition, the SARC reviewed separate working papers containing detailed supporting material for the Subcommittee reports.

Table 1. SAW-18 SARC composition

Chair, NEFSC Chief Scientific Advisor:

Vaughn Anthony

Four *ad hoc* assessment members chosen by the Chair

Michael Fogarty
Steve Murawski
Anne Richards
Fred Serchuk

One person from NMFS, Northeast Regional Office

Pete Colosi

One person from each Regional Management Council

Andy Applegate, NEFMC
Chris Moore, MAFMC

Atlantic States Marine Fisheries Commission/ State personnel:

Mark Gibson, RI FWE
Kim McKown, NY DEC
Jeff Ross, NC DMF

One scientist from

Canada:	**John Neilson** **DFO, St. Andrews Bio. Sta.**
Academia:	**David Conover** **State University of New York**
Other Region:	**Dick Beamish** **Pacific Biological Station, Nanaimo, B.C.**

Table 2. List of particpants

National Marine Fisheries Service

Northeast Fisheries Science Center

Almeida, Frank
Anderson, Emory
Anthony, Vaughn C.
Basson, Marinelle
Brodziak, Jon
Burnett, Jay
Christensen, Darryl
Clark, Stephen
Conser, Ray
Dow, David
Fogarty, Mike
Gabriel, Wendy L.
Greenfield, Richard
Grosslein, Marv
Haas-Castro, Ruth
Helser, Thomas E.
Hendrickson, Lisa
Idoine, Josef
Lambert, Marjorie C.
Mayo, Ralph D.
Morrissey, Tom
Murawski, Steve
Mustafa, Helen
O'Brien, Lorretta
Overholtz, Bill
Rago, Paul
Richards, Anne
Serchuk, Fred
Sheehan, Tim
Shepherd, Gary
Sosebee, Katherine
Terceiro, Mark
Wei-Ling, Shih
Weinberg, Jim
Wigley, Susan

Northeast Regional Office

Christopher, Pete
Colosi, Peter
Davidson, Bridgette
Goodale, Hannah
Helvenston, Lucille
Mantzaris, Mary
McCarron, Chris
Murphy, Susan
Raizin, Myles
Spallone, Regina
Verry, Alison

Office of Research and Environmental Information

Rosenberg, Andy

Connecticut Department of Environmental Protection

Johnson, Mark
Simpson, David

Massachusetts Division of Marine Fisheries

Cadrin, Steve
Correia, Steven
Pierce, David

Mid-Atlantic Fisheries Management Council

Moore, Chris

New York DEC Marine Resources

Mason, John

New York, State University

Conover, David

New England Fisheries Management Council

Applegate, Andy

New York Department of Environmental Conservation

McKown, Kim

North Carolina Division of Marine Fisheries

Ross, Jeff

Pacific Biological Station, Nanamino, BC

Beamish, Dick

Rhode Island Division of Fish, Wildlife & Estuarine Resources

Gibson, Mark
Lazar, Najih

Rutgers University

McCay, Bonnie

St. Andrews Department of Fisheries and Oceans

Neilson, John

SUNY -- Marine Sciences Research Center

Buckel, Jeff

Table 3. 18th Northeast Regional Stock Assessment Workshop, Stock Assessment Review Committee (SARC) Meeting agenda

Woods Hole, Massachusetts
June 20 - 24 1993
AGENDA

Species/Stock	Subcommittee	SARC Leader & Presenter	Rapporteur
Monday June 20 (12:00 PM - 7:30 PM)			
Opening Welcome Agenda Conduct of Meeting		V. Anthony Chairman	H. Mustafa/ T. Morrissey
Bluefish	Pelagic/Coastal	M. Terceiro	
Tuesday, June 21 (9:00 AM - 6:00 PM)			
Summer Flounder	So. Demersal	W. Gabriel	
Assessment Methods Subcommittee Report	Assessment Methods	R. Conser	
Witch Flounder	No. Demersal	R. Mayo	
Review available drafts			
Wednesday, June 22 (9:00 AM - 6:00 PM)			
Spiny Dogfish	So. Demersal	E. Anderson	
Georges Bank Yellowtail Flounder	So. Demersal	W. Gabriel	
Review available drafts			
Thursday, June 23 (9:00 AM - 6:00 PM)			
Georges Bank Cod	No. Demersal	R. Mayo	
Review available drafts			
Friday, June 24 (9:00 AM - 6:00 PM)			
Complete unfinished discussion of species/stocks under review			
Complete SARC Report sections		H. Mustafa/T. Morrissey (Coordination)	
Complete Advisory Report sections		T.P. Smith (Editor)	
Other Business		H. Mustafa/T. Morrissey	

CONTACT: Helen Mustafa, SAWs Coordinator
or Tom Morrissey
Northeast Fisheries Science Center
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166 Water Street
Woods Hole, MA 02540-1097

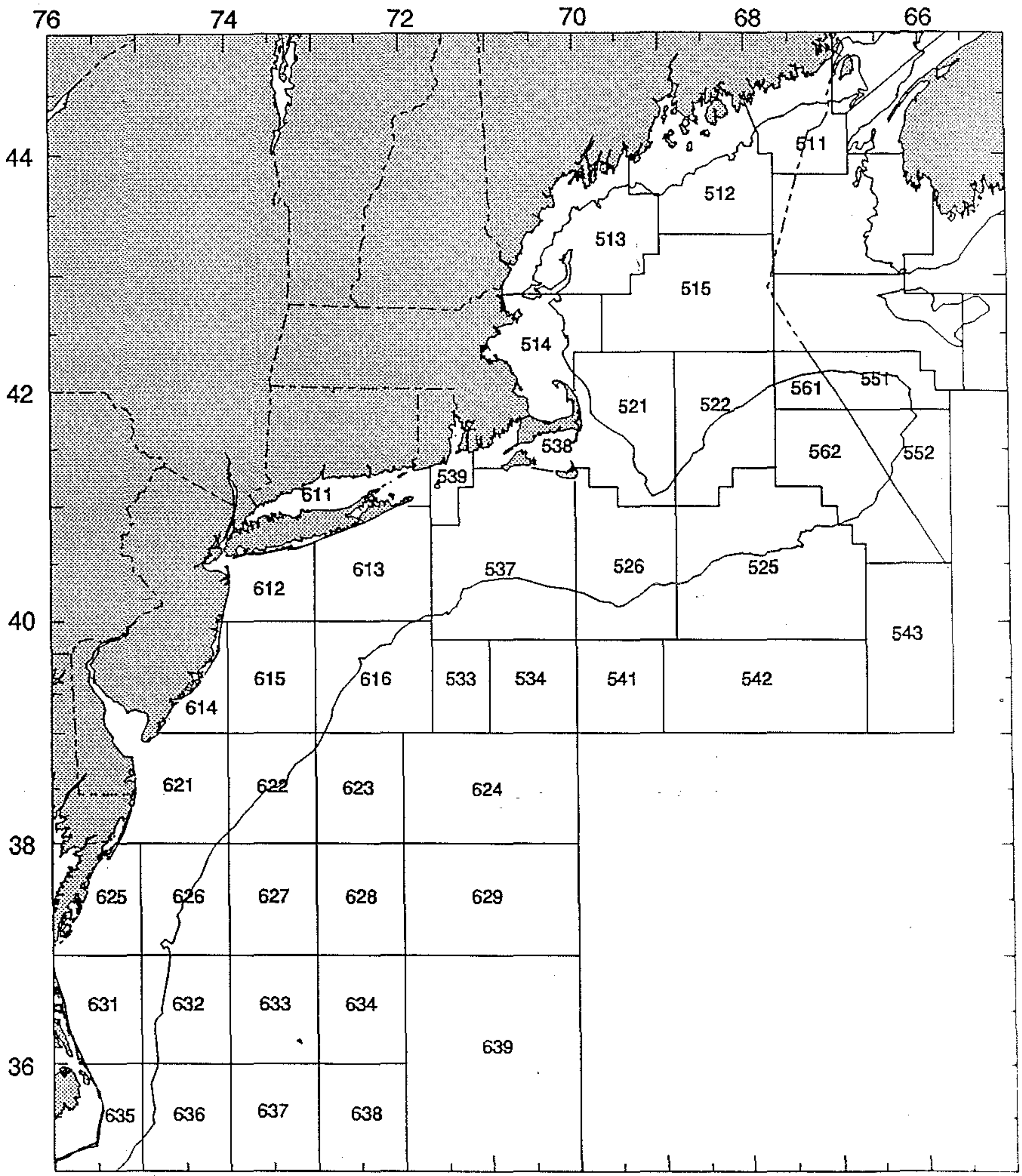

Figure 1. U.S. commercial statistical areas used to report landings in the Northwest Atlantic.

Table 4. Subcommittee meetings, participants, and analyses prepared

Participants	Participants	Meeting Date/Location
Northern Demersal Subcommitee- Georges Bank Cod Analysis		
R. Mayo, Chair		8-12 November 1993
A. Applegate	S. Gavaris	Woods Hole, MA
D. Hayes	T. Helser	
L. Hendrickson	T. Hoff	23-27 May 1994
J. Hunt	J. Mason	Woods Hole, MA
L. O'Brien	F. Serchuk	
K. Sosebee	S. Wigley	
Northern Demersal Subcommittee- Gulf of Maine-Georges Bank Witch Flounder Analysis		
R. Mayo, Chair		24-28 May 1993
A. Applegate	D. Hayes	Woods Hole, MA
T. Helser	L. Hendrickson	
J. Hunt	L. O'Brien	23-27 May 1994
F. Serchuk	K. Sosebee	Woods Hole, MA
S. Wigley		
Southern Demersal Subcommittee- Summer Flounder Analysis		
W. Gabriel, Chair		9-13 May 1994
M. Gibson	H. Goodale	Woods Hole, MA
M. Lambert	S. Michels	
C. Moore	P. Rago	
G. Shepherd	D. Simpson	
M. Terceiro		
Southern Demersal Subcommittee - Georges Bank Yellowtail Flounder Analysis		
W. Gabriel, Chair		2 - 5 November 1994
A. Applegate	M. Lambert	Woods Hole, MA
R. Conser	P. Rago	9-13 May 1994
		Woods Hole, MA
Southern Demersal Subcommittee - Spiny Dogfish Analysis		
E. Anderson, Chair		24-26 May 1994
J. Brodziak	K. Sosebee	Woods Hole, MA
M. Fogarty	S. Murawski	
M. Grosslein	R. Seagraves	
P. Rago	J. Weinberg	
Pelagic/Coastal Subcommittee - Bluefish Analysis		
F. Serchuk, Chair		5 January 1994
V. Crecco	M. Gibson	Woods Hole, MA
C. Moore	W. Overholz	
T. Smith	M. Terceiro	
S. Murawski, Chair		5-6 April 1994
J. Buckler	V. Crecco	Old Lyme, CT
M. Gibson	D. Hayes	
C. Moore	W. Overholtz	
J. Ross	L. Rugolo	
F. Serchuk	T. Smith	
M. Terceiro		
Methods Subcommittee		
R. Conser, Chair		4-6 May 1994
E. Anderson	A. Applegate	Woods Hole, MA
S. Cadrin	S. Correia	
K. Friedland	W. Gabriel	
J. Idoine	S. Murawski	
L. O'Brien	W. Overholtz	
P. Rago	A. Rosenberg	
G. Shepherd		

Table 5. 18th SAW SARC NEFSC Research Documents

CRD 94-15	Bluefish assessment, 1994, report of the SARC Pelagic/Coastal Subcommittee
CRD 94-16	Assessment of summer flounder (*Paralichthys detatus*), 1994, report of the SAW Summer Flounder Working Group
CRD 94-17	Assessment of Gulf of Maine - Georges Bank witch flounder stock for 1994 by S.E. Wigley and R.K. Mayo
CRD 94-18	Application of a biomass dynamics model to the spiny dogfish (*Squalus acanthias*) by P. Rago and K. Sosebee
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	by F. Serchuk, R. Mayo, and L. O'Brien

From the materials reviewed, seven papers were recommended for publication in the NEFSC Reference Document series (Table 5).

The SARC also prepared a draft Advisory Report on Stock Status for the species/stocks reviewed. Information in the Advisory Report was compiled according to the format approved by the SAW Steering Committee. Copies of this report will be provided to the Steering Committee two weeks prior to the SAW Plenary Meeting scheduled to be held on 9 - 10 August 1994 in conjunction with the Fishery Management Council meeting in Danvers, Mass. The final version of the Advisory Report will be included in the Report of the 18th SAW, The Plenary (NEFSC Reference Document 94-23)

A. BLUEFISH

TERMS OF REFERENCE

The following terms of reference were established for bluefish by the Steering Committee for SAW 18:

a. Assess the status of bluefish through 1993 and characterize the variability of stock abundance and fishing mortality rates. Review and update biological reference points as necessary.

b. Provide 1994 projections of catch and 1995 SSB options at various levels of F.

INTRODUCTION

Bluefish (*Pomatomus saltatrix*) are found along the U.S. Atlantic coast from Maine to Florida, migrating northward from the South Atlantic Bight in the spring and returning southward in the late fall. They are the target of a major recreational fishery along the Atlantic coast, with catches averaging 44,200 mt (metric tons) per year during 1979 to 1992. For the same period, the commercial landings of bluefish, mainly by trawls and gillnets, averaged 6,300 mt per year. The management unit for the Fishery Management Plan (FMP) for the bluefish fishery, developed jointly by the Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASMFC), has been defined as the entire bluefish population along the Atlantic Coast of the United States (MAFMC 1990).

Atlantic coast bluefish exhibit fast growth during the first two years of life, attaining fork lengths of more than 40 cm by age 2 (Hamer 1959, Lassiter 1962, Richards 1976, Wilk 1977). They may reach ages of at least 12 years and sizes in excess of 100 cm fork length and 14 kg in weight. About fifty percent of bluefish reach sexual maturity by the second year of life, and they are fully mature by age 2 (Wilk 1977). Spawning occurs during two major periods: March and April in the South Atlantic Bight near the inner edge of the Gulf Stream, with a peak about 1 April; and June through September in the Mid-Atlantic Bight, with a peak about 1 August (Wilk 1977, Kendall and Walford 1979, Nyman and Conover 1988). Some spawning also occurs in the South Atlantic Bight during the fall and into early winter (September through January; McBride *et al.* 1993).

Lund and Maltezos (1970) used analysis of mark and recapture data to conclude that several bluefish populations are present along the Atlantic coast. Wilk (1977) suggested that two populations of bluefish, corresponding to the major spawning groups, exist along the Atlantic coast. Chiarella and Conover (1990) presented evidence that fish from the major spawning groups mix extensively during their lifespan, as summer spawning fish were observed to originate from both spring- and summer-spawned cohorts, and concluded that year classes of bluefish therefore consist of varying proportions of seasonal cohorts. Graves *et al.* (1992) used analysis of mitochondrial DNA to investigate the genetic basis of stock structure of bluefish along the Atlantic coast, and were unable to detect significant genetic differences among spring- and summer-spawned bluefish. Graves *et al.* (1992) concluded that bluefish along the mid-Atlantic coast constitute a single genetic stock.

FISHERY DATA

Commercial Landings

Total U.S. commercial landings of bluefish from Maine to Florida peaked in 1981 at nearly 7,500 mt (16 million lb, Table A1, Figure A1). The projected landings in 1993 of about 4,000 mt (about 8.8 million lb) were a 20% decrease from 1992. Large variability in bluefish landings exist among the states over time, but generally the states of North Carolina, Virginia, New Jersey, New York, Florida, Rhode Island, and Massachusetts have accounted for more than 90% of the commercial landings (Table A2). In the Northeast region (Maine to Virginia) otter trawl and gillnet landings constitute about 82% of the regional landings, averaging 33% and 49%, respectively,

Table A1. Estimated bluefish catch: commercial landings, recreational landings, recreational catch, and foreign landings, Maine to Florida, U.S. East Coast (metric tons)[1]

Year	Commercial Landings	Foreign Landings	Recreational Landings	Recreational[2] Catch	Total Landings	Total Catch
1960	1,251	0	N/A	11,475	N/A	12,726
1961	1,401	0	N/A	N/A	N/A	N/A
1962	2,256	0	N/A	N/A	N/A	N/A
1963	2,123	0	N/A	N/A	N/A	N/A
1964	1,743	0	N/A	N/A	N/A	N/A
1965	1,847	0	N/A	20,528	N/A	22,375
1966	2,172	0	N/A	N/A	N/A	N/A
1967	1,671	0	N/A	N/A	N/A	N/A
1968	2,159	0	N/A	N/A	N/A	N/A
1969	2,445	0	N/A	N/A	N/A	N/A
1970	2,952	0	N/A	27,024	N/A	29,976
1971	2,624	23	N/A	N/A	N/A	N/A
1972	3,115	18	N/A	N/A	N/A	N/A
1973	4,556	214	N/A	N/A	N/A	N/A
1974	4,538	99	N/A	N/A	N/A	N/A
1975	4,502	103	N/A	N/A	N/A	N/A
1976	4,547	1	N/A	N/A	N/A	N/A
1977	4,802	4	N/A	N/A	N/A	N/A
1978	5,629	35	N/A	N/A	N/A	N/A
1979	4,983	28	59,168	63,759	64,179	68,770
1980	6,858	23	64,559	69,612	71,440	76,493
1981	7,466	71	50,197	58,216	57,734	65,753
1982	6,996	77	52,133	56,573	59,206	63,646
1983	7,166	33	55,464	62,859	62,663	70,058
1984	5,381	68	33,389	39,327	38,838	44,776
1985	6,124	18	40,833	44,977	46,975	51,119
1986	6,657	28	51,151	59,365	57,836	66,050
1987	6,579	2	35,952	43,479	42,533	50,060
1988	7,162	0	28,575	35,666	35,737	42,828
1989	4,740	0	18,225	22,965	22,965	27,705
1990	6,246	0	18,223	23,705	24,469	29,951
1991	6,160	0	15,280	21,067	21,440	27,227
1992	5,024	0	12,241	16,994	17,265	22,018
1993	4,000[3]	0	10,511	14,759	14,511!	18,759!

[1] **Recreational landings include catch type A (fish landed and available for sampling), type B1 (fish landed but not available for sampling), and 25% of type B2 (fish released alive, assuming a 25% discard mortality rate). Recreational catch includes catch types A and B1, plus all catch type B2. Total landings include commercial landings, recreational landings, and foreign landings. Total catch includes commercial landings, recreational catch, and foreign landings.**

[2] **Marine Angling Survey estimates, adjusted per Boreman (1983). These surveys used a different methodology than the MRFSS, and are not directly comparable to recreational catch estimates since 1979.**

[3] **Projected landings**

during 1991-1993. Pound nets, purse and beach seines, and handlines account for the remainder (Table A3). In North Carolina, winter trawl and gillnet fisheries constitute about 78% of the commercial landings, averaging 15% and 63%, respectively, during 1990-1992. Pound net, seine, and handline fisheries, which land fish mainly during the summer months, account for the other 22% of the landings (Table A4). In Florida, most commercial landings of bluefish are taken in the winter gillnet fishery.

Northeast Region Commercial Fishery

A summary of length frequency and age sampling of bluefish landings sampled by the NEFSC commercial fishery weighout system in the Northeast Region (NER, Maine to Virginia) is presented in Table A5. For comparison with the manner in which length frequency sampling in the recreational fishery has been evaluated, sampling intensity is expressed in terms of metric tons of total NER landings per 100 fish lengths measured. The sampling is proportionally stratified by market category and fishing gear, with the sampling distribution generally reflecting the distribution of weighout landings by market category and gear. Sampling intensity has been in general low, has deteriorated since 1988, and was very poor during 1990-1993.

Length composition of the NER commercial landings for 1982-1993 was estimated annually for pooled market categories and statistical areas, using standard NEFSC procedures (length frequency samples converted to mean weights by length-weight relationships; mean weights in turn divided into landings to calculate numbers at length). Length compositions were estimated by gear type when samples were adequate (1983-1988). The NER commercial landings at length matrix does not include the landings from states not participating in the NEFSC weighout system (*e.g.*, North Carolina to Florida).

No age data from NER fisheries are available for conversion of the NER landings at length, although the age structures (scales) are archived. For this assessment, the Subcommittee compared the mean weights in the NER fishery with those from the North Carolina (NC) winter fisher-

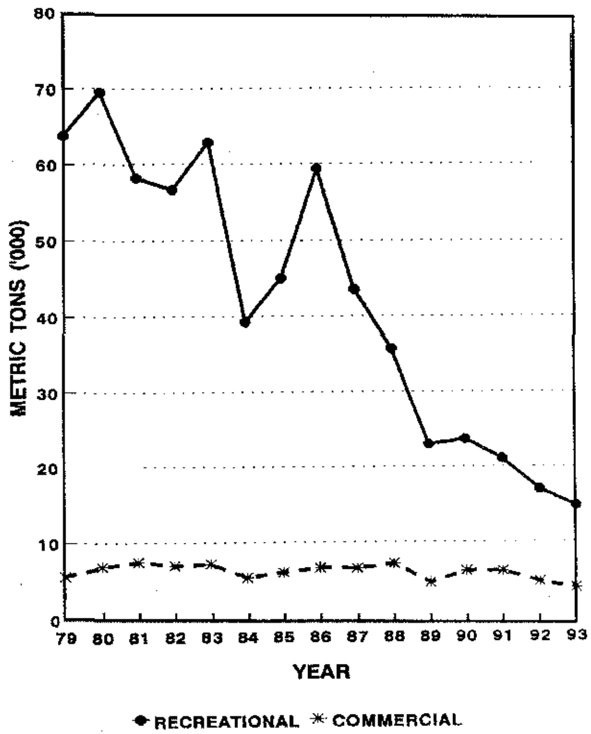

Figure A1. Trends in recreational catch (includes catch type B2, fish released alive) and commercial landings for bluefish, Maine to Florida, 1979-1993.

Table A2. Bluefish commercial landings by state (metric tons), 1979-1993

Year	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Total
1979	15	1	362	170	25	792	719	18	147	1243	884	1	*	606	4983
1980	44	1	315	166	22	675	635	74	198	1278	2469	1	0	978	6858
1981	44	20	371	160	142	581	832	89	188	1061	2998	1	*	978	7466
1982	75	30	406	270	136	781	898	232	131	1176	1946	4	*	911	6996
1983	77	14	454	235	31	765	873	132	150	689	3060	5	0	680	7166
1984	22	8	318	462	45	742	767	71	83	525	1614	1	0	719	5381
1985	41	10	362	767	82	968	902	85	231	749	1635	*	0	288	6124
1986	48	28	709	518	86	733	1362	181	207	686	1565	4	1	528	6657
1987	47	58	362	537	79	709	1149	161	165	536	2069	1	1	702	6579
1988	4	10	366	464	46	510	1126	95	468	1186	2286	1	1	596	7162
1989	35	62	562	549	88	256	718	47	125	349	1493	1	0	453	4740
1990	24	89	546	537	81	731	984	65	129	491	2077	*	0	488	6246
1991	56	58	343	676	117	716	1110	153	106	373	1778	*	0	672	6160
1992	39	103	215	703	112	675	997	42	93	269	1288	1	0	487	5024
1993[1]	8	68	165	505	na	371	984	na	23	35	1227	na	na	na	3386

Source: unpublished NMFS General Canvas data.

Key: * = less than 1 mt; na = not available. Numbers may not total due to rounding and preliminary nature of 1992 data by state.

[1] **For 1993, if FL = 400 mt, DE = 20 mt, CT = 50 mt, and VA = 100 mt, then projected total commercial landings are 3386 + 570 = 3956, or about 4000 mt.**

Table A3. Distribution of Northeast region commercial fishery landings by gear type

Gear type Landings (mt)

Year	Trawl	Gillnet	Pound Net	Seine	Other	Total
1982	1535	2193	337	0	70	4135
1983	1317	1719	293	0	91	3420
1984	1331	1482	140	25	66	3043
1985	2150	1517	303	141	85	4197
1986	1545	1674	644	449	247	4558
1987	1084	1914	513	28	265	3803
1988	1080	2206	608	131	201	4225
1989	870	1737	113	7	64	2791
1990	1157	2026	275	4	215	3677
1991	1243	1819	249	228	169	3708
1992	1232	1608	245	41	122	3248
1993	883	1665	467	166	203	3384

Percentage of Landings

Year	Trawl	Gillnet	Pound Net	Seine	Other	Total
1982	37.1	3.0	8.2	0.0	1.7	100.0
1983	38.5	50.3	8.6	0.0	2.7	100.0
1984	43.7	48.7	4.6	0.8	2.2	100.0
1985	51.2	36.2	7.2	3.4	2.0	100.0
1986	33.9	36.7	14.1	9.8	5.4	100.0
1987	28.5	50.3	13.5	0.7	7.0	100.0
1988	25.6	52.2	14.4	3.1	4.8	100.0
1989	31.2	62.2	4.0	0.3	2.3	100.0
1990	31.5	55.1	7.5	0.1	5.9	100.0
1991	33.5	49.1	6.7	6.2	4.6	100.0
1992	37.9	49.5	7.5	1.3	3.7	100.0
1993	26.1	49.2	13.8	4.9	0.6	100.0
1991-1993 mean	33.0	49.2	9.0	4.1	4.7	100.0

Table A4. Distribution of North Carolina commercial fishery landings by gear type

Gear type Landings (mt)

Year	Trawl	Gillnet	Pound Net	Seine	Other	Total
1982	723	517	101	236	372	1949
1983	1686	937	39	181	217	3060
1984	494	645	41	164	270	1614
1985	402	672	60	241	259	1634
1986	302	790	36	221	216	1565
1987	212	1262	50	249	296	2069
1988	547	1158	89	225	267	2286
1989	290	882	18	155	148	1493
1990	116	1455	25	275	206	2077
1991	116	1094	26	264	278	1778
1992	339	646	11	196	95	1287
1993	170	968	8	64	17	1227

Percentage of Landings

Year	Trawl	Gillnet	Pound Net	Seine	Other	Total
1982	37.1	26.5	5.2	12.1	19.1	100.0
1983	55.1	30.6	1.3	5.9	7.1	100.0
1984	30.6	40.0	2.5	10.2	16.7	100.0
1985	24.6	41.1	3.7	14.7	15.9	100.0
1986	19.3	50.5	2.3	14.1	13.8	100.0
1987	10.2	61.0	2.4	12.0	14.3	100.0
1988	23.9	50.7	3.9	9.8	11.7	100.0
1989	19.4	59.1	1.2	10.4	9.9	100.0
1990	5.6	70.1	1.2	13.2	9.9	100.0
1991	6.5	61.5	1.5	14.8	15.6	100.0
1992	26.3	50.2	0.9	15.2	7.4	100.0
1993	13.9	78.9	0.7	5.2	1.3	100.0
1991-1993 mean	14.6	63.1	1.0	12.2	9.1	100.0

Table A5. Summary of NEFSC sampling of the NER (Maine-Virginia) commercial fishery for bluefish, 1982-1993

Year	Samples	Lengths	Ages	NEFSC Weigh-out Landings (mt)	NER Total Landings (mt)	Sampling Intensity (mt/100 lengths)
1982	9	942	141	1,622	4,135	439
1983	20	1,900	401	1,515	3,420	180
1984	22	2,045	456	1,477	3,043	149
1985	18	1,581	376	2,087	4,197	265
1986	20	1,838	445	3,411	4,558	248
1987	11	1,105	250	2,847	3,803	344
1988	20	1,961	450	2,401	4,225	215
1989	6	590	150	1,953	2,791	473
1990	4	402	52	2,765	3,677	915
1991	2	201	51	2,792	3,708	1,845
1992	4	400	50	2,839	3,248	812
1993	2	200	25	2,059	2,159	1,080

Note: Age samples are currently archived. NEFSC weighout landings are those characterized directly by length frequency sample data. Total NER landings include weighout plus general canvas data. Length frequency distributions based on NEFSC weighout landings are raised to NER total landings.

Table A6. Northeast Region (Maine to Virginia) commercial fishery landings at age for bluefish (thousands of fish)

Year	Age												
	0	1	2	3	4	5	6	7	8	9	10	11	Total
1982	505	994	848	846	51	56	49	14	4	0	0	0	3368
1983	2	364	1498	369	68	27	43	31	15	2	0	3	2422
1984	247	1184	2358	195	29	19	12	10	3	1	0	0	4059
1985	83	640	790	375	400	40	53	60	40	20	0	1	2503
1986	74	2069	2025	70	32	139	87	35	21	9	0	0	4561
1987	0	47	488	1064	292	22	44	25	10	0	0	0	1993
1988	230	318	717	323	398	220	98	75	23	9	9	0	2420
1989	49	490	713	53	62	201	113	60	26	0	4	0	1770
1990	341	624	71	37	53	110	376	105	137	4	0	0	1858
1991	569	1017	2465	10	15	48	86	163	86	1	1	0	4461
1992	976	4858	203	124	42	202	2	2	3	2	0	0	6414

Note: The 1982-1989 lengths were converted to age using NC DMF annual age-length keys from the North Carolina winter fishery. The 1990-1992 landings were assumed to have the same age composition as the North Carolina winter fishery landings.

Table A7. Northeast Region (Maine to Virginia) commercial fishery landings mean weights at age (kilograms) for bluefish

Year	Age												
	0	1	2	3	4	5	6	7	8	9	10	11	ALL
1982	0.198	0.621	1.159	1.979	2.853	4.511	5.297	5.684	5.194				1.228
1983	0.416	0.852	0.981	1.980	3.054	4.296	5.715	6.354	6.751	7.870		7.449	1.410
1984	0.422	0.610	0.682	1.561	2.381	4.410	5.331	6.068	6.378	7.030		0.749	
1985	0.430	0.562	0.882	2.113	2.787	3.552	5.276	6.174	6.407	6.755		7.247	1.677
1986	0.583	0.689	0.727	2.024	3.199	4.201	4.621	5.398	6.284	6.816		0.999	
1987	0.427	0.771	0.995	1.897	2.575	3.976	5.088	5.615	5.887			1.908	
1988	0.270	0.428	0.856	1.686	2.769	3.507	4.368	5.017	5.858	6.192	5.645		1.766
1989	0.347	0.509	0.649	1.947	3.552	4.042	4.162	4.719	5.580		7.247		1.576
1990	0.343	0.569	0.864	1.782	2.591	3.565	3.854	4.040	4.710	7.710			1.811
1991	0.334	0.300	0.502	1.764	3.251	3.578	4.435	5.421	5.252	7.710	6.928		0.671
1992	0.214	0.381	1.113	1.745	2.333	2.980	4.145	4.731	4.981	7.710			0.507

ies (gillnet and otter trawl) as a means of judging the applicability of North Carolina Division of Marine Fisheries (NC DMF) commercial winter fishery age-length keys for aging NER commercial fishery lengths. The Subcommittee judged that mean weights in the fisheries were similar, and so NC DMF commercial winter fishery annual age-length keys were used to convert NER commercial fishery length data to age. For 1990-1993, the NER commercial fishery length sampling was judged to be inadequate to provide a reliable sample of the landings (Table A5). To overcome this deficiency, the North Carolina commercial winter fishery proportions 1 at age were applied to the NER commercial fishery landings to estimate landings at age and mean weights at age (Tables A6-A7).

North Carolina Commercial Fishery

The North Carolina commercial fishery accounts for about one-third (30-35%) of the commercial landings along the Atlantic coast. A separate landings at age matrix for this component of the commercial fishery was developed from NC DMF length-age frequency sampling data. The NC DMF program sampled the commercial fishery landings at a rate of about 100 mt

Table A8. Summary of NC DMF sampling of the North Carolina commercial fishery for bluefish, 1982-1992

Year	Sampled Ages	North Carolina Commercial Landings (mt)	Sampling Intensity (mt/25 Ages)
1982	490	1,946	99
1983	596	3,060	129
1984	854	1,614	47
1985	548	1,635	75
1986	437	1,565	89
1987	381	2,069	136
1988	346	2,286	166
1989	320	1,493	117
1990	372	2,077	140
1991	279	1,778	159
1992	606	1,288	53

Table A9. North Carolina commercial fishery landings at age for bluefish

Year	Age												
	0	1	2	3	4	5	6	7	8	9	10	11	Total
1982	2621	1464	42	17	4	17	45	57	42	18	3	1	4331
1983	647	1277	592	66	51	190	191	86	32	1	0	0	3134
1984	553	583	308	20	36	145	79	45	19	0	2	0	1790
1985	551	922	56	19	38	55	127	39	25	4	0	1	1837
1986	870	744	178	4	24	126	64	51	27	9	1	0	2097
1987	699	894	323	146	105	82	151	60	12	3	0	0	2474
1988	287	323	163	38	100	182	14	224	50	3	0	0	1385
1989	300	424	92	33	78	173	46	44	12	5	0	0	1208
1990	430	721	87	24	33	68	232	65	84	2	0	0	1747
1991	505	977	1562	6	9	28	50	95	50	1	1	0	3283
1992	511	2798	156	63	20	98	1	1	1	1	0	0	3649

This matrix is a sum of component matrices from the North Carolina landings from pound nets, long haul seines, gill nets, and trawls. Landings from South Carolina, Georgia, and Florida are included in the gillnet landings.

Table A10. North Carolina commercial fishery mean weights at age for bluefish

Year	Age												
	0	1	2	3	4	5	6	7	8	9	10	11	All
1982	0.307	0.603	1.597	2.357	3.123	4.293	5.100	5.468	6.221	7.000	6.928	7.710	0.661
1983	0.236	0.391	0.903	1.866	2.852	3.931	4.733	5.104	5.936	7.000			1.195
1984	0.249	0.489	0.840	1.330	3.393	4.655	5.467	5.835	6.506		6.500		1.304
1985	0.207	0.404	0.759	1.816	2.545	4.530	4.729	5.734	5.981	6.800		7.710	1.045
1986	0.308	0.487	0.860	2.602	3.275	3.944	4.235	4.608	6.015	6.009	6.123		1.000
1987	0.217	0.316	0.924	1.617	3.246	4.035	4.837	5.197	6.250	7.250			1.121
1988	0.288	0.533	0.842	1.745	2.445	3.386	6.100	4.960	5.350	6.500			2.024
1989	0.280	0.487	0.734	1.819	3.130	4.261	4.705	5.398	5.670	4.989			1.611
1990	0.255	0.599	0.932	1.821	2.598	3.566	3.854	4.041	4.710	7.700			1.469
1991	0.271	0.350	0.526	1.764	3.251	3.578	4.432	5.421	5.252	7.710	6.928		0.746
1992	0.212	0.375	0.960	1.725	2.333	2.980	4.145	4.731	4.981	7.710			0.487

of landings per 25 ages during 1982-1992 (Table A8). Lengths and ages are sampled from the summer pound net, summer long haul seine, winter gillnet, and winter trawl fisheries, and separate matrices were developed for each, before summing to provide an estimate of total North Carolina commercial fishery landings at age and mean weights at age (Tables A9 and A10).

Commercial Discards

Data on bluefish catch collected by the NEFSC sea sampling program in the Gulf of Maine groundfish gillnet fishery and the Southern New England/Mid-Atlantic otter trawl fishery have been analyzed for 1989-1992. The Subcommittee found these data indicated that in both fisheries, discards have constituted less than 10% of the total catch per trip. Length frequency sampling has been inconsistent, and the data are not adequate to develop an estimate of either total discard or discard at length for the 1989-1992 period.

Recreational Catch and Effort

The 1993 recreational fishery total landings (catch type A: fish landed and available for sampling, plus type B1: fish landed but not available for sampling, plus type B2: fish released alive, of which 25% are assumed to die) was about 10,500 mt (23.2 million lb), or 14% below the 1992 landings of 12,200 mt (26.9 million lb). The proportion of fish released alive has increased since 1979, peaking at 43.7% of total catch in 1993. The time series of recreational catch is under revision by the MRFSS, with "new" estimates available for 1992 (total catch in numbers about 6% lower) and 1993 (35% lower). The subcommittee elected to use catch for 1992 and 1993 estimated with the "old" methodology until the entire data set has been revised, to preserve the integrity of the current time series.

The number of directed bluefish trips (those catching bluefish, or with bluefish indicated as a target species but with zero catch) was estimated by applying the proportion of sampled trips targeting bluefish by two-month sampling wave/state/fishing mode/fishing area (distance from shore) strata to the estimated number of fishing trips for all species in those strata (Figure A2). Nominal catch per trip in number and weight (Tables A11 and A12) was calculated from the total catch estimates. These indices of abundance indicate a steady decline in bluefish stock size and biomass since 1979. On a regional and fishing mode basis, these nominal indices of abundance have declined at higher rates in the North Atlantic region (Maine to Connecticut) than in the Mid-Atlantic (New York to Virginia) and South Atlantic (North Carolina to Florida) regions. This may imply that the availability of bluefish to anglers in New England waters has declined relative to the more southern waters (Figures A3-A4).

Figure A2. Trends in recreational catch and effort for bluefish, Maine to Florida, 1989-1993. Catch includes fish released alive (catch type B2), effort is trips catching or targeting bluefish.

The length frequency sampling intensity for the recreational fishery for bluefish was calculated on a metric tons of total catch per 100 lengths measured basis. Sampling intensity has not met the generally accepted target of 200 mt per 100 lengths measured, and in most years has been very poor relative to this target level (Burns *et al.* 1983; Table A13). The length composition of the recreational catch during 1979-1993 was estimated by two-month sampling period (wave), state, fishing mode (shore and boat), and fishing area (inland and territorial sea, EEZ) strata by merging MRFSS intercept length frequency samples with estimated type A, B1, and B2

Table A11. Estimated catch per unit effort (number/trip) for bluefish, MRFSS 1979-1993 (trips with bluefish catch or bluefish indicated as a target species)

Region Mode	Year														
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
North (Maine-Connecticut)															
Shore	3.939	8.793	4.075	6.207	5.784	4.456	3.292	1.893	2.968	0.732	1.06	1.147	1.398	0.759	0.478
Boat	4.444	3.537	6.413	7.054	3.668	3.582	3.103	3.786	3.398	1.529	1.532	1.436	1.945	1.517	1.517
Total	4.251	4.848	5.638	6.707	4.508	3.903	3.151	3.135	3.242	1.224	1.404	1.306	1.649	1.155	1.101
Mid (New York-Virginia)															
Shore	2.045	2.806	4.207	1.488	2.537	3.775	2.207	2.965	2.801	0.837	2.935	1.658	3.123	0.928	1.231
Boat	4.342	2.696	3.489	3.089	3.302	2.905	3.268	2.934	3.377	2.707	2.540	2.613	2.571	1.981	2.016
Total	3.751	2.726	3.699	2.527	3.053	3.168	2.871	2.944	3.234	2.178	2.675	2.314	2.802	1.657	1.743
South (North Carolina-Florida)															
Shore	2.315	3.207	1.608	2.088	1.509	1.400	1.164	1.552	1.814	1.449	1.182	1.542	0.945	1.071	0.949
Boat	2.714	3.297	2.825	3.193	4.719	1.770	1.876	2.246	2.280	1.606	1.426	1.613	1.445	1.696	1.771
Total	2.466	3.262	1.904	2.607	2.834	1.550	1.451	1.764	2.013	1.512	1.258	1.571	1.123	1.319	1.152
All Regions															
Shore	2.404	3.470	2.852	2.402	2.877	2.645	1.856	2.300	2.549	1.088	1.891	1.475	1.854	0.917	0.931
Boat	4.120	2.879	4.017	3.698	3.669	2.729	2.888	3.155	3.261	2.203	2.129	2.128	2.174	1.788	1.817
Total	3.500	3.050	3.508	3.166	3.341	2.694	2.451	2.819	3.025	1.756	2.025	1.850	2.010	1.406	1.355

Shore fishing mode includes catch taken from beaches, banks, and man-made structures; boat fishing mode includes catch taken from party/charter and private/rental boats.

Table A12. Estimated catch per unit effort (kilograms/trip) for bluefish, MRFSS 1979-1993 (trips with bluefish catch or bluefish indicated as a target species)

Region Mode	Year														
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
North (Maine-Connecticut)															
Shore	1.958	2.644	1.545	1.213	2.724	0.834	2.138	2.435	1.530	1.150	2.236	2.213	1.648	0.971	1.098
Boat	13.163	10.078	22.387	28.699	10.311	8.793	7.140	11.794	8.837	5.563	5.434	4.233	4.604	3.870	4.308
Total	8.888	8.223	15.479	17.454	7.300	5.874	5.860	8.575	6.176	3.878	4.561	3.327	3.003	2.485	3.022
Mid (New York-Virginia)															
Shore	0.735	1.379	1.428	0.463	1.532	0.607	1.151	1.814	0.917	0.535	0.799	0.939	1.121	0.467	0.466
Boat	9.450	6.423	7.738	6.254	5.283	5.702	6.613	5.629	6.224	7.221	4.236	4.342	3.925	2.988	3.568
Total	7.208	5.044	5.894	4.222	4.065	4.163	4.569	4.354	4.909	5.331	3.060	3.274	2.753	2.211	2.490
South (North Carolina-Florida)															
Shore	1.377	2.474	2.065	0.790	1.124	0.890	0.623	1.314	1.558	1.442	0.847	0.827	0.954	0.827	0.498
Boat	4.039	3.473	1.126	2.550	8.996	3.051	4.697	2.728	2.611	1.803	1.493	0.934	1.586	1.377	1.294
Total	2.386	3.079	1.837	1.617	4.375	1.768	2.267	1.746	2.007	1.587	1.049	0.871	1.179	1.045	0.695
All Regions															
Shore	1.162	1.742	1.772	0.693	1.645	0.781	1.034	1.840	1.267	1.078	0.977	1.239	1.274	0.773	0.600
Boat	9.112	6.446	9.964	8.738	7.249	5.531	6.312	7.389	6.409	5.737	4.040	3.647	3.769	2.972	3.322
Total	6.244	5.080	6.381	5.438	4.925	3.553	4.080	5.209	4.705	3.871	2.707	2.622	2.488	2.008	1.904

Shore fishing mode includes catch taken from beaches, banks, and man-made structures; boat fishing mode includes catch taken from party/charter and private/rental boats.

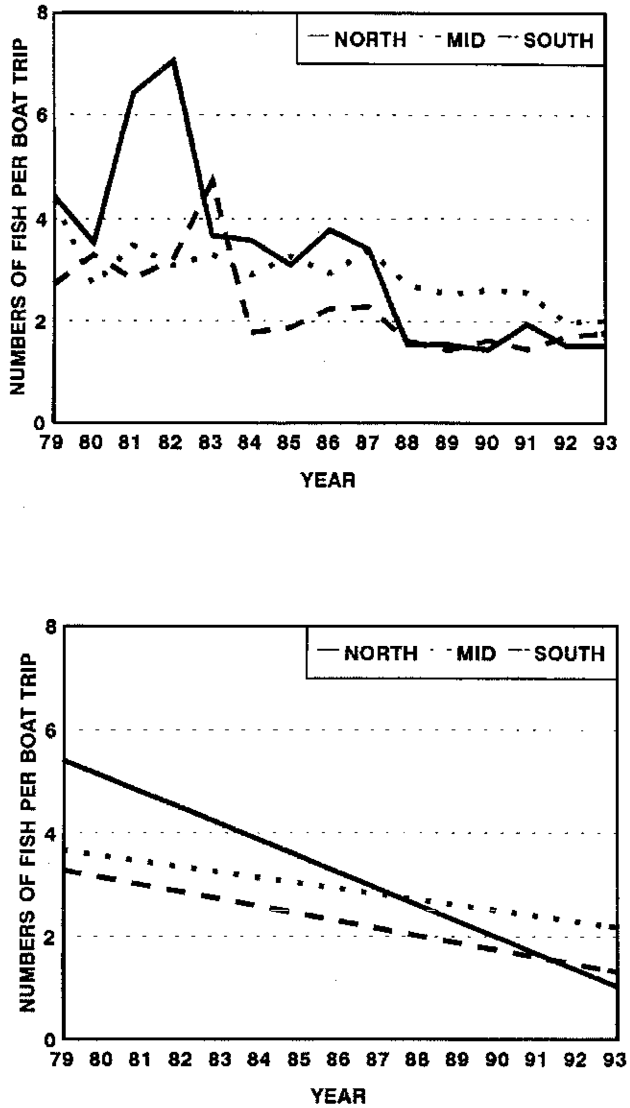

Figure A3. Trends in nominal recreational catch per trip (CPUE) for bluefish for anglers fishing from boats in the North Atlantic (Maine-Connecticut), Mid-Atlantic (New York-Virginia) and South Atlantic Regions (North Carolina-Florida). Top panel shows nominal CPUE, bottom panel shows linear regression line over the time series.

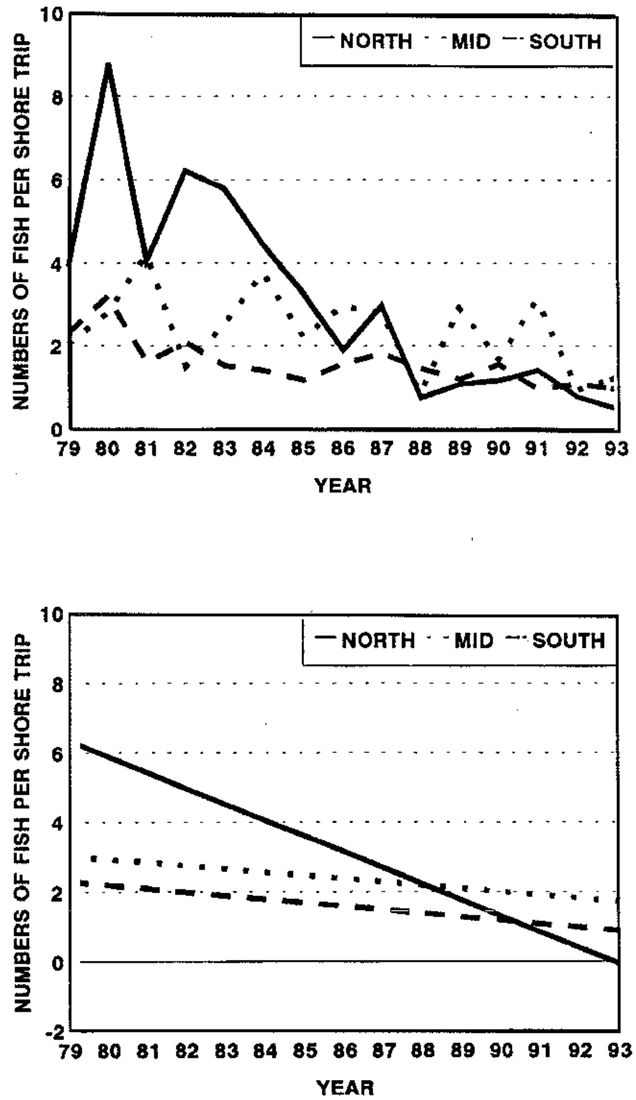

Figure A4. Trends in nominal recreational catch per trip (CPUE) for bluefish for anglers fishing from shore in the North Atlantic (Maine-Connecticut), Mid-Atlantic (New York-Virginia) and South Atlantic Regions (North Carolina-Florida). Top panel shows nominal CPUE, bottom panel shows linear regression line over the time series

catches. Catch types B1 and B2 were assumed to have the same length frequency distribution as catch type A, and catch type B2 was assumed to have a hooking (discard) mortality rate of 25%, based on analogy with species such as striped bass (Diodati 1991), black sea bass (Bugley and Shepherd 1991), and Pacific halibut (IPHC 1988).

No age structures are sampled by the MRFSS from fish captured in the recreational fishery. The Subcommittee considered two options for converting recreational lengths to ages: 1) using MULTIFAN (Fournier *et al.* 1990), a mixture of distributions method for resolving ages from length frequencies using maximum likelihood methods, and incorporating consideration of growth patterns, or 2) application of NC DMF commercial fishery annual age length keys. An initial comparison for three years (1983, 1987, and 1992) suggested the results would be comparable for ages 0-3, with some divergence at older ages. The MULTIFAN method tended to convert larger lengths to ages based on the mean

Table A13. Summary of MRFSS sampling of the recreational fishery for bluefish, 1979-1993

Year	Lengths	Estimated Total Catch (mt)	Sampling Intensity (mt/100 lengths)
1979	6,883	63,759	926
1980	10,825	69,612	643
1981	5,221	58,216	1,115
1982	3,835	56,573	1,479
1983	5,322	62,859	1,181
1984	4,206	39,327	935
1985	6,699	44,977	671
1986	4,952	59,365	1,199
1987	5,325	43,479	817
1988	2,762	35,666	1,291
1989	8,009	22,965	287
1990	7,189	23,705	330
1991	6,705	21,066	314
1992	5,120	16,994	332
1993	3,951	14,759	374

pattern of growth (which is influenced strongly by the growth pattern evident for the younger ages) and to form a large "plus group." The NC DMF keys tended to provide a smoother decline in numbers at age, improved coherence of strong and weak cohorts at age-5 and older, and a broader distribution at older ages.

The Subcommittee performed a comparison of Connecticut Department of Marine Fisheries (CT DMF) trawl survey age-length keys for 1984-1987 with the NC DMF commercial keys using the method of Hayes (1993) to determine if application of the NC DMF keys would cause a serious bias in conversion of lengths to age if applied to recreational fishery length frequencies. The method computes the probability of obtaining the observed difference between proportions at age for a given length interval in the age-length key by random chance. The method suggested no serious bias would be caused if the annual NC DMF age-length keys were used to age the recreational length data.

Table A14. Recreational fishery (Maine to Florida) catch at age (thousands of fish) for bluefish

Year	Age													Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	
1982	9179	9669	2516	1966	805	1212	1427	1181	953	1140	175	83	57	30363
1983	8559	8361	8469	2980	1179	1506	2569	1607	921	1071	127	216	64	37628
1984	7377	5789	4642	1927	900	725	948	975	717	1015	107	128	64	25314
1985	4633	5629	5419	3413	1038	636	1415	728	732	779	60	0	58	24539
1986	5930	4704	6876	3244	1111	1474	1159	927	1318	905	31	0	0	27679
1987	2510	4662	4575	4779	1721	1039	1584	1054	661	501	34	0	0	23120
1988	1464	2307	2585	1374	1368	1023	696	825	562	514	181	12	55	12965
1989	2774	4503	2367	946	245	765	627	556	514	273	37	7	19	13631
1990	1967	6205	1798	681	322	280	575	287	315	411	8	8	4	12860
1991	2448	3169	3151	1532	291	149	421	632	384	131	17	11	4	12339
1992	631	2255	1717	2275	528	180	176	317	320	159	6	6	2	8572
1993[1]	370	2185	1279	1438	824	332	148	213	165	105	3	2	0	7064

Catch type B2 (catch released alive) included with a hooking mortality rate of 25%. Lengths converted to age using NC DMF commercial fishery annual age-length keys.

[1] 1993 estimate is based on preliminary MRFSS data and 1992 NC DMF age-length keys

Table A15. Recreational fishery (Maine to Florida) mean weights at age (kilograms) for bluefish

Year	Age													All
	0	1	2	3	4	5	6	7	8	9	10	11	12	
1982	0.094	0.429	1.674	2.107	3.178	4.304	5.097	5.831	6.576	8.582	7.756	8.260	8.187	1.774
1983	0.057	0.383	0.971	2.205	3.168	4.591	5.718	6.261	6.854	8.744	8.404	7.916	8.404	1.936
1984	0.078	0.348	1.022	1.866	2.932	4.505	5.696	6.297	7.195	8.418	7.209	8.404	8.404	1.756
1985	0.085	0.362	1.014	1.890	2.810	4.073	5.198	6.158	6.892	8.327	8.404		7.812	1.802
1986	0.059	0.405	1.395	2.303	3.156	4.392	4.848	5.674	6.819	7.557	7.812			2.032
1987	0.089	0.287	1.222	2.068	3.011	3.917	4.990	5.908	6.525	8.652	7.812			2.134
1988	0.169	0.388	0.996	1.967	2.817	3.710	4.795	5.358	6.134	7.655	6.360	8.404	7.877	2.383
1989	0.111	0.269	1.206	2.167	3.826	4.099	4.824	5.596	6.117	7.805	7.901	7.247	8.203	1.643
1990	0.186	0.483	0.879	1.727	3.421	4.585	5.159	5.652	5.946	7.447	8.404	8.404	8.404	1.415
1991	0.072	0.333	0.916	1.737	2.790	4.133	5.139	5.882	6.338	7.659	7.635	7.532	8.042	1.440
1992	0.055	0.434	1.002	1.878	2.849	3.821	5.132	5.805	5.962	7.876	7.980	7.980	8.404	1.775
1993	0.077	0.412	0.916	2.211	3.029	3.564	4.427	5.628	6.217	8.052	7.707	7.707		1.802

Lengths converted to age using NC DMF commercial fishery annual age-length keys.

For further comparison, the recreational lengths were converted to age using both methods to develop parallel recreational catch at age and mean weights at age matrices, and thus parallel total (commercial and recreational) catch at age and mean weights at ages matrices, for the 1982-1992 time series. After considering the results of application of the Hayes method (1993) and upon inspection of the catch at age matrices developed with the alternative length to age conversion methods, the Subcommittee judged the use of the NC DMF keys to be the preferred approach, and adopted the catch at age matrices compiled with the keys as the best estimate of recreational catch at age and mean weights at age (Tables A14 and A15).

Recreational Fishery-Based CPUE Indices

In addition to the nominal indices derived from estimated catch and effort statistics (described above), the intercept sample data from the MRFSS 1979-1993 were used directly to develop an index of abundance. The Subcommittee reviewed four alternative definitions of recreational fishing effort: 1) trips that caught bluefish, regardless of whether bluefish was the target species or not (CAT ONLY), 2) trips that caught bluefish, plus trips in which bluefish were the target species and in which some fish (of any species) were caught (CAT/TAR), 3) trips in which bluefish was a target species, irrespective of whether bluefish were caught or not (TAR ONLY), and 4) trips that caught bluefish, plus trips in which bluefish was a target species even if no fish of any species were caught during the trip (ALL CAT/TAR). For each of the four effort measures, both nominal and GLM standardized CPUE series were presented and discussed.

The Subcommittee noted the four recreational CPUE indices showed similar trends during 1979-1993 but differed in their downward rates during the most recent years. Subsequent discussion related to three principal issues: 1) the use of a standardized versus a nominal CPUE series, 2) the most appropriate effort measure for calculating CPUE, and 3) the relevance of the CPUE series to the interpretation of abundance trends, as opposed to the efficacy of the series as a tuning index in analytical assessments.

With regard to issue 1 the Subcommittee decided that theoretical considerations imply that a standardized series would be a better measure of trends in abundance than any nominal series. Issue 2, the choice of the most appropriate effort index, had been discussed at SARC 17, with the SARC deciding that index 2 (CAT/TAR) was the most appropriate and using this index in the SAW 17 SARC Advisory Report. The Subcommittee was split between those favoring indices 2 or 3 (CAT/TAR or TAR ONLY) and those taking a position that both indices were flawed. This latter group felt that selection of a "best" series was not possible and perhaps, unnecessary, depending on subsequent empirical analyses. The point was also raised that estimates of recreational fishing effort are confounded with estimates of recreational catch, and therefore might not be appropriate as a tuning measure for analytical fishery models. No consensus was reached on this point however.

Issue 3, the use of the series, was partially resolved to the extent that all of the CPUE measures showed similar trends (with differences in the rate of decline). No agreement was reached on the empirically "best" series to use. It was felt that additional analyses were needed to evaluate the sensitivity of model outputs to the CPUE tuning series used. The Subcommittee examined alternative DeLury and CAGEAN model runs using the CAT/TAR and TAR ONLY indices, and found similar results using either index (see subsequent discussion on DeLury and CAGEAN models in the "Estimation of mortality and stock size" section of this report).

For the CAT/TAR GLM standardized index, a main effects (year, state, two-month sampling wave, and fishing mode) model accounted for about 8% of the variation in intercept catch per trip. This standardized index suggests a general decline in bluefish abundance since 1979 (Table A16, Figure A5).

Total Catch Composition at Age

Northeast Region commercial landings, North Carolina commercial landings, and recreational fishery landings (actual landings plus release mortalities) at age matrices were summed to provide an estimate of total catch at age of bluefish, 1982-1993. Mean weights at age in the total catch were calculated as a weighted mean (by number) of the mean weights at age in the component fisheries (Tables A17-A18). Catch-at-length data from the NER commercial fishery, catch-at-length data from the North Carolina commercial fisheries, and age-length keys from the North Carolina commercial fisheries for 1993 were not available to the Subcommittee. The

Table A16. General Linear Model (GLM) of recreational fishery (MRFSS 1979-1993) intercept catch (types A+B1+B2) per trip data to develop standardized index of abundance

Dependent variable: LOGCA

Source	DF	SS	MSE	F	PR > F	R-SQUARE
Model	34	6371.6	187.4	265.9	0.0001	0.08
Error	99992	70471.7	0.7			
Total	100026	76843.3				

Model SS

Variable	DF	Type III SS	F	PR > F
YR	14	1620.9	164.6	0.0001
ST	13	2336.5	255.0	0.0001
WAVE	5	148.1	42.0	0.0001
MODE	2	2267.4	1608.9	0.0001

Corrected, re-transformed YR parameter estimates

	Estimate	Lower 95% CI	Upper 95% CI
1979	1.371	1.330	1.413
1980	1.337	1.300	1.374
1981	1.331	1.289	1.375
1982	1.300	1.256	1.345
1983	1.155	1.119	1.191
1984	1.283	1.240	1.328
1985	1.385	1.345	1.425
1986	1.277	1.239	1.315
1987	1.113	1.080	1.146
1988	1.089	1.058	1.122
1989	1.214	1.184	1.245
1990	1.161	1.132	1.191
1991	1.059	1.033	1.086
1992	1.052	1.025	1.079
1993	1.000		

Includes trips with bluefish catch and trips with zero bluefish catch but which targeted bluefish (CAT/TAR index). Variation in log-transformed catch per trip (LOGCA) is modeled with year (YR), state (ST), two-month sampling period (WAVE) and fishing mode (MODE) as main effects, with no interactions. The corrected, re-transformed YR parameter estimates are indices of stock numbers (total number of fish caught per trip).

Table A17. Total commercial landings and recreational catch at age for bluefish

Year	Age													Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	
1982	12304	12127	3406	2829	861	1285	1520	1253	1000	1159	178	84	57	38063
1983	9208	10002	10559	3416	1298	1723	2803	1724	967	1074	128	218	64	43184
1984	8178	7556	7308	2142	965	888	1039	1030	739	1016	109	128	64	31162
1985	5268	7191	6264	3807	1476	731	1594	827	797	804	60	3	58	28880
1986	6874	7516	9079	3318	1165	1739	1310	1013	1367	923	33	0	0	34337
1987	3209	5604	5386	5989	2118	1143	1778	1139	684	503	34	0	0	27587
1988	1981	2948	3465	1736	1866	1425	807	1124	635	526	190	12	55	16770
1989	3123	5417	3172	1032	386	1139	785	660	552	277	42	7	19	16610
1990	2737	7551	1956	742	408	457	1182	457	537	417	8	8	4	16465
1991	3521	5163	7178	1547	315	225	558	890	520	132	20	11	4	20084
1992	2117	9911	2076	2462	591	480	179	320	324	162	6	6	2	18635
1993	612	3611	2114	2375	1361	547	245	353	272	174	4	4	1	11673

Lengths converted to age using NC DMF commercial fishery annual age-length keys.

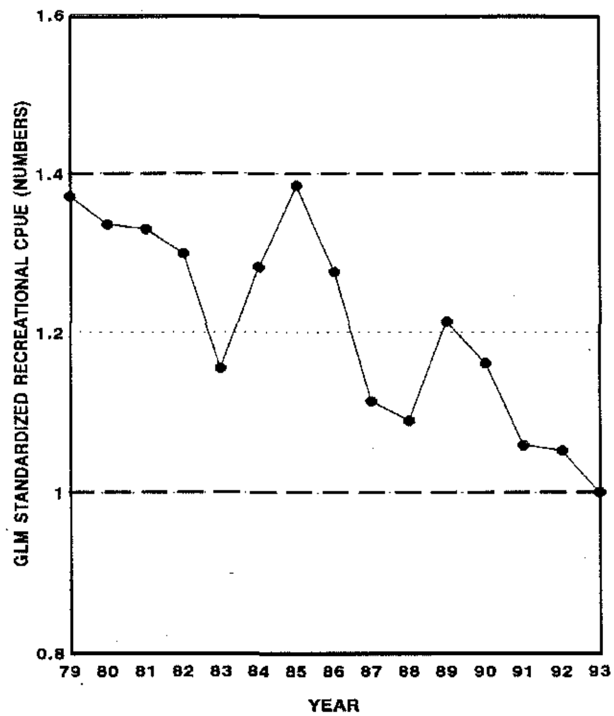

Figure A5. Index of stock abundance for bluefish, based on recreational fishery General Linear Model (GLM) standardized catch (numbers) per unit effort.

Subcommittee instead assumed that the commercial fishery landings for 1993 would be about 4,000 mt. At a mean weight of 1.2 kg/fish (1982-1992 average), the commercial fishery was projected to catch about 3.3 million fish. An initial estimate of recreational catch at age (5.1 million fish) was then raised to estimate total catch at age in numbers (8.4 million fish) for 1993. The estimate of recreational catch was subsequently revised to 7.1 million fish, and so the total catch at age was raised by a factor of about 1.4 to provide the current estimate of 1993 total catch in numbers of 11.7 million fish. The Subcommittee notes the 1993 commercial and recreational catch data are both still preliminary, due to ongoing revision and update.

RESEARCH SURVEY ABUNDANCE AND BIOMASS INDICES

NEFSC Autumn Inshore

Long-term trends in bluefish abundance were derived from a stratified random bottom trawl survey conducted by NEFSC between Cape Hatteras and Nova Scotia. Catches of bluefish in spring surveys and in offshore strata are low and sporadic. Bluefish are caught consistently in relatively large numbers during the fall survey, in inshore strata (Tables A19-A21). Generally, more than 90% of the bluefish caught in the fall inshore survey are less than 40 cm fork length, and therefore mainly age 0 and age 1 fish. For 1982-1993, lengths were converted to ages using the corresponding annual NC DMF commercial fishery age-length keys. The NEFSC survey suggests that strong year classes of bluefish recruited to the stock in 1977, 1981, 1984, 1986, 1988, and 1989. The series indicates that poor recruitment occurred in 1974, 1978, 1983, 1987, 1990, and 1993 (Figure A6).

Table 18.Total commercial landings and recreational catch mean weights at age (kilograms) for bluefish

Year	Age													
	0	1	2	3	4	5	6	7	8	9	10	11	12	ALL
1982	0.143	0.465	1.554	2.066	3.158	4.313	5.104	5.812	6.556	8.557	7.743	8.251	8.187	1.599
1983	0.070	0.401	0.968	2.174	3.149	4.514	5.651	6.205	6.823	8.740	8.374	7.909	8.376	1.853
1984	0.100	0.400	0.904	1.833	2.932	4.527	5.674	6.275	7.174	8.416	7.171	8.404	8.404	1.599
1985	0.103	0.385	0.995	1.912	2.797	4.079	5.164	6.140	6.839	8.279	8.356	7.473	7.812	1.743
1986	0.097	0.491	1.235	2.298	3.160	4.344	4.803	5.611	6.795	7.534	7.672			1.832
1987	0.117	0.296	1.183	2.027	2.962	3.927	4.979	5.865	6.511	8.644	7.812			2.027
1988	0.198	0.408	0.960	1.909	2.787	3.638	4.765	5.256	6.062	7.623	6.327	8.404	7.877	2.264
1989	0.131	0.308	1.067	2.144	3.641	4.113	4.722	5.504	6.082	7.758	7.815	7.228	8.203	1.634
1990	0.216	0.501	0.881	1.732	3.246	4.189	4.488	5.053	5.436	7.451	8.404	8.404	8.404	1.485
1991	0.143	0.330	0.689	1.738	2.826	3.944	4.966	5.748	6.055	7.659	7.631	7.509	8.042	1.191
1992	0.166	0.391	1.010	1.867	2.794	3.296	5.116	5.796	5.950	7.873	7.869	7.869	8.404	1.086
1993	0.077	0.412	0.916	2.211	3.029	3.564	4.427	5.628	6.217	8.052	7.707	7.707		1.802

Lengths converted to age using NC DMF commercial fishery annual age-length keys.

Table A19. Stratified mean number per tow of bluefish from Cape Cod to Cape Hatteras (inshore strata 1-46) from NEFSC autumn inshore bottom trawl survey

Year	95% Confidence Interval			Coefficient of Variation
	Mean	Low	High	
1974	9.830	5.335	14.326	25.3
1975	14.223	0.351	28.094	49.8
1976	43.944	26.723	61.164	20.0
1977	58.332	15.189	101.474	37.7
1978	14.550	11.105	17.995	12.1
1979	45.528	29.678	61.379	17.8
1980	37.605	13.482	61.729	32.7
1981	107.368	69.352	145.384	18.1
1982	34.246	15.066	53.425	28.6
1983	21.006	6.738	35.425	28.6
1984	59.841	39.575	80.108	17.3
1985	17.736	12.135	23.336	16.1
1986	40.748	-1.037	82.533	52.3
1987	7.444	2.958	11.933	30.8
1988	30.468	-16.489	77.424	78.6
1989	91.273	46.512	136.035	25.0
1990	9.321	5.099	13.543	23.1
1991	15.797	5.670	25.923	32.7
1992	17.865	14.467	21.264	9.7
1993	1.979	0.952	3.006	26.5

Table A20. Stratified mean weight per tow (kilograms) of bluefish from Cape Cod to Cape Hatteras (inshore strata 1-46) from NEFSC autumn inshore bottom trawl survey

Year	95% Confidence Interval			Coefficient of Variation
	Mean	Low	High	
1974	1.475	0.783	2.166	23.9
1975	5.581	1.868	9.293	33.9
1976	5.724	3.765	7.682	17.5
1977	6.546	2.785	10.307	29.3
1978	5.875	4.843	6.906	9.0
1979	7.443	5.604	9.282	12.6
1980	7.031	2.430	11.633	33.4
1981	13.183	9.517	16.849	14.2
1982	4.823	2.484	7.161	24.7
1983	3.958	1.609	6.307	30.3
1984	7.682	5.960	9.404	11.4
1985	3.451	2.658	4.244	11.7
1986	3.913	1.860	5.966	26.8
1987	2.703	1.940	3.467	14.4
1988	1.982	0.379	3.585	41.3
1989	9.132	3.456	14.808	31.7
1990	2.513	1.488	3.358	20.8
1991	2.063	1.109	3.017	23.6
1992	1.363	0.931	1.795	16.2
1993	0.736	0.543	0.928	13.3

Table A21. Stratified mean number per tow of bluefish at age: NMFS NEFSC autumn inshore bottom trawl survey, Cape Cod to Cape Hatteras (strata 1-46), 1982-1993

Year	Age									Total
	0	1	2	3	4	5	6	7	8+	
1982	21.632	12.434	0.074	0.061	0.013	0.000	0.002	0.004	0.020	34.246
1983	6.654	13.566	0.687	0.028	0.003	0.014	0.023	0.011	0.021	21.006
1984	39.210	19.697	0.606	0.097	0.058	0.025	0.031	0.033	0.007	59.841
1985	10.770	5.981	0.570	0.264	0.059	0.022	0.026	0.018	0.010	17.736
1986	31.524	8.514	0.448	0.080	0.053	0.039	0.031	0.019	0.033	40.748
1987	1.996	4.670	0.346	0.150	0.069	0.032	0.073	0.044	0.030	7.444
1988	28.733	1.421	0.077	0.018	0.032	0.055	0.033	0.025	0.050	30.468
1989	51.015	40.007	0.130	0.026	0.008	0.031	0.026	0.018	0.012	91.273
1990	4.614	4.369	0.225	0.009	0.013	0.015	0.026	0.017	0.033	9.321
1991	8.856	6.603	0.210	0.089	0.026	0.007	0.001	0.001	0.000	15.797
1992	14.181	3.399	0.169	0.066	0.020	0.003	0.006	0.007	0.009	17.865
1993	0.559	1.203	0.108	0.047	0.019	0.018	0.014	0.003	0.008	1.979

Aged using annual NC DMF age-length keys from North Carolina commercial fisheries, 1993 NC DMF keys used to age 1992 NEFSC lengths.

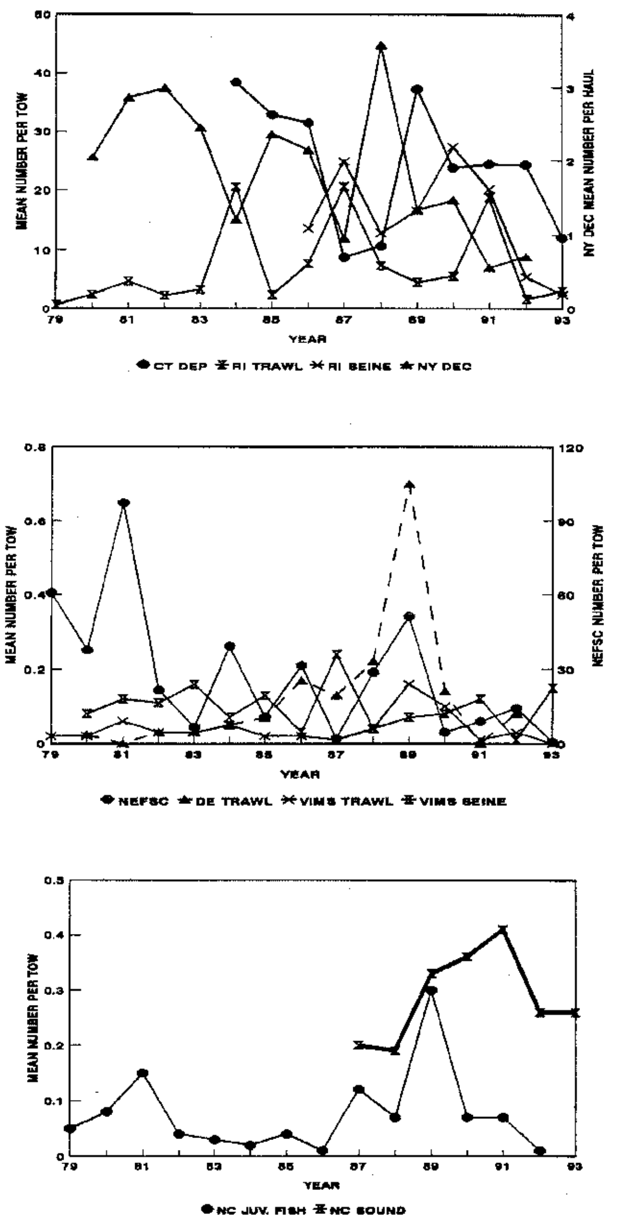

Figure A6. Indices of recruitment (age 0) for bluefish from research trawl surveys.

Rhode Island DFW

A standardized bottom trawl survey has been conducted during the fall months in Narragansett Bay and state waters of Rhode Island Sound by the Rhode Island Division of Fish and Wildlife (RI DFW) since 1979. An index of age 0 bluefish abundance developed from this survey (mean number per tow less than 30 cm) indicated strong year classes in 1984, 1987, and 1991, with very weak year classes in 1979 and 1992. The RI DFW has also conducted a beach seine survey consisting of 15 stations sampled during June-October since 1986. An age-0 index developed from those data indicated strong year classes in 1987, 1990, and 1991, with the poorest year classes in 1992 and 1993 (Figure A6).

Connecticut DEP

A fall (September-October) bottom trawl survey conducted by the Connecticut Department of Environmental Protection (CT DEP) catches bluefish over the full range of lengths in the stock. These data suggest that strong year classes recruited to the stock in 1984-1986, and 1989, with poor year classes in 1987, 1988 and 1993 (Figure A6).

New York DEC

The New York Department of Environmental Conservation (NY DEC) conducts a seine survey for striped bass in the Hudson River in which age-0 bluefish are also captured. These data suggest that strong year classes recruited to the stock in 1981, 1982, 1983, and 1988, with the poorest year classes since 1980 recruiting in 1991 and 1992 (Figure A6).

Delaware DFW

The Delaware Division of Fish and Wildlife (DE DFW) has conducted a standardized bottom trawl survey (30 ft headrope trawl with 0.5 in. stretch mesh) since 1980. A recruitment index (age 0, fish less than 30 cm) has been developed from these data for the 1980 to 1992 year classes. The index incorporates data collected from June through October (arithmetic mean number per tow), with age 0 bluefish separated from older fish by visual inspection of the length frequency. This index suggests that strongest year classes recruited to the stock in 1988 and 1989, with poorest recruitment in 1981 and 1991 (Figure A6).

Virginia Institute of Marine Science

The Virginia Institute of Marine Science (VIMS) has conducted a juvenile fish survey using trawl gear in Virginia rivers since 1955. A index of recruitment developed from these data suggests that since 1979, strongest year classes recruited to the bluefish stock in 1981, 1984, 1989, and

1990, and poorest year classes in 1979-1980, 1985-1987, and 1991. Results are incomplete for 1993. VIMS also conducts a haul seine survey targeting juvenile striped bass in Chesapeake Bay. An index of age 0 abundance for bluefish from this survey indicates strong year classes recruiting in 1983, 1985, 1987, 1991, and 1993, with poor year classes in 1986 and 1992 (Figure A6).

North Carolina DMF

The NC DMF has conducted a juvenile fish trawl survey that samples fixed stations from the Cape Fear River to the mouth of Albermarle and Currituck Sounds at depths less than 2 m, during May and June since 1979. One minute tows are made using a trawl with a 3.2 m headrope and 3.2 mm (0.13 in.) mesh codend. Indices of abundance developed from this survey using data for shrimp, croaker, and spot have shown good correlation with landings for those species. For age-0 bluefish, the NC DMF juvenile fish trawl survey suggests that strong year classes recruited to the stock in 1981, 1987, and 1989, with the poorest year classes recruiting in 1984, 1986, and 1992.

A recently established survey has sampled the Neuse and Pamlico Rivers and Pamlico Sound at depths greater than 2 m since 1987. This survey uses a demersal trawl rigged with a 9.1 m headrope and 1.9 cm (0.75 in.) mesh codend. An index of age-0 bluefish abundance developed from these survey data suggests that the best year classes of bluefish recruited in 1990 and 1991 (Figure A6).

Summary of Recruitment Trends in Research Surveys

Indices of abundance for bluefish from research surveys were used to qualitatively detect recent trends in recruitment. Most surveys agreed that the best recent year classes recruited in 1984 and 1989, with relatively poor year classes in 1992 and 1993 (Figure A6).

ESTIMATES OF MORTALITY AND STOCK SIZE

Natural Mortality Rate

At SARC 17, the SARC suggested that "values of M for bluefish in the range of 0.2 to 0.25 might be more appropriate" [than the value of 0.35 used in some previous analyses]. The Subcommittee has concluded that a value of M = 0.25 is consistent with the maximum age of 12 observed for bluefish, and that value of M has been used in the current analyses.

Partial Recruitment Pattern

The Subcommittee reviewed a series of separable VPA runs (SVPAs) to examine the sensitivity of the partial recruitment pattern to a range of values of terminal S (selection on the oldest true age in the catch-at-age matrix [age 8] relative to the SVPA reference age [age 2]). Over a wide range of terminal S values (0.1 to 1.0), partial recruitment increased from age 0 to age 2, declined at ages 3 through 5, and increased at age 6 (with the rate of increase dependent on the terminal S used). Analyses of catch-at-age matrices by fishery (recreational, NER commercial, and North Carolina commercial) revealed that this "saddle-shaped" partial recruitment pattern was common to all of the fisheries. Inspection of the residuals of the log-catch ratios showed no systematic patterns that might suggest model misspecification - indicating that the separable model was appropriate and that the partial recruitment pattern appeared constant during the 1982-1992 period.

Using the total catch-at-age matrix, a terminal value of 0.7 at age 8 produced stable PR values (at about 0.7) for age groups 6-8. The Subcommittee noted that because the selection pattern was not flat-topped, catch curve analyses used to estimate fully-recruited fishing mortality should include only those age groups with PR values near 1.0. In summary, the Subcommittee agreed that the "saddle-shaped" partial recruitment pattern indicated by the SVPAs were real, but could not conclusively establish why they occurred for bluefish.

CAGEAN Model

A series of different configurations of the CAGEAN model for the analysis of catch-at-age and effort data (Deriso *et al.* 1985) were conducted as a means to estimate fishing mortality rates and stock size for bluefish. The CAGEAN model is based on the log-catch equation (Doubleday 1976) that incorporates the separability assumption and the assumption that observed catch-at-age differs from predicted values

Table A22. Fishing mortality at age (F) for bluefish: CAGEAN CT run point estimates

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	0.144	0.228	0.160	0.175	0.217	0.143	0.126	0.105	0.109	0.127	0.123	0.146
1	0.196	0.311	0.217	0.238	0.296	0.437	0.385	0.322	0.333	0.389	0.377	0.447
2	0.196	0.311	0.217	0.238	0.296	0.437	0.385	0.322	0.333	0.389	0.377	0.447
3	0.147	0.233	0.163	0.178	0.222	0.353	0.311	0.260	0.269	0.314	0.304	0.361
4	0.072	0.115	0.08	0.088	0.110	0.204	0.180	0.151	0.156	0.182	0.176	0.209
5	0.092	0.146	0.102	0.112	0.139	0.249	0.219	0.183	0.190	0.221	0.214	0.254
6	0.176	0.280	0.196	0.214	0.267	0.263	0.232	0.194	0.200	0.234	0.227	0.269
7	0.317	0.505	0.353	0.386	0.480	0.388	0.342	0.285	0.295	0.345	0.334	0.396
8	0.527	0.838	0.585	0.641	0.796	0.440	0.388	0.324	0.336	0.392	0.380	0.450
9+	0.344	0.548	0.383	0.419	0.521	0.163	0.144	0.120	0.125	0.146	0.141	0.167
mean F: 0-9+	0.221	0.352	0.246	0.269	0.334	0.308	0.271	0.227	0.235	0.274	0.265	0.315
F @ S=1.0	0.196	0.311	0.217	0.238	0.296	0.437	0.385	0.322	0.333	0.389	0.377	0.447

by a log-normal random variable. The model can incorporate various types of auxiliary (tuning) data, including measures of fishing effort and survey catch at age, to help calibrate estimates of stock size and fishing mortality rates. If fecundity at age data are available, a spawner-recruit relationship (Ricker) can be added to the model. CAGEAN uses the Marquardt technique to solve this system of non-linear least-squares equations to provide estimates of total population numbers, total stock biomass, fully recruited fishing mortality rates, catchability coefficients, and partial recruitment values. The influence that the various types of tuning data have on the parameter estimates from the objective function can be varied by adjusting penalty weights (lambda) for each component of the objective function: 1) fishery catch, 2) survey catch, 3) fishery effort, and 4) Ricker S-R function. The final CAGEAN run assumes two periods with differing catchability to the fisheries. This adjustment was necessary to ameliorate highly trended residual patterns with respect to observed vs. predicted effort trends. The two-period catchability helps to reconcile the modest decline in standardized recreational CPUE of 29% over the 1979-1993 period (Figure A5), with the 79% reduction in recreational catch over the same period (Figure A2). An ADAPT formulation incorporating stock-size dependent catchability, as compared with time-varying catchability in the CAGEAN analysis was also completed.

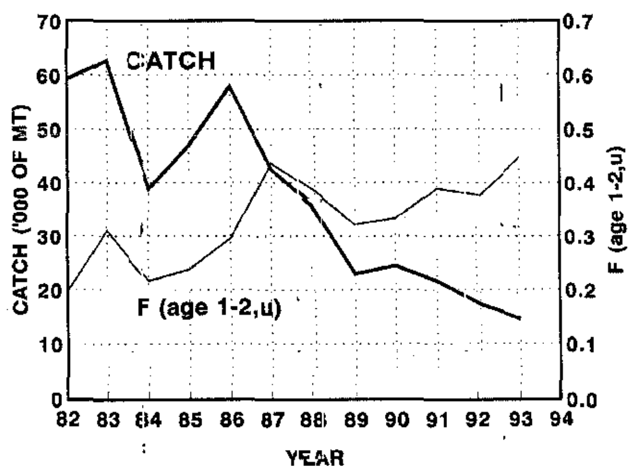

Figure A7. Trends in total catch (commercial landings, recreational landings and discard, 1000 mt) and fishing mortality (fully recruited F) for bluefish, 1982-1993.

CAGEAN Results

Point estimates of stock size and fishing mortality

Fully recruited fishing mortality rates for bluefish increased from about 0.20 in 1982 to about 0.4 in 1987, declined slightly to about 0.3 in 1989 and 1990, and then increased to about 0.45 in 1993 (Table A22, Figure A7). Recruitment at age-0 varied from 75 to 87 million fish during

Table A23. Stock numbers at age (thousands of fish) for bluefish: CAGEAN CT run point estimates

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	87156	75388	78609	39292	30337	18842	40770	44614	28324	23692	17140	4223
1	69051	58791	46715	52170	25688	19006	12709	27974	31249	19770	1623	411792
2	33850	44212	33531	29261	32012	14875	9556	6731	15782	17435	10428	8670
3	20875	21676	25220	21009	17959	18543	7482	5063	3799	8808	9200	5571
4	17389	14041	13369	16689	13689	11205	10145	4269	3040	2261	5009	5285
5	12169	12596	9745	9607	11901	9555	7113	6598	2860	2026	1468	3271
6	5047	8644	8473	6851	6689	8063	5803	4450	4279	1843	1264	922
7	4689	3295	5086	5425	4306	3990	4828	3585	2855	2727	1136	785
8	4780	2658	1549	2784	2872	2075	2109	2672	2099	1655	1504	633
9+	7075	6103	3644	2607	2478	2155	2466	2777	3422	3521	3242	2994
Total:	262081	247404	225941	185695	147931	108309	102981	108733	97709	83738	66625	44146

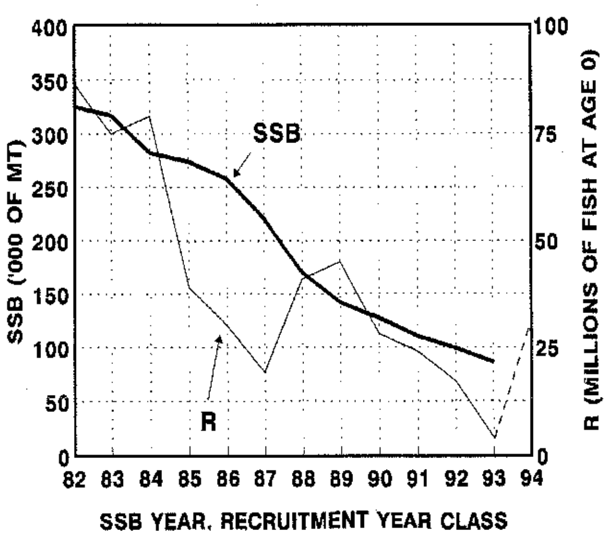

Figure A8. Trends in spawning stock biomass (1000 mt) and recruitment (millions of fish at age-0) for bluefish, 1982-1993.

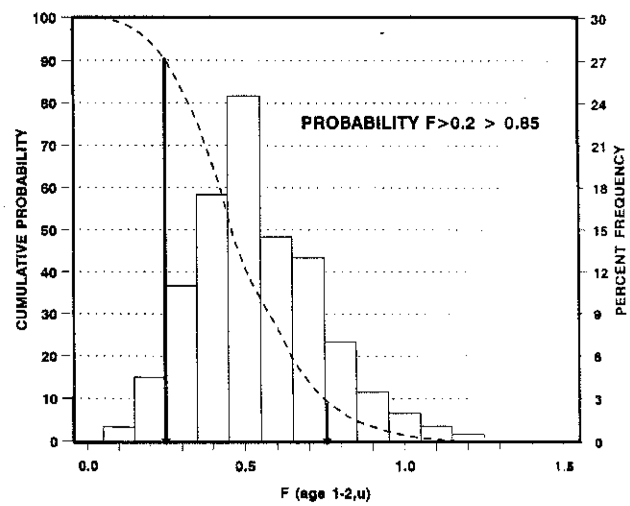

Figure A9. Precision of the estimates of fully recruited F in 1993 for bluefish. Vertical bars display the range of the bootstrap estimate and the probability of individual values in that range. The dashed line gives the probability that F is greater than anyvalue along the X axis.

1982-1984, but has declined substantially since then, with the best recent year classes recruiting to the stock in 1988 (41 million) and 1989 (45 million). Geometric mean recruitment during 1982-1993 was about 32 million age-0 bluefish. Recruitment since 1989 has been below average, and the 1993 year class of only 4 million fish is the poorest of the time series (Table A23, Figure A8). Thus, although catches have dropped in recent years, F has risen because poor recruitment has resulted in reduced stock abundance (Figures A7-A8).

Bootstrap estimates of stock size and fishing mortality rates

Coefficients of variation for CAGEAN estimates of spawning stock biomass, recruitment and fishing mortality varied from less than 20% during 1982-1984 to about 50% in 1993 (Table A24). The distribution of bootstrapped fully recruited F estimated for ages 1 and 2 was broad, with 80% of the values between 0.3 and 0.7 (Figure A9). This distribution resulted in a bootstrap mean value for F in 1993 (0.494) that is higher than the point estimate (0.447). The bootstrap results suggest there is greater than an 85% chance that F in 1993 was greater than 0.20, the mid-point of Fmsy values. The distribution of bootstrap estimates of bluefish spawning stock biomass indicated an 80% probability that 1993 spawning stock biomass was between 75,000 and 125,000 mt (Figure A10).

Table A24. CAGEAN point estimate and bootstrap replication results (200 runs) for run configuration: CT

Year	Point SSB (1000 mt)	Boot SSB (1000 mt)	Boot SSB CV(%)	Point Recruits (E+6)	Boot Recruits (E+6)	Boot Recruits	Point Full CV (F%) (CV%)	Boot Full F	Boot Full F
1982	326	407	8	87	90	11	0.196	0.197	18
1983	317	372	8	75	77	12	0.311	0.316	19
1984	282	316	9	79	81	13	0.217	0.220	19
1985	274	295	9	39	42	14	0.238	0.237	20
1986	258	298	10	30	33	15	0.296	0.301	20
1987	221	239	12	19	21	17	0.437	0.452	21
1988	170	179	15	41	43	17	0.385	0.416	25
1989	142	156	20	45	46	21	0.322	0.336	25
1990	127	138	24	28	30	25	0.333	0.350	29
1991	110	116	30	24	25	29	0.389	0.415	31
1992	99	107	40	17	20	42	0.377	0.401	40
1993	86	95	50	4	6	47	0.447	0.494	48

Fishery Partial Recruitment Pattern: Point Estimate

1982-1986		1987-1993	
Age	**S**	**Age**	**S**
0	0.73	0	0.33
1	1.00	1	1.00
2	1.00	2	1.00
3	0.75	3	0.81
4	0.37	4	0.47
5	0.47	5	0.57
6	0.90	6	0.60
7	1.62	7	0.89
8	2.69	8	1.01
9+	1.76	9+	0.37

Note: Run uses CAT/TAR GLM CPUE index to derive fishery effort, NEFSC catch at age, time-varying fishery catchability (q) and selectivity (S) and constant survey catchability (q) and selectivity (S), S fixed in fishery for ages 1-2, S fixed in survey for ages 3 and older. The fit to the Ricker spawner-recruit relationship is given moderate weight ($\lambda = 0.50$) in the objective function.

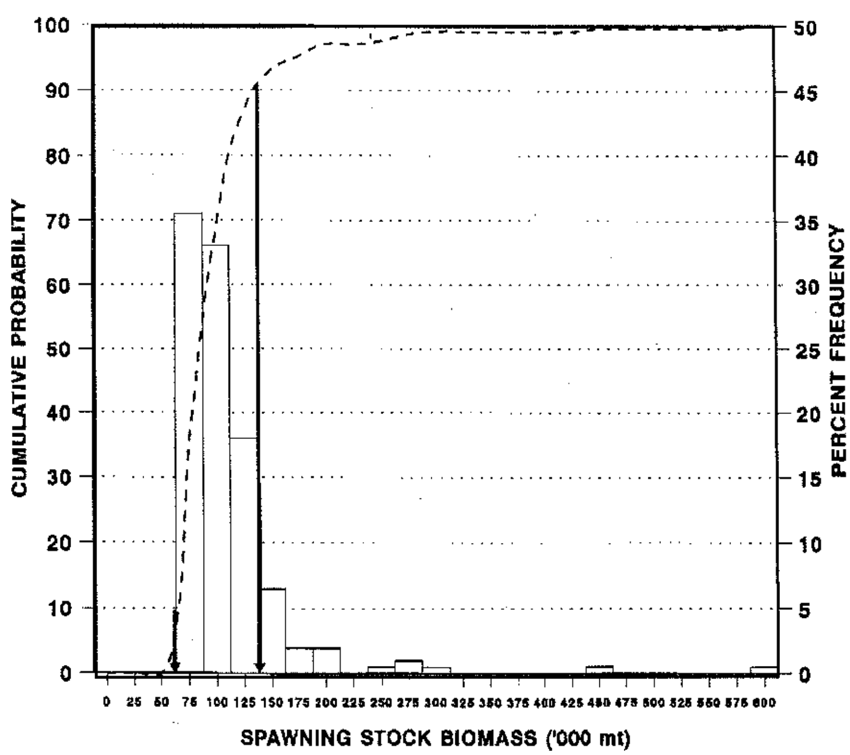

Figure A10. Precision of the estimates of SSB in 1993 for bluefish. Vertical bars display the range of the bootstrap estimate and the probability of individual values in that range. The dashed line gives the probability that SSB is less than any value along the X axis.

Table A25. Results of ADAPT tuning of bluefish catch at age, recreational abundance indices and NMFS survey indices; analyses based on a flexible catchability model for the relationship between recreational abundance indices and stock numbers (*e.g.* I = q ln N)

STOCK NUMBERS (Jan 1) in thousands - T93

	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	93119	78496	83996	46124	35692	22686	26591	47946	33660
1	78698	61663	53007	58199	31272	21731	14836	18961	34584
2	38867	50588	39196	34614	38979	17722	11978	8953	9986
3	26161	27264	30079	24077	21429	22345	9049	6271	4173
4	36705	17878	18218	21536	15391	13761	12117	5515	3973
5	23955	27826	12778	13337	15469	10959	8848	7790	3955
6	22718	17522	20151	9168	9742	10513	7526	5633	5062
7	13457	16351	11172	14776	5733	6431	6618	5149	3694
8	15809	9375	11213	7792	10778	3571	4003	4162	3428
9+	23285	14312	19914	8987	7486	2782	4903	2579	2777
	372773	321275	299725	238610	191973	132501	106470	112959	105292

	1991	1992	1993	1994
0	28388	16809	3799	0
1	23799	19001	11223	2419
2	20270	13978	6052	5553
3	6051	9452	9054	2848
4	2595	3347	5189	4956
5	2734	1743	2085	2840
6	2677	1931	934	1141
7	2899	1592	1346	511
8	2474	1472	1037	737
9+	788	793	691	946
	92675	70119	41409	21950

FISHING MORTALITY - T93

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.1622	0.1426	0.1169	0.1386	0.2462	0.1747	0.0882	0.0767	0.0967	0.1515
1	0.1919	0.2031	0.1762	0.1508	0.3179	0.3456	0.2551	0.3912	0.2842	0.2821
2	0.1046	0.2699	0.2373	0.2295	0.3064	0.4222	0.3972	0.5133	0.2510	0.5129
3	0.1307	0.1531	0.0841	0.1974	0.1929	0.3620	0.2451	0.2064	0.2250	0.3421
4	0.0269	0.0859	0.0619	0.0808	0.0897	0.1917	0.1918	0.0826	0.1237	0.1480
5	0.0627	0.0727	0.0820	0.0641	0.1363	0.1258	0.2015	0.1811	0.1404	0.0979
6	0.0788	0.2000	0.0602	0.2194	0.1653	0.2128	0.1295	0.1719	0.3074	0.2695
7	0.1115	0.1272	0.1103	0.0655	0.2234	0.2240	0.2137	0.1569	0.1510	0.4275
8	0.0744	0.1243	0.0776	0.1232	0.1552	0.2447	0.1981	0.1628	0.1954	0.2720
9	0.0744	0.1243	0.0776	0.1232	0.1552	0.2447	0.1981	0.1628	0.1954	0.2720

	1992	1993
0	0.1540	0.2016
1	0.8942	0.4535
2	0.1843	0.5039
3	0.3498	0.3527
4	0.2232	0.3527
5	0.3740	0.3527
6	0.1110	0.3527
7	0.1788	0.3527
8	0.2868	0.3527
9	0.2868	0.3527

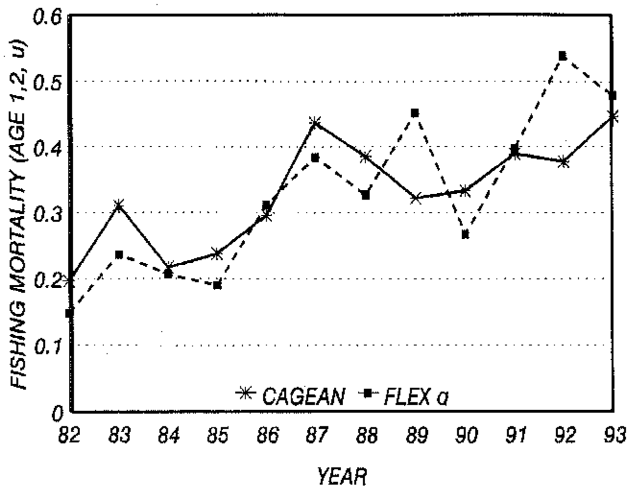

Figure A11. Comparison of average fishing mortality rates (ages 1 and 2, unweighted) from CAGEAN and ADAPT analyses. The CAGEAN analysis includes a time-varying catchability parameter, while the ADAPT includes a variable catchability of the recreational fishery to stock abundance.

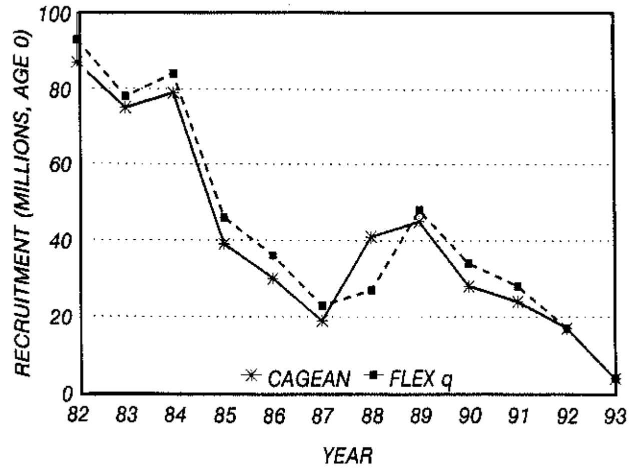

Figure A12. Comparison of recruitment levels (age 0, in millions of fish) from CAGEAN and ADAPT analyses. The CAGEAN analysis includes a time-varying catchability parameter, while the ADAPT includes a variable catchability of the recreational fishery to stock abundance.

ADAPT VPA Model

A series of retrospective ADAPT VPA runs (Parrack 1986, Gavaris 1988, Conser and Powers 1990), using SARC recommendations of M=0.25, ages 0-9+, and a time series from 1982-1992, were conducted to examine sensitivity of the model to input tuning series, and the suitability of VPA for estimating bluefish mortality and abundance. The ADAPT VPAs were tuned using various combinations of the following indices of abundance: 1) recreational fishery CAT/TAR and TAR ONLY indices, 2) NEFSC fall inshore survey catch-at-age indices, 3) CT DEP survey catch-at-age indices, and 4) recruitment indices from the states of Rhode Island, Delaware, Virginia, and North Carolina trawl surveys. The retrospective VPAs produced inconsistent results among the different runs. This is probably due to: 1) the relatively low F indicated by the tuning data with the best fit (smallest residuals) in the analysis (*i.e.*, the recreational CPUE indices), 2) the large number of ages in the catch-at-age matrix (10 ages), and 3) the brevity of the VPA time series (11 years) relative to the number of age groups in the catch-at-age matrix. Most importantly, the trial ADAPT runs indicated a strong pattern of residuals indicating that the modest declines in standardized recreational CPUE could not be completely reconciled with the very large decline in (particularly) the recreational catch. This inconsistency was reconciled partially in the CAGEAN run by using a time-varying catchability, which resulted in an approximate doubling of F in recent years, even though CPUE declined more modestly.

A new ADAPT formulation was attempted in which the standard objective function was modified slightly to allow the recreational CPUE index of abundance to vary as a non-linear function of stock size. In the standard ADAPT formulation, both survey and fishery abundance indices are assumed linearly-related to stock size (*e.g.* $I = q N$, where I is the abundance index, q is the age-specific catchability coefficient, and N is stock numbers). The alternative ADAPT function allowed the index of recreational abundance to vary as a logarithmic function of stock size: $I = q \ln N$. With this formulation, the highly trended residual pattern was ameliorated, and estimates of fishing mortality and stock sizes were similar to CAGEAN results (Table A25; Figures A11 and A12). In particular, estimates of average fishing mortality (age 1 and 2, unweighted) and recruitment were very similar in most years. SSB estimates were similar in both runs, except in the earliest years, when the ADAPT run estimated higher SSBs.

Although the ADAPT run incorporating variable catchability was only presented as a sensitivity analysis, conceptually it has advantages over the time-varying catchability model proposed with the CAGEAN run. If fishery catchability is increasing as the bluefish stock declines, the ADAPT formulation ($I = q \ln N$) can model this phenomenon as a continuous function, and no

Table A26. Thompson and Bell (1934) yield per recruit analysis for bluefish:1987-1993 arithmetic mean weights at age, CAGEAN 1987-93 PR vector, CT run configuration

Proportion of F before spawning:	.2500
Proportion of M before spawning:	.5000
Natural mortality is constant at:	.250
Initial age is: 0; Last age is:	12
Last age is a PLUS group;	

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Stock	Average Weights Catch
0	.3300	1.0000	.0000	.150	.150
1	1.0000	1.0000	.5000	.386	.386
2	1.0000	1.0000	1.0000	.958	.958
3	.8100	1.0000	1.0000	1.947	1.947
4	.4700	1.0000	1.0000	3.041	3.041
5	.5700	1.0000	1.0000	3.810	3.810
6	.6000	1.0000	1.0000	4.780	4.780
7	.8900	1.0000	1.0000	5.550	5.550
8	1.0100	1.0000	1.0000	6.045	6.045
9	.3700	1.0000	1.0000	6.812	6.812
10	.3700	1.0000	1.0000	7.615	7.615
11	.3700	1.0000	1.0000	7.869	7.869
12+	.3700	1.0000	1.0000	8.184	8.184

Slope of the Yield/Recruit Curve at F=0.00:----->5.7627
F level at slope=1/10 of the above slope (F0.1): ——> .203
Yield/Recruit corresponding to F0.1: ——> .4933
F level to produce Maximum Yield/Recruit (Fmax): ——>.295
Yield/Recruit corresponding to Fmax: ——> .5160
F level at 20 % of Max Spawning Potential (F20): ——> .369
SSB/Recruit corresponding to F20: ————> 1.8347

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	4.5208	10.6989	2.7635	9.1767	100.00
	.050	.11894	.22844	4.0479	8.3892	2.3295	7.0850	77.21
	.100	.21287	.36706	3.6752	6.6863	1.9892	5.5503	60.48
	.150	.28834	.44789	3.3763	5.4114	1.7179	4.4071	48.02
	.200	.34993	.49153	3.1330	4.4429	1.4985	3.5433	38.61
F0.1	.203	.35320	.49326	3.1201	4.3933	1.4869	3.4993	38.13
	.250	.40090	.51131	2.9322	3.6969	1.3187	2.8819	31.40
Fmax	.295	.43978	.51597	2.7794	3.1659	1.1830	2.4137	26.30
	.300	.44364	.51593	2.7643	3.1150	1.1695	2.3690	25.82
	.350	.47990	.51107	2.6223	2.6555	1.0445	1.9666	21.43
F20%	.369	.49245	.50750	2.5733	2.5042	1.0015	1.8347	19.99
	.400	.51098	.50047	2.5010	2.2885	.9386	1.6473	17.95
	.450	.53788	.48658	2.3963	1.9923	.8481	1.3914	15.16
	.500	.56136	.47100	2.3053	1.7509	.7703	1.1843	12.91
	.550	.58202	.45477	2.2255	1.5523	.7027	1.0152	11.06
	.600	.60034	.43854	2.1551	1.3876	.6438	.8760	9.55
	.650	.61668	.42272	2.0925	1.2500	.5921	.7606	8.29
	.700	.63135	.40756	2.0365	1.1340	.5464	.6642	7.24
	.750	.64459	.39320	1.9862	1.0357	.5059	.5832	6.36
	.800	.65661	.37969	1.9407	.9519	.4698	.5147	5.61
	.850	.66756	.36705	1.8995	.8798	.4374	.4564	4.97
	.900	.67760	.35527	1.8618	.8177	.4084	.4065	4.43
	.950	.68683	.34431	1.8273	.7637	.3821	.3637	3.96
	1.000	.69536	.33413	1.7956	.7166	.3584	.3267	3.56

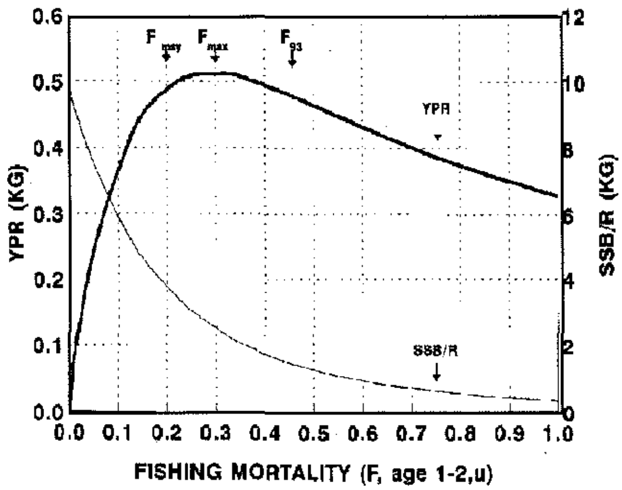

Figure A13. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R)for bluefish.

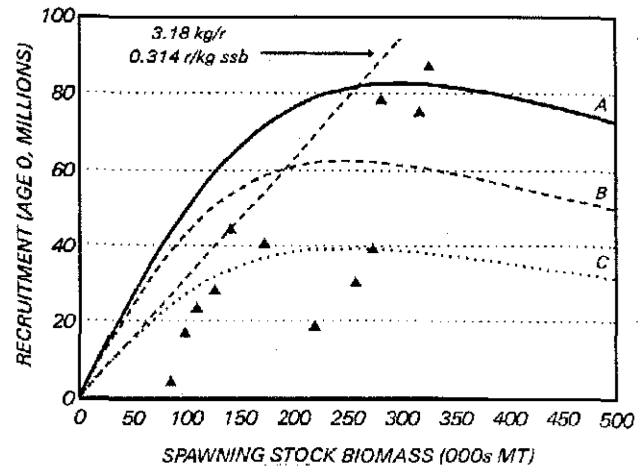

Figure A14. Stock-recruitment calculations for bluefish, based on CAGEAN results of calculated spawning stock biomass (1000 mt) and recruitment (age 0, millions of fish). Parameters for S/R curves labeled A, B and C are given in Table 27.

constant partial recruitment pattern is modeled (separability assumption). The current CAGEAN model must employ a discrete time step, and the separability assumption must be accepted. In spite of these differences in the underlying concepts, however, the ADAPT VPA and CAGEAN models produce similar assessment results, particularly in the most recent years. Advice was provided using CAGEAN results.

BIOLOGICAL REFERENCE POINTS

Revised biological reference points for bluefish were calculated with the Thompson and Bell (1934) model and the Shepherd (1982) approach for developing sustainable yield curves and estimates of F_{msy}. Input data included M = 0.25, mean weights at age for ages 0-12 in the stock and fishery averaged for 1987-1993, and partial recruitment vector estimated by CAGEAN for 1987-1993 (CT run configuration). The Thompson and Bell yield per recruit analysis indicated that $F_{0.1}$ = 0.203, F_{max} = 0.295, and $F_{20\%}$ = 0.369 (Table A26, Figure A13).

The sensitivity of Y/R and SSB/R to age 0 catches was evaluated. By eliminating fishing on age 0 fish, SSB/R and Y/R increased 16% and 11% respectively at the current fish mortality rate (F=0.45).

Stock-recruitment data from the CAGEAN analysis were used to give some general guidance as to the shape of stock recruitment curves for

Table A27. Parameters of Shepherd stock-recruitment curves fitted to data for bluefish.

Run	Alpha	Beta	Kappa	Fmsy	MSY
A	0.550	2.0	300	0.24	41.167
	0.500	2.0	300	0.22	36.82
B	0.500	2.0	250	0.22	30.689
	0.314	2.0	300	0.19	29.052
C	0.314	2.0	250	0.15	16.226
	0.314	2.0	200	0.15	13.005

The S/R curve is given by R = alpha*beta/[1+(beta/kappa)^beta]. Letter designations A,B and C refer to curves plotted in Figure 14. MSY values are in metric tons.

bluefish, and in particular, the slope of the S/R curve near the origin, and the level of spawning stock biomass necessary for producing various levels of recruitment (Figure A14; Table A27). Because of the short time series of stock/recruitment available, and the strong time trend in the series, no definitive conclusions regarding the S/R curve can be given. Nevertheless, a number of alternative S/R functions generally bound high and low levels of recruitment observed since 1982, and allow for the calculation of F_{msy} as a range (Table A27). It is likely that at very high levels of spawning stock biomass some overcompensation occurs due to cannibalism. Therefore the Beta parameter of the S/R curve was set to 2.0. The time series of S/R data used in the

Table A28. Input parameters and projection results for bluefish: landings and stock biomass (thousands of mt)

Age	Stock size in 1993	Fishing Mortality Pattern	Proportion Mature	Mean Weights Landings
0	4223	0.33	0.00	0.158
1	11792	1.00	0.50	0.366
2	8670	1.00	1.00	0.952
3	5571	0.81	1.00	1.897
4	5285	0.47	1.00	3.028
5	3271	0.57	1.00	3.839
6	922	0.60	1.00	4.835
7	785	0.89	1.00	5.529
8	633	1.01	1.00	6.008
9+	2994	0.37	1.00	7.780

$F_{1994-95}$		1994		1995	
		Landings	SSB	Landings	SSB
F_{msy_low}	=0.150	5.6	59.8	6.2	58.8
F_{msy}	=0.200	7.3	59.3	7.9	56.5
F_{msy_high}	=0.250	9.0	58.9	9.5	54.4
F_{max}	=0.295	10.5	58.5	10.7	58.5
F_{93}	=0.447	15.2	57.2	14.2	46.7

Starting stock sizes on 1 January 1993 are as estimated by CAGEAN. Mean weights at age (stock biomass, landings) are arithmetic means of 1987-93 values. Recruitment levels in 1994-95 are estimated as the geometric mean of numbers (thousands) at age 0 (31,688) during 1982-93. F_{93} is the fully recruited F point estimate of the CAGEAN CT run configuration. F_{max} = 0.295 is a biological reference point calculated in the yield per recruit analysis for this assessment. F_{msy} values reflect low, medium, and high values for the initial slope of the stock-recruitment relationship. Proportion of F and M before spawning = 0.25 (spawning peak at 1 April). Partial recruitment vector and landings include recreational discard with a 25% hooking mortality rate.

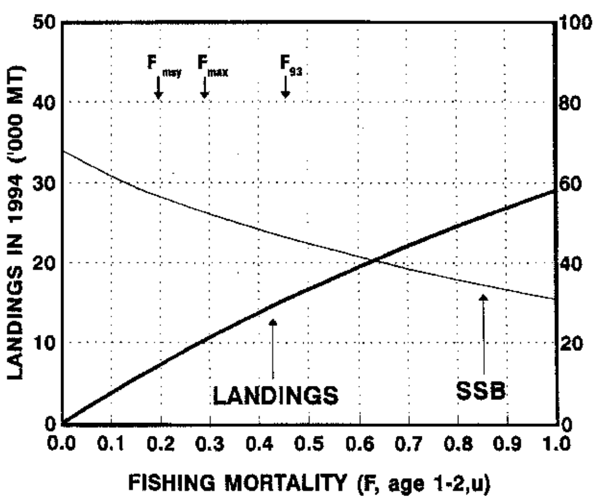

Figure A15. Predicted landings (commercial landings, recreational landings, and recreational discards) in 1994 and spawning stock biomass in 1995 for bluefish over a range of fishing mortalities in 1994, from F = 0.0 to F = 1.0 (data are given in Table 28).

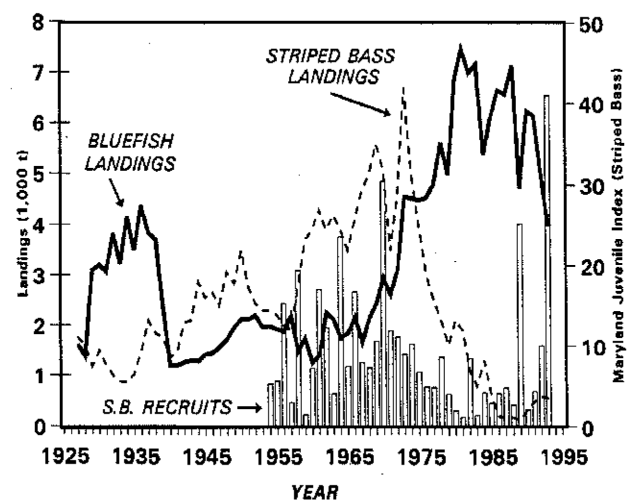

Figure A16. Trends in commercial landings of striped bass and bluefish, 1927-1993, and the Maryland juvenile striped bass abundance index, 1954-1993.

analysis suggest a rather shallow slope of the S/R curve near the origin (0.314 million recruits per thousand mt of SSB), consistent with a species highly susceptible to recruitment overfishing, even at moderate F levels. Even when steeper curves were simulated, the F_{msy} values were in all cases below F = 0.25. Given the time-series of data available for this analysis, F_{msy} is tentatively determined to be in the range of 0.15-0.25 (Table A27).

PROJECTIONS

Projections of landings and spawning stock biomasses in 1994 and 1995 are given in Table A28 and Figure A15. These projections were made using the terminal population sizes in 1993 from the CAGEAN run. Recruitment was assumed to be constant at the geometric mean of the 1982-1993 period (31.7 million age-0 fish). Projections are made assuming five biological reference points for the stock (F_{93}, F_{max}, and three alternative F_{msy} values; Table A28, Figure A15). Landings at the status quo fishing mortality level (F_{93} = 0.447) generate catches of 15,200 and 14,200 mt in 1994 and 1995, respectively. Spawning stock biomass declines from 57,200 to 46,700 mt. At F_{max}, landings in both years are about 11,000 mt, and SSB is 59,000 mt. If the mid-range F_{msy} value of 0.2 is used, landings are less than 8,000 mt in both prediction years, but SSB remains below 60,000 mt. Thus, even under average recruitment scenarios, SSB will decline substantially below the 1993 value of 86,000 mt, although landings do stabilize under status quo F. If recruitment in 1994 and 1995 is similar to that in 1993 (4 million fish), then 1994 and 1995 landings and SSB will decline substantially from 1993 levels.

COMPARISON OF BLUEFISH AND STRIPED BASS POPULATION TRENDS

The apparent coincident decline of the bluefish stock with increased abundance of striped bass has prompted much speculation regarding the potential for biological interactions among the species. The SARC reviewed long-term changes in commercial landings, and recruitment data for the two species (Figure A16). Based on this information, there is no evidence to suggest that increased predation by striped bass is implicated in the decline of bluefish, since the decline in bluefish preceded the appearance of the 1989 year class of striped bass in Chesapeake Bay. An exhaustive analysis of information on the subject was beyond the scope of the SARC, and further work on the subject is warranted.

SARC DISCUSSION

There was a lengthy discussion regarding the use of the CAGEAN model and the assumptions on which model results were based. The SARC focused on the use of catchability coefficients (q) and selectivities for the fishery that varied for two time periods (1979-1986; 1987-1993) in the assessment. Subcommittee members indicated that the use of two different q's removed trends in fishery effort residuals and improved the fit of the model. Selectivities in the fishery were divided into the same time periods to be consistent. It was noted that changes in q could be theoretically justified based on a possible range contraction in the stock. The MRFSS data, which indicate a greater decline in bluefish CPUE in the more northern states, support this hypothesis (Figures A3-A4). The SARC noted that it was important to indicate that the model results were sensitive to the assumption of time-varying q and that evidence to support this assumption was based primarily on indirect evidence. Work on a variable catchability version of ADAPT, conducted at the SARC, represents a promising new development for the assessment of not only bluefish, but for other pelagic stocks for which fishery performance measures change at different rates than the size of the stock.

There was some discussion regarding the use of the NEFSC fall survey as an index of stock size, specifically since this index was used as a tuning index in the CAGEAN model. The SARC discussed the possibility that larger, older fish may be less available to the survey gear resulting in a bias in the index. However, it was noted that the survey index did indicate a decline in older fish in recent years. In addition, the Subcommittee had examined model configurations which did not use the NEFSC survey as a tuning index and the results were unrealistic.

The SARC discussed the possible reasons for the decline in stock size from 1982 to 1993. (Note that the following discussion occurred prior to the calculation of the F_{msy} [0.2] each year since 1982. Fishing mortality rates in excess of F_{msy} would also account for reductions in stock biomass.) The discussion focused on the fact that fishing mortality rates based on model results were not high in earlier years and only recently exceeded F's associated with various biological reference points. Assessment results suggested that a consistent decline in recruitment over the time period largely accounted for the decline in stock biomass. However, the SARC noted that increases in F in recent years suggest that the stock is overfished and mortality rates should be reduced to help stabilize the decline in stock biomass.

The SARC discussed the possible reasons for the decline in recruitment. Several factors were identified including changes in the relative contribution of the spring and summer cohorts to the coastwide age-0 year class. It was noted that Rhode Island trawl survey data indicate a greater decline in the spring cohort relative to the summer cohort in recent years. In addition, the SARC noted that bluefish are continental shelf spawners that are highly dependent on ocean currents for transport of larvae into inshore nursery areas. As such, changes in currents could produce conditions that were unfavorable to year class success.

The SARC also indicated that reductions in stock biomass could be associated with an underestimation of fishing mortality rates and an overestimation of the biological reference points. Specifically, the mortality rates on age-0 fish over the time series could have been underestimated for two reasons: the assessment assumes that natural mortality of age-0 fish was identical to that used for older bluefish, and the assessment did not account for bycatch/discard mortality of age-0 fish in the commercial shrimp fishery. The SARC noted that higher mortality rates on age-0 fish would decrease the biological reference points.

The SARC noted that software limitations had restricted the ability of the Subcommittee to conduct additional analyses with non-traditional model formulations. They indicated that the current DeLury software allowed the input of only one abundance index. In addition, the ADAPT VPA software restricts input of only one catchability coefficient. The SARC recommended that these software packages be modified to increase the flexibility of future analyses.

SARC RESEARCH RECOMMENDATIONS

1. The intensity of biological sampling of the NER commercial and coastwide recreational fisheries (expressed as mt/100 lengths) has historically been low, and has worsened since 1989 for the NER commercial fishery. The Subcommittee recommends increased biological sampling of the NER commercial and recreational fisheries (including discards of age 0 fish from all sources), and the extreme importance of initiating the collection of age samples from the recreational fishery.

2. The Subcommittee noted the discrepancy between mean weight per fish in the recreational catch as calculated from the MRFSS weight frequency sample data (Table A20) and as calculated from the MRFSS length frequency sample data, converted to weight by the Wilk (1977) length-weight equation. Previous examination of the MRFSS length-weight data during SAW 11 indicated that the length-weight data for bluefish (and for other species such as summer flounder) are quite variable, to the degree that length-weight relationships estimated from the MRFSS sample data are too imprecise to be used in assessments. The Subcommittee feels that better quality (more precise) length and weight sample data, along with age sample data, needs to be collected in the MRFSS to improve the quality of recreational fishery component of stock assessments.

3. A great deal of discussion was undertaken regarding the appropriate measure of effort for the recreational fishery. The Subcommittee recommends further research on recreational fishery CPUE measures, including the use of non-parametric methods (*e.g.*, ranks, bootstrap) to provide estimates of the mean and variance of CPUE, and the use of the proportion of positive catch trips as an alternate index of abundance.

4. The question of the units of effort expended in recreational CPUE was also raised, *i.e.* whether catch per trip is a realistic measure when trips may be of variable duration. The Subcommittee intends to assess these topics and explore the potential effect of these parameters.

5. The time series of estimates of recreational catch is being revised by the MRFSS staff, and new estimates are available for 1992 and 1993. Revision of recreational fishery catch estimates used in the assessment should be done when the entire revised time series is available.

6. The SARC reviewed recent trends in landings and recruitment of striped bass and bluefish, to evaluate the potential for biological interactions among the species to influence recruitment. Although no definitive conclusions were reached, it is unlikely that recent declines in the bluefish stock are due to increased striped bass recruitment. Nevertheless, the potential for competition for prey exists, and bluefish may prey on striped bass. It was therefore concluded that additional research on interactions among these species is warranted.

7. The SARC recommended that research be conducted to determine the timing of sexual maturity and fecundity of bluefish. It was suggested that maturity schedules used in the assessment may have changed as the population has declined.

8. The SARC discussed bluefish recruitment dynamics and indicated that research on oceanographic influences on bluefish recruitment should be emphasized. This research is particularly important since observed declines in recruitment could not be attributed to sustained recruitment overfishing (see discussion of Maltiple cohort hypotheses on page 18).

9. The SARC noted that the assumption of 2 periods of differing catchability incorporated into the CAGEAN model should be more rigorously tested. Preliminary work conducted by the SARC indicated that a version of the ADAPT procedure incorporating increasing fishery q an inverse function of stock size was a promising approach for this and other pelagic stocks, and should be pursued.

10. No direct information on hooking mortality of bluefish is available. Given the high rate of release of recreationally-caught fish, such studies are considered important in refining assessment results.

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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.

b. Provide catch and SSB forecasts incorporating uncertainty in recruitment and F estimates (*e.g.*, in a Risk format).

INTRODUCTION

For assessment purposes, the previous definition of Wilk *et al.* (1980) of a unit stock extending from Cape Hatteras north to New England has been accepted. The Mid-Atlantic Fishery Management Council (MAFMC) Fishery Management Plan (FMP) for summer flounder has as a management unit all summer flounder from the southern border of North Carolina, northeast to the U.S.-Canadian border. Amendment 2 to the FMP was accepted by the Secretary of Commerce in August, 1992. The FMP has set a target fishing mortality rate (F_{tgt}) of 0.53 for 1993-1995, with a target of F_{max} = 0.23 for 1996 and beyond.

Major regulations enacted under Amendment 2 to meet these fishing mortality rate targets include 1) an annual commercial fishery quota, to be distributed to the states based on their share of commercial landings during 1980-1989; 2) commercial fish size limitation to remain at a 13 in. (33 cm) minimum size, which may be changed annually if needed; 3) a minimum mesh size of 5.5 in. (140 mm) diamond or 6.0 in. (152 mm) square mesh for commercial vessels using otter trawls that possess 100 lb (45 kg) or more of summer flounder, with exemptions for the flynet fishery and vessels fishing in an exempted area off southern New England during 1 November to 30 April; 4) permit requirements for the sale and purchase of summer flounder; and 5) annually adjustable regulations for the recreational fishery.

Amendment 3 to the FMP revised the area included in the southern New England exempted fishery to include the Hudson Canyon area, increased the large mesh net threshold to 200 lb during the winter fishery (1 November to 30 April), and stipulated that otter trawl vessels fishing from 1 May to 31 October could retain only 100 lb of summer flounder before using the large mesh net. Amendment 4 to the FMP adjusted the state of Connecticut's commercial fishery quota and revised the state-specific shares of the coastwide commercial quota.

Amendment 5 to the FMP allowed states to transfer or combine their shares of the commercial fishery quota.

Amendment 6 allowed multiple nets (varying mesh) on board.

FISHERY DATA

Northeast Region (NER: Maine to Virginia) commercial landings for 1980-1993 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). Total U.S. commercial landings of summer flounder from Maine to North Carolina peaked in 1979 at nearly 18,000 mt (metric tons), or 40 million lb. The reported landings in 1993 of about 5700 mt (about 12.6 million lb), about 2% over the target quota, were a 24% decrease from 1992. Recreational landings were based on statistics from the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS), for type A+B1 landings (recreational statistics reported herein do not reflect changes in estimation procedures implemented by MRFSS for 1992-1993 data). In 1993, recreational landings were 4000 mt, somewhat above 1992 levels, but more than twice the record low observed in 1989 (1500 mt). Landings are still well below levels of the early 1980s, when landings ranged between 5000 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 1982-1993 (Table B2). A landings-at-age matrix for 1982-1993 was also developed for the North Carolina winter trawl fishery (Table B3), which historically accounts for about 99% of summer flounder commercial landings in North Carolina.

Table B1. Commercial and recreational landings (metric tons, A+ B1 recreational type) of summer flounder, Maine to North Carolina (NAFO Statistical Areas 5, 6), 1980-1992, as reported by NMFS Fisheries Statistics Division (U.S.) and NEFSC (foreign)

Year	U.S.		Foreign[2]	Total	U.S.	
	Commercial	Recreational[1]			Commercial	Recreational
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	**	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	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
1993	5,715	3,982	NA	9,697	59	41
Average	10,716	7,364	19	18,093	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.
** Less than 0.5 metric ton.
NA = not available

Table B2. Commercial landings at age of summer flounder (thousands of fish), Maine-Virginia

Year	Age										Total
	0	1	2	3	4	5	6	7	8	9	
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	114	5,760	3,575	338	19	22	0	1	0	0	9,829
1993	151	4,308	2,340	174	29	43	19	2	1	0	7,067

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

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 1993).

Discards from the commercial fishery during 1989-1993 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 landings any summer flounder) from the weighout data base in the corresponding area-quarter cell, to provide estimates of

Table B3. Number (thousands) of summer flounder at age landed in the North Carolina commercial winter trawl fishery

Year	Age									Total
	0	1	2	3	4	5	6	7	8	
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	36	795	697	131	21	2	<1	0	1,682
1993	0	515	1,101	252	44	<1	<1	0	0	1,912

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 1988-1993 NCDMF length samples were aged using NCDMF age-lengths keys.

fishery discard by cell. Discard estimates were 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. Because existing sea sampling data are useful, but not adequate to characterize discards at this level of resolution, length and age samples are applied at a coarser stratum level, and large amounts of effort may otherwise be represented by one or no samples. Alternative levels of aggregation may be appropriate.

A discard-at-age matrix for 1989-1993 was developed using sea sampled length frequency and age-length distribution samples from 1989-1992, assuming biological characteristics of 1993 discards were the same as 1989-1992 averages and a commercial fishery discard mortality rate of 80%, as recommended by SAW 16 (NEFSC 1993)(Table B5). Sampling intensity was at least one 100 length sample per 29 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. Discards likely increased in 1989-1993 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 fishery mortality and population sizes in 1982-1988.

Potential large scale discarding of summer flounder arising from trip limits and seasonal fishery closures implemented in 1993 was investigated. Examination of 1989-1993 sea sample data showed that fewer than 10% of all sea sampling trips that caught any summer flounder discarded the entire catch, and the total discard per trip for those trips was much lower than the discard per trip rate for trips that landed summer flounder (Table B6). This suggests 1) that trips with summer flounder discards but no summer flounder landings probably caught summer flounder incidentally, and 2) that no widespread discarding has taken place during areal or seasonal closures.

Sampling coverage during 1993 was low or lacking in several key area-quarter strata (*e.g.*, area 61, quarter 3, and area 62, quarters 1 and 2) with significant trawl fishery days fished and summer flounder landings (Table B4), however. Examination of preliminary length frequency data suggested discards in 1993 were mainly age 1 fish smaller than the regulated minimum size, consistent with patterns observed in earlier years.

Recreational landings (catch type A+B1, National Marine Fisheries Service, Marine Recreational Fishery Statistics Surveys (MRFSS)) in 1993 were estimated to be 3982 mt (8.8 million lb). This estimate does not reflect changes in estimation procedures recently implemented by MRFSS only for 1992-1993 data. Maintaining the original estimation procedure ensures comparability of results over the entire 1982-1993 time series of data included in this analysis. It presently cannot be determined if new estimates will vary consistently over the time series. If new

Table B4. Summary of sea sample data for summer flounder by NAFO division and quarter for 1993

DIV	QTR	SS TRIPS	K_DF	D_DF	WO DF LAND MT	SS EST MT	WO LAND	SS EST
51	1	0	0	0	77	0	<1	0
	2	0	0	0	76	0	8	0
	3	0	0	0	78	0	3	0
	4	1	1	55	9	<1	<1	<1
52	1	4	1018	44	977	995	205	43
	2	3	12	4	2425	30	44	9
	3	0	21	6	499	11	8	3
	4	2	21	6	172	4	24	1
53	1	9	429	58	918	394	344	53
	2	5	105	2	1719	180	109	3
	3	2	143	26	1544	220	304	40
	4	8	121	6	1144	135	143	7
61	1	7	534	48	1374	733	409	66
	2	3	29	23	2160	63	191	50
	3	0	526	63	669	352	266	42
	4	2	526	63	237	125	48	15
62	1	1	52	3	2019	105	850	6
	2	0	52	3	896	47	102	3
	3	4	646	177	1132	731	298	201
	4	3	693	55	799	553	420	44
63	1	0	52	3	366	19	76	1
	2	0	52	3	261	14	4	1
	3	0	646	177	3	2	<1	1
	4	2	604	18	425	257	134	8
TOTAL/ MEAN		56	368	29	19,949	4,970	3,990	597

SSTRIPS =Number of sea sampling trips (trips in more than one statistical area are split)
K_DF, D_DF =Kept and discard rates (kilograms per day fished)
WO DF =NEFSC weighout database days fished on trips landing any summer flounder
SS EST LAND M =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 DISCARD =Sea sampling estimate of discard in mt

estimates were to vary consistently, for example 25% lower than current estimates, analytic results from VPA could be compared with results based on the original data set: with lower landings, estimates of fishing mortality rates would be slightly lower as would stock size estimates (*e.g.*, Table B7, the difference between case 2 and case 5).

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 70% in 1993) as minimum size regulations have been implemented on a state-by-state basis. Because discard lengths and weights are unobserved, mean weight at age in the discard is set equal to mean weight at age in the landings. The SARC noted that discard weight at age consequently would be overestimated (although sub-legal sized fish are observed in landings). The combined recreational catch at age matrix (landed plus discarded dead) is displayed in Table B8.

NER total commercial landings and discards at age, North Carolina winter trawl landings and discards at age, and MRFSS recreational landings and discards at age totals were summed to provide a total fishery catch at age matrix for 1982-1993 (Table B9). The numbers and proportions at age of fish age 4 and older are low and quite variable, reflecting the limited numbers of fish available to be sampled. For the total catch at age during 1982-1993, the average catch com-

Table B5. Summary of Northeast Region sea sample data to estimate summer flounder discard at age in the commercial fishery, 1989-1993

Year	Lengths	Ages	Sea Sample Discard Estimate	Sampling Intensity (mt/ 100 lengths)	Raised Discard Estimates	Raised Estimate with 80% Mortality Rate (mt)
1989	2,337	54	642	26	886	709
1990	3,891	453	1,121	29	1,516	1,213
1991	5,326	190	993	19	1,315	1,052
1992	9,626	331	956	10	1,147	918
1993	?	?	597	?	811	650

Discard numbers at age (thousands)

Year	0	1	2	3	Total
1989	775	1,628	94	0	2,497
1990	1,440	2,753	67	0	4,260
1991	891	3,424	<1	0	4,315
1992	1,966	1,569	57	7	3,636
1993	846	1,569	37	1	2,453

Discard mean length at age

Year	0	1	2	3	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	29.3	30.0	36.6	51.2	30.0
1993	27.7	31.1	40.6	51.2	30.1

Discard mean weight at age

Year	0	1	2	3	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	0.238	0.256	0.498	1.450	0.252
1993	0.208	0.284	0.695	1.450	0.265

Notes: Estimates developed using sea sample length samples, age-length data, and estimates of total discard in mt. Because 1993 length data were not available to the committee, mean 1989-1992 proportions, mean lengths, and mean weights at age were assumed for the 1993 discard. An 80% discard mortality rate is assumed.

position at age was: age 0 - 12%, age 1 - 51%, age 2 - 29%, and age 3 - 6%. Summer flounder age 4 and older comprised an average of less than 3% of the catch. 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 commercial (Maine to Virginia), North Carolina commercial winter trawl, and recreational (Maine to North Carolina) fisheries (Table B10, B11).

RESEARCH SURVEY ABUNDANCE AND BIOMASS INDICES

Age-specific mean catch rates, in numbers, from the NEFSC spring offshore survey (Table B12, 1976-1994 (1994 preliminary)), the Massachusetts Department of Marine Fisheries (MADMF) spring and fall inshore surveys (Table B13, 1978-1993), the Connecticut Department

Table B6. NEFSC sea sample data for 1989-1993: examination of trips with summer flounder discard (kilograms) that did not land any summer flounder (kept catch was zero)

Year	Trips	Total Discard	Discard Per Trip	Trips Without Landings	TotalDiscard on Trips Without Landings	Discard per Trip
1989	57	2,408	42	4	11	3
1990	61	5,435	89	5	81	16
1991	75	5,098	68	1	5	5
1992	57	8,443	148	0	0	0
1993	37	3,320	90	3	28	9

Trips fishing in more than 2-digit division are not split.

Table B7. Trial runs for SARC 18 Summer Flounder VPA to examine effect of 1) adding NEFSC Winter trawl survey as a tuning index, 2) assumptions about recreational fishery hooking mortality rate, and 3) the level of the recreational catch

1) SAW 16: All survey indices as in SAW 16 (revised Connecticut, Virginia, and North Carolina), updated catch (1982-93), recreational catch (ages 0 and 1) with 25% hooking mortality

Age	CV94	F93	N94 (E+6)	F92	N93 (E+6)
1	0.42	0.54	13.1	0.51	36.9
2	0.52	0.49	17.6	1.50	16.4
3	0.40	0.49	8.2	1.79	1.5

2) SARC 18: All survey indices as in SAW 16 (revised Connecticut, Virginia, and North Carolina), plus NEFSC winter survey (1992-94), recreational catch (ages 0 and 1) with 25% hooking mortality

Age	CV94	F93	N94 (E+6)	F92	N93 (E+6)
1	0.39	0.57	13.5	0.51	35.7
2	0.46	0.49	16.6	1.50	16.4
3	0.36	0.49	8.2	1.78	1.5

3) SARC 18_W_REC125: Configuration #2, SARC 18, with recreational hooking mortality = 12.5 % (affects ages 0 and 1 in recreational catch)

Age	CV94	F93	N94 (E+6)	F92	N93 (E+6)
1	0.39	0.49	13.1	0.48	34.1
2	0.44	0.49	17.1	1.49	16.5
3	0.36	0.49	8.3	1.78	1.5

4) SARC 18_W_REC500: Configuration #2, with recreational hooking mortality = 50% (affects ages 0 and 1 in recreational catch)

Age	CV94	F93	N94 (E+6)	F92	N93 (E+6)
1	0.39	0.72	14.2	0.57	38.7
2	0.50	0.50	15.4	1.50	16.3
3	0.37	0.50	8.1	1.79	1.5

5) SARC 18_W_REC25: Configuration #2, SARC 18, with recreational catches reduced by 25% to simulate effect of new MRFSS catch estimation method (affects all ages)

Age	CV94	F93	N94 (E+6)	F92	N93 (E+6)
1	0.37	0.47	11.7	0.44	30.7
2	0.42	0.46	15.7	1.45	15.2
3	0.35	0.46	7.9	1.69	1.5

Table B8. Estimated recreational catch at age of summer flounder (thousands of fish), MRFSS 1982-1993 (catch type A+B1+B2)

Year	Age									Total
	0	1	2	3	4	5	6	7	8	
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
1993	130	7,694	2,611	158	0	2	0	0	0	10,595

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

Table B9. Total catch at age of summer flounder (thousands of fish), Maine-North Carolina

Year	Age										Total
	0	1	2	3	4	5	6	7	8	9	
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	1,023	4,856	7,107	1,984	356	65	8	3	7	0	15,399
1990	1,692	10,035	2,224	995	202	36	8	2	1	0	15,189
1991	1,568	12,668	7,340	759	214	40	4	1	0	0	22,596
1992	2,267	12,345	6,094	1,318	151	74	2	1	0	0	22,252
1993	1,127	14,086	6,089	585	73	45	20	2	1	0	22,028

of Environmental Protection (CTDEP) fall trawl survey (Table B14, 1984-1993), and the Rhode Island Division of Fish and Wildlife (RIDFW) fall trawl survey (Table B15, 1979-1993) were available as indices of abundance. Three years of observations are currently available from the NEFSC winter trawl survey (Table B16, 1992-1994).

Young-of-year (YOY) survey indices were also available from NCDMF Pamlico Sound trawl survey (1987-1993), Virginia Institute of Marine Science (VIMS) juvenile fish trawl survey (1979-1993), 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 B17). 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.

Nine indices (MADMF spring and fall, RIDFW, CTDEP, DEDFW, VIMS, NCDMF, and NEFSC winter and spring) are available to estimate the strength of the 1993 year class. The New England indices suggest that the 1992 and 1993 year classes were smaller than those recruiting in 1990 and 1991. The Mid-Atlantic and NEFSC indices indicate that the 1993 year class may be the poorest since 1988. Spatial distribution of recruitment success may not be uniform over the range of the stock, and may be important in recovery dynamics. Considered in aggregate, available research surveys indicate that the 1993

Table B10. Mean length (centimeters) at age of summer flounder catch, Maine-North Carolina

Year	Age									All Ages
	0	1	2	3	4	5	6	7	8	9	
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	31.2	35.8	39.1	46.2	53.4	66.9	72.7	68.7	72.7		37.7
1989	27.2	35.8	40.7	45.7	50.8	58.7	60.0	63.1	59.0		39.2
1990	29.4	35.3	42.0	47.0	51.4	57.8	64.1	71.4	75.2		36.7
1991	27.0	34.6	40.6	47.0	54.4	60.9	65.4	68.1			36.7
1992	29.9	36.2	41.3	48.4	49.8	61.3	58.8	72.2			37.8
1993	28.6	36.6	40.8	50.6	52.9	54.7	62.6	70.6	75.5		37.8

Table B11. Mean weight (kilograms) at age of summer flounder catch, Maine-North Carolina

Year	Age									Mean Weight All Ages
	0	1	2	3	4	5	6	7	8	9	
1982	0.254	0.435	0.654	1.687	2.135	2.795	2.620	3.758	4.408		0.534
1983	0.218	0.447	0.786	1.297	1.466	1.705	2.572	3.171	3.849	4.370	0.475
1984	0.228	0.399	0.640	1.055	1.592	2.245	3.280	3.620	4.640	4.030	0.485
1985	0.282	0.426	0.612	1.092	1.782	2.343	2.671	4.682	4.780	4.800	0.611
1986	0.256	0.454	0.659	1.173	1.790	2.503	3.268	2.995	4.432		0.624
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	3.671	4.319		0.582
1989	0.211	0.465	0.723	1.049	1.502	2.320	3.445	2.861	2.251		0.675
1990	0.246	0.442	0.821	1.193	1.542	2.181	3.004	3.951	5.029		0.545
1991	0.193	0.413	0.713	1.174	1.821	2.534	3.203	3.586			0.539
1992	0.243	0.472	0.757	1.338	1.396	2.731	2.302	4.479			0.592
1993	0.232	0.482	0.706	1.476	1.658	1.858	2.816	4.136	5.199		0.567

year class is the weakest to recruit to the stock since 1988 (Figure B1).

ESTIMATES OF MORTALITY AND STOCK SIZE

ADAPT tuning for the VPA (1982-1993) was used. All survey indices were included in the tuning procedure. Indices were not weighted: weighting would have lead to estimates strongly influenced by the NEFSC winter trawl survey, which consists of only three observations at age. Instantaneous natural mortality rate (M) was assumed to be 0.2 (Henderson 1979). Fishing mortality rates in 1993 and abundances of ages 1-4 were directly estimated for 1994, while abundance of age 5+ was estimated from F's estimated in 1993 and the input partial recruitment pattern. Because no recruitment indices were available for 1994, stock size at age 0 was not estimated. The F on age 4 (oldest true age) was estimated from back-calculated stock sizes for ages 2-4. The F on the age 5+ group was set equal to the rate for age 4.

Several trial VPA runs to examine the effect on results of 1) inclusion of the NEFSC winter survey indices, 2) various assumptions about the hooking mortality rate in the recreational fishery, and 3) potential impact of a systematic decrease in recreational catch estimates throughout the time series (one possible form of the effect of new statistical methods to estimate the recreational catch). These trials showed that VPA results were robust with respect to the changes and assumptions tested (Table B7).

Fishing mortality rates on fully recruited ages have on average exceeded 1.0 between 1982-

Table B12. NEFSC spring trawl survey (offshore strata) mean number of summer flounder per tow at age (delta values), 1994 values are preliminary

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
1993	0.87	0.34	0.04	0.01							1.27
1994	0.15	0.68	0.08	0.01		<0.01					0.92

1992 (except for 1983), varying between 1.2 and 1.8 (Table B18, Figure B2). The fishing mortality rate showed a marked decline in 1993, to 0.54, in spite of stable catch in numbers, due to recruitment to the fishery of the above average (for 1989-1993) 1991 and 1992 year classes in 1993 at ages 1 and 2.

Summer flounder spawn in the late autumn and into early winter (peak spawning on November 1), and age 0 fish recruit to the fishery the autumn after they are spawned. For example, summer flounder spawned in autumn 1990 (from the 1990 spawning stock biomass) recruit to the fishery in autumn 1991, and appear in VPA tables as age 0 fish in 1991. This assessment indicates that the 1982 and 1983 year classes were the largest of the VPA series, at 81 and 95 million fish, respectively. The 1988 year class was the smallest of the series, at only 16 million fish. The sizes of the 1991 and 1992 year class were about 41 and 43 million fish, respectively, the largest since 1987. The 1993 year class is estimated at only 21 million fish, the worst since 1988 (Table B18, Figure B3).

Total stock size in 1993 (ages 0 and older) was estimated at about 71 million fish, about 40% of the peak abundance estimated for 1983 (178 million). This is a decrease from the 1992 level of 86 million fish, due to recruitment of the poor 1993 year class. Spawning stock biomass on November 1, 1993 was estimated to be about 14,000 mt, about 63% of the peak estimated for 1983 (22,200 mt). The SARC noted that age 2-5+ spawning stock biomass may be a more realistic estimate of viable spawners, given the uncertain spawning potential of age 0 and age 1 summer flounder. Age 2-5+ spawning stock biomass was estimated to be about 6800 mt, about 80% of the peak estimated in 1983 (8400 mt)(Table B18, Figure B3).

A comparison between catch biomass as calculated in the VPA and reported landings plus estimated discard is made in Table B19.

In summary, the VPA results indicate that fishing mortality rates on summer flounder have declined substantially in 1993 to the MAFMC target level, due to limits on the catch and recruitment of the 1991 and 1992 year classes. Improved recruitment during 1989-1992 has resulted in an increase in spawning stock biomass, but this biomass continues to be concentrated in a few age classes. Recruitment in 1993 is estimated to be the poorest since 1988.

The distribution of bootstrap F's was positively skewed, resulting in the bootstrap mean F for 1994 (0.58) being slightly higher than the point estimate from the VPA (0.54) (Figure B4). There is an 80% chance that F in 1993 was between 0.4 and 0.8. The distribution of F's is significantly lower (statistically) than 1992 levels, and the peak in the distribution of 1993 values is centered near the target value of 0.53.

Table B13. MADMF Spring and Fall survey cruises: stratified mean number per tow at age

Spring	Age									Total
	0	1	2	3	4	5	6	7	8+	
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
1993		0.120	0.470	0.060	0.010		0.020			0.68
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		1.110	0.170							1.28
1993	0.010	0.300	0.430	0.020	0.020					0.79

Table B14. CTDEP fall (September-October) trawl survey: summer flounder index of abundance: delta mean number per tow at age

Year	Age								Total
	0	1	2	3	4	5	6	7	
1984	0.014	0.659	0.221	0.039	0.004	0.013		0.001	0.95
1985	0.228	0.450	0.410	0.058	0.010	0.004		0.001	1.16
1986	0.175	1.080	0.371	0.047	0.006			0.001	1.68
1987	0.107	1.020	0.213	0.050	0.008	0.002			1.40
1988	0.018	0.954	0.386	0.056	0.005	0.007		0.001	1.43
1989		0.017	0.085	0.024	0.009	0.004		0.001	0.14
1990	0.012	0.493	0.304	0.056	0.007	0.009			0.88
1991	0.039	0.701	0.416	0.080	0.012	0.005		0.003	1.26
1992	0.017	0.565	0.351	0.068	0.011	0.009		0.001	1.02
1993	0.064	0.694	0.291	0.050	0.009	0.001		0.001	1.11

Table B15. RIDFW fall trawl survey summer flounder index of abundance

Year	Mean Number/Tow	Mean Kg/Tow	Proportion[1] Age 0	Mean Age 0 Number/Tow	Proportion[2] Age 1	Mean Age 1 Number/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
1993	0.96	1.11	0.00	0.00	0.28	0.27

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

Table B16. NEFSC winter trawl survey (offshore strata 1-18,61-76; Southern Georges Bank to Cape Hatteras) mean number, mean weight (kilograms), and mean number at age per tow, 1992-1994[1]

Year	Stratified Mean Number Per Tow	Coefficient of Variation	Stratified Mean Weight (Kg Per Tow)	Coefficient of Variation
1992	12.295	15.6	4.898	15.4
1993	13.577	15.2	5.486	11.9
1994	11.917	17.3	5.818	14.4

Year	Age 1	2	3	4	5	6	7	8	Total
1992	7.15	4.74	0.33	0.04	0.01	0.03	0.00	0.00	12.29
1993	6.48	6.69	0.31	0.05	0.02	0.02	0.00	0.00	13.58
1994	3.42	6.95	1.22	0.27	0.15	0.03	0.01	0.00	11.92

[1] 1994 data are preliminary

The corrected coefficients of variation for the F's on individual ages were 36% for age 0, 30% for age 1, and 27% for fully recruited ages.

The bootstrap estimate of spawning stock biomass was relatively precise, with a corrected CV of 25%. The bootstrap mean (14,600 mt) was higher than the VPA point estimate (14,000 mt). The bootstrap results suggest a high probability (>90%) that spawning stock biomass in 1992 was at least 12,000 mt (Figure B5), more than double the VPA estimate of 5400 mt in 1989.

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). No revised analysis was performed. The 1990 analysis indicated $F_{0.1} = 0.136$, $F_{max} = 0.232$, and $F_{20\%} = 0.270$ (Figure B6).

Yield and stock size projections were made for 1995-1996 assuming that the 1994 quota would be landed, and that fishing mortality targets in 1994-1995 would be achieved. Thus,

Table B17. Summary of recruitment indices from NEFSC research surveys

Survey	Year Class													
	1980	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
NEFSC														
Spring (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	0.87	
Spring (age 2)	1.41	0.39	0.33	1.56	0.43	0.43	0.79	0.23	0.03	0.28	0.41	0.34		
Winter (age 1)												7.15	6.48	3.42
Winter (age 2)											4.74	6.69	6.95	
MASS														
Spring (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	0.12	
Spring[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	0.47		
CT														
(age 0)					0.01	.23	0.17	0.11	0.02	0.00	0.01	0.04	0.02	0.06
(age 1)					0.45	1.08	1.02	0.95	0.02	0.49	0.70	0.57	0.69	
RI														
(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	0.27	
(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	0.00
MASS														
Seine (age 0)			3	3	1	19	5	5	2	3	11	4	0	2
DE														
16 ft (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	0.02
30 ft (age 0)												1.44	0.47	0.04
MD														
(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														
Rivers only (age 0)	7.23	5.29	3.23	3.76	1.21	0.70	1.15	0.45	0.54	0.96	2.61	1.42	0.49	0.49
Rivers and Bay (age 0)									0.53	1.23	2.54	2.78	0.91	0.53
NC														
Pamlico Trawl (age 0)								19.86	2.61	6.63	4.27	5.85	9.41	5.01

fishing mortality in 1994 (F_{94}) was assumed to be the F realized if total 1994 landings were 12,100 mt (7260 mt commercial, 4840 mt recreational). Fishing mortality was assumed to be 0.53 in 1995, falling to 0.23 in 1996. The projections also assume that recent patterns of discarding will continue over the time span of the projections. Different patterns that could develop during 1994-1996 due to trip and bag limits and fishery closures have not been evaluated. The partial recruitment pattern (including discards) used in the projections was estimated as the geometric mean of F at age for 1991-1993. Mean weights at age were estimated as weighted (by fishery) arithmetic means of 1991-1993 values. Separate mean weight at age vectors were developed for the spawning stock, landings, and discards (Table B20).

Three options for initial stock sizes in 1994 were evaluated. Recruitment at age 0 in 1994 was assumed equal to the geometric mean of VPA estimates during 1989-1993, ± one standard error. Stock size at age 1 in 1994 was assumed equal to the VPA point estimate, ± one bootstrap standard error. Stock sizes at ages 2-5+ were assumed equal to the VPA point estimates. These combinations of starting stock sizes in 1994 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 1994.

If the 1994 catch quotas are landed and current relative discard levels remain stable, F in 1994 will be about 0.77 with average recruitment in 1994 (Table B20). Given average recruitment again in 1995 and 1996, the fishing mortality targets in 1995 (F = 0.53) and 1996 (F = 0.23) could be met with a total landings quota of about 8800 mt (19.4 million pounds) in 1995 and 5,400 mt (11.9 million pounds) in 1996 (Figure B7). Assumption of the worst and best case scenarios will result in landings 20% below or 20-25% above the average case in 1995-1996.

Stochastic projections were made to evaluate the probability of exceeding the target fishing mortality rate (F=0.53) under alternative quota levels in 1995, and 1996, given uncertainty in 1994 stock size estimates and 1994-1995 recruitment levels. Two hundred projections were made for each of the 200 bootstrapped realizations of 1994 stock sizes from ADAPT runs, using algorithms and software described by Brodziak and Rago (1994 manuscript). Recruitment in 1994-1995 was generated randomly from a cumulative frequency distribution of observed recruitment levels from 1989-1993. Other input parameters were as in Table B20; uncertainty in partial recruitment patterns, discard rates or

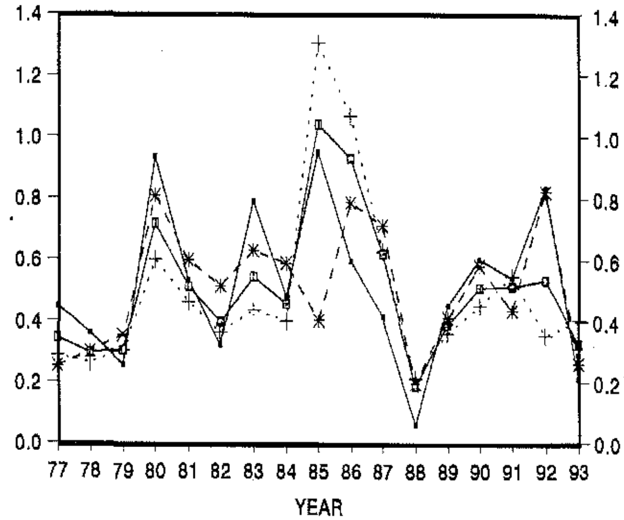

Figure B1. Regional indices of age 0 recruitment for summer flounder. Numbers per tow are retransformed Z-scores scaled to NEFSC index.

other components was not reflected. As in the deterministic projection, it was assumed that 12,100 mt would be landed in 1994 with no changes in discard patterns or partial recruitment. The proportion of cases in which F fell above the management target (F=0.53) is plotted by alternative 1995 quota levels in Figure B8. If a quota of 6500 mt were landed in 1995, the probability of exceeding the target F level would be approximately 20% (the probability level adopted by the Summer Flounder Plan Monitoring Committee for the 1994 quota). It should be noted that realized F levels exceeding the 0.53 target can be very high: in some cases, a quota could be larger than the entire stock biomass. If a quota of 10,000 mt were set in 1995, there would be a 0.5% chance that the quota would be larger than the total available biomass, and a 9% probability that realized F would exceed 1.0.

The probabilities of exceeding the 1996 target F level (F=0.23) are plotted in Figure B9 for different combinations of 1995 and 1996 quota levels. If a quota of 5300 mt were adopted in 1995, the probability of exceeding the target F level in 1996 would be 20% if a quota of about 5000 mt were adopted in 1996.

The 1993 year class as estimated by VPA appears to be the weakest since the recruitment failure of 1988, and may be of comparable size. The assessment indicates that some stock rebuilding has occurred with the recruitment of the 1991 and 1992 year classes, with F in 1993 falling as a result of improved recruitment and stable total catches (landings plus discards) during 1991-1993. However, the improvement may

Table B18. Summer flounder SARC 18 VPA, unweighted run configuration

Catch at Age (thousands) - SARC18

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	5225	11989	12056	2427	4411	2393	3409	1023	1692	1568	2267	1127
1	19070	33271	31614	16933	16170	19038	21221	4856	10035	12668	12345	14086
2	12329	8790	14242	17510	10665	10426	14404	7107	2224	7340	6094	6089
3	814	1072	3401	2805	4166	1651	2444	1984	995	759	1318	585
4	280	167	1075	1663	295	609	843	356	202	214	151	73
5	214	146	367	456	752	134	253	83	47	45	77	68
0+	37932	55435	62755	41794	36459	34251	42574	15409	15195	22594	22252	22028

CAA summary for Ages 2-5+

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	13637	10175	19085	22434	15878	12820	17944	9530	3468	8358	7640	6815

Fishing Mortality - SARC18

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	0.07	0.15	0.25	0.06	0.09	0.06	0.27	0.04	0.06	0.04	0.06	0.06
1	0.68	0.91	0.74	0.68	0.66	0.64	1.10	0.77	0.64	0.84	0.55	0.64
2	1.52	0.78	1.52	1.33	1.40	1.36	1.80	1.69	1.05	1.59	1.47	0.58
3	1.13	0.47	0.83	1.96	1.63	0.87	1.75	1.88	1.41	1.46	1.97	0.50
4	1.58	0.75	1.36	1.46	1.54	1.31	1.95	1.87	1.18	1.69	1.64	0.54
5+	1.58	0.75	1.36	1.46	1.54	1.31	1.95	1.87	1.18	1.69	1.64	0.54

Avg F for Ages 2-4

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	1.41	0.67	1.24	1.58	1.52	1.18	1.83	1.81	1.21	1.58	1.69	0.54

Back-calculated Partial Recruitment

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.05	0.16	0.17	0.03	0.05	0.04	0.14	0.02	0.04	0.03	0.03	0.10
2	0.43	1.00	0.48	0.35	0.41	0.47	0.56	0.41	0.45	0.50	0.28	1.00
3	0.96	0.86	1.00	0.68	0.86	1.00	0.92	0.90	0.74	0.94	0.75	0.92
4	0.72	0.52	0.54	1.00	1.00	0.64	0.90	1.00	1.00	0.86	1.00	0.79
5	1.00	0.82	0.89	0.74	0.95	0.97	1.00	1.00	0.83	1.00	0.83	0.85
6	1.00	0.82	0.89	0.74	0.95	0.97	1.00	1.00	0.83	1.00	0.83	0.85

be short-lived if future recruitment continues to be poor, since stock biomass is still concentrated at ages 3 and younger. Consequently, a conservative approach is recommended in setting the fishery quotas for 1995.

MAJOR SOURCES OF UNCERTAINTY

The VPA estimates of stock size in 1994 are not precise because they depend on imprecise survey indices. Therefore, projected landings should be considered with caution. Indices of recruitment are not available for 1994, and so estimates of age 0 in 1994 for projections are based on a geometric mean, ± 1 standard error.

The landings from the commercial fisheries used in this assessment assume no misreporting or nonreporting of summer flounder landings. Therefore, reported landings from the commercial fisheries should be considered minimum estimates.

Table B18. Continued

Stock Numbers (Jan 1) in thousands - SARC18

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	80738	95232	59505	47655	59035	45656	15978	29861	32001	41107
1	42911	61375	67121	37810	36821	44342	35215	9997	23522	24669
2	17457	17877	20144	26349	15634	15515	19078	9630	3791	10178
3	1328	3137	6683	3606	5729	3150	3269	2587	1454	1092
4	390	351	1598	2394	414	921	1085	465	323	290
5+	290	303	533	640	1029	198	315	105	74	59
0+	143114	178274	155585	118454	118662	109783	74941	52645	61164	77395

	1992	1993	1994
0	42839	20512	0
1	32237	33023	15774
2	8735	15223	14291
3	1692	1638	6954
4	207	193	811
5+	103	177	176
0+	85812	70766	38007

Summaries for ages 2-5+

1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
19466	21668	28959	32990	22807	19784	23748	12787	5641	11619	10736

1993	1994
17230	22232

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

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	6207	5901	3538	4123	4529	3343	1181	1964	2410	2464	3187	1554
1	6498	7835	8874	5572	5874	7071	4045	1497	3735	3099	5877	5718
2	2472	5588	2783	4090	2453	2484	2053	1305	997	1473	1483	5048
3	742	2325	3008	654	1474	1453	718	482	455	322	373	1349
4	191	235	697	1076	174	507	324	125	159	110	63	172
5+	192	291	339	392	651	175	151	45	58	32	61	217
0+	16302	22175	19238	15906	15155	15033	8472	5417	7813	7500	11044	13959

Summariesfor ages 2-5+

1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
3597	8439	6827	6212	4752	4619	3246	1957	1669	1937	1980	6786

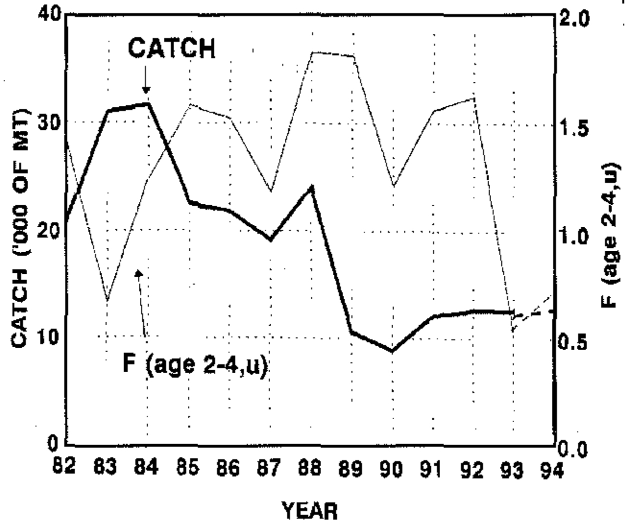

Figure B2. Total catch (landings and discard, thousands of metric tons) and fishing mortality rate (fully recruited F, ages 2-4, unweighted) for summer flounder.

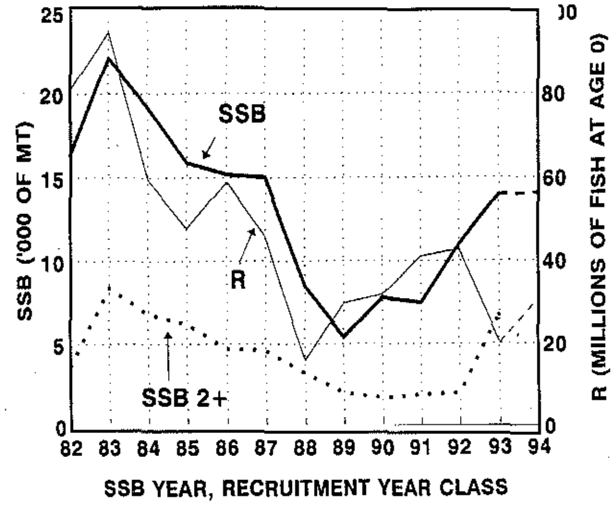

Figure B3. Spawning stock biomass (SSB ages 0 to 5, thousands of metric tons) and recruitment (millions of fish at age 0) for summer flounder. Note that because summer flounder spawn in late autumn, fish recruit to the fishery at age 0 the following autumn. For example, fish spawned in autumn 1987 recruit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

Table B19. Commercial and recreational fishery landings, estimated discard, and total catch statistics (metric tons) as used in the assessment of summer flounder, Maine to North Carolina, compared with VPA estimates of total catch biomass

Year	Commercial[1]			Recreational			Total			VPA	VPA:Catch
	Landings	Discard	Catch	Landings	Discard	Catch	Landings	Discard	Catch	Calculated Catch Biomass	Ratio
1982	10,400	N/A	10,400	9,621	709	10,330	20,021	709	20,730	20,640	1.00
1983	13,403	N/A	13,403	16,357	1,221	17,578	29,760	1,221	30,981	26,716	0.86
1984	17,130	N/A	17,130	13,147	1,341	14,488	30,277	1,341	31,618	31,156	0.99
1985	14,675	N/A	14,675	7,558	286	7,844	22,233	286	22,519	26,266	1.17
1986	12,186	N/A	12,186	8,497	1,150	9,647	20,683	1,150	21,833	23,356	1.07
1987	12,271	N/A	12,271	5,658	1,252	6,910	17,929	1,252	19,181	19,580	1.02
1988	14,686	N/A	14,686	8,487	895	9,382	23,173	895	24,068	25,501	1.06
1989	8,125	709	8,834	1,460	109	1,569	9,585	818	10,403	10,691	1.03
1990	4,199	1,213	5,412	2,435	651	3,086	6,634	1,864	8,498	8,418	0.99
1991	6,224	1,052	7,276	3,533	1,034	4,567	9,757	2,086	11,843	12,425	1.05
1992	7,302	918	8,220	3,364	911	4,275	10,666	1,829	12,495	13,423	1.07
1993	5,715	650	6,365	3,982	2,098	6,080	9,697	2,748	12,445	12,631	1.01

N/A = not available
[1]Includes foreign landings (directed foreign and joint venture fishing)

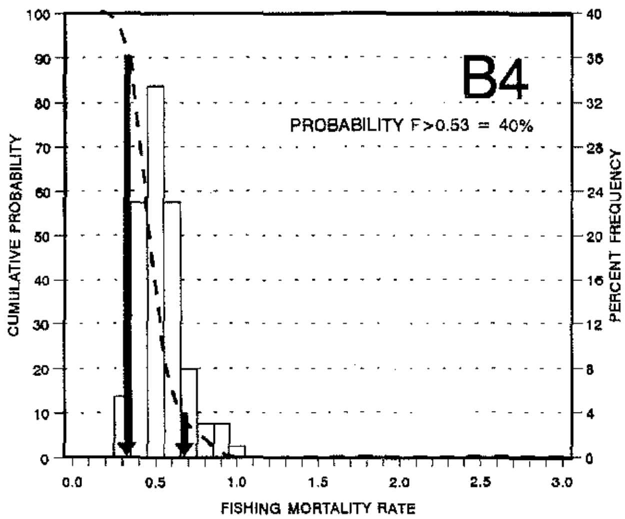

Figure B4. Precision of the estimates of fully recruited F (ages 2-4,u) in 1993 for summer flounder. Vertical bars display the range of the bootstrap estimate and the probability of individual values in the range. The dashed line gives the probability that F is greater than any value along the X axis.

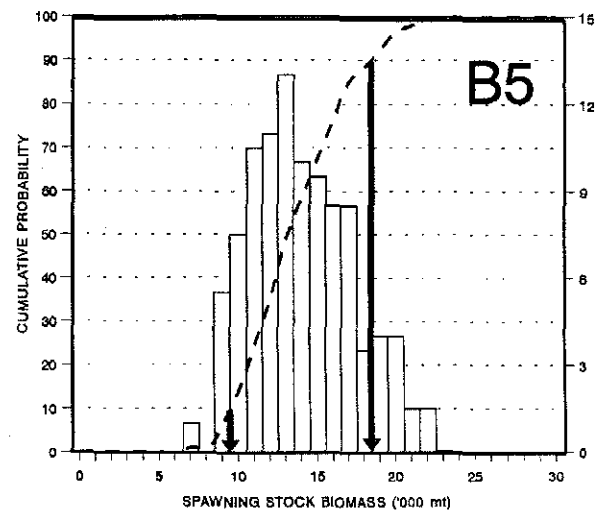

Figure B5. Precision of the estimates of spawning stock biomass on November 1, 1993 for summer flounder. Vertical bars display the range of the bootstrap estimate and the probability of individual values in the range. The dashed line gives the probability that SSB is less than any value along the X axis.

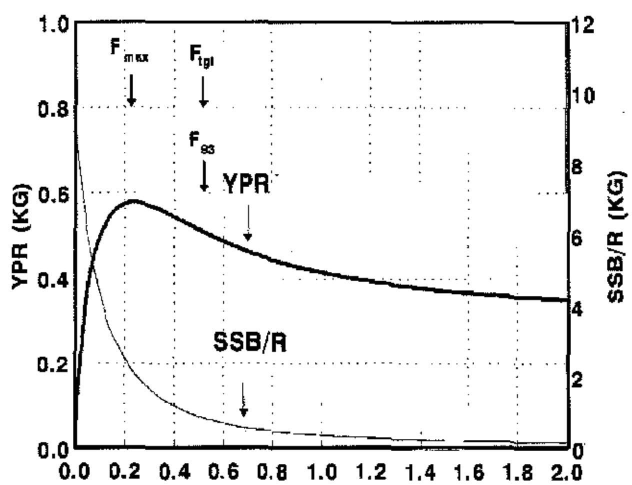

Figure B6. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for summer flounder.

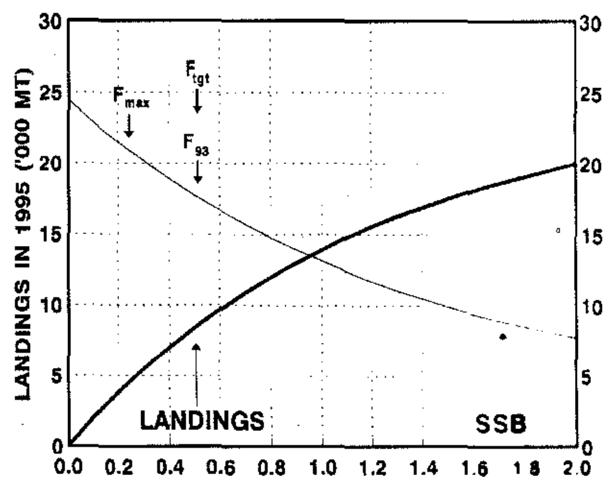

Figure B7. Predicted landings in 1995 and spawning stock biomass (SSB) in 1995 of summer flounder over a range of fishing mortalities in 1995, from F = 0 to F = 2.0.

Sea sampling length frequency data for 1993 are unavailable, and so 1989-1992 mean proportions at age, length at age, and weights at age have been used to characterize the 1993 commercial fishery discard. The Subcommittee examined preliminary 1993 discard data and found no evidence that large quantities of summer flounder, or summer flounder of large size, were being discarded due to trip limits or seasonal fishery closures. The current assumptions accepted to allow characterization of the age composition of the recreational live discard are based on data from a limited geographic area (Long Island, New York).

The time series of estimates of recreational catch is being revised by the MRFSS staff, and new estimates are available for 1992 and 1993. Revision of recreational fishery catch estimates

Table B20. Input parameters and projection results for summer flounder: landings (L), discard (D), and spawning stock biomass (SSB), metric tons

Age	Stock size in 1994	Fishing Mortality Pattern	Proportion Landed	Proportion Mature	Mean Weights Spawning	Mean Weights Landings	Mean Weights Discards
0	24698, 32181, 41932	0.05	0.170	0.38	0.223	0.294	0.210
1	10173, 15774, 21375	0.58	0.630	0.72	0.456	0.492	0.396
2	14291	1.00	0.991	0.90	0.725	0.725	0.576
3	6954	1.00	0.998	1.00	1.329	1.322	1.450
4	811	1.00	1.000	1.00	1.625	1.647	-
5+	176	1.00	1.000	1.00	2.541	2.537	-

F_{94} = F realized if 1994 quota is taken

F94	Stock Size at Age 0	Stock Size at Age 1	1994 1000 mt			1995 F = 0.53 1000 mt			1996 F = 0.23 1000 mt		
			L	D	SSB	L	D	SSB	L	D	SSB
0.83	24698	10173	12.1	0.7	12.3	7.3	0.8	14.1	4.3	0.4	19.5
0.77	32181	15774	12.1	1.0	14.4	8.8	1.1	17.4	5.4	0.5	24.9
0.72	41932	21375	12.1	1.3	16.6	10.6	1.4	21.3	6.8	0.7	31.4

NOTES:
Starting stock sizes on 1 January 1994 are as estimated by VPA, except age 0 which is the geometric mean of VPA estimated numbers at age 0 (000s) for 1989-93, ± 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 1991-93.
Mean weights at age (spawning stock, landings, and discards) are weighted (by fishery) arithmetic means of 1991-93 values. Recruitment levels in 1995-96 are also estimated as the geometric mean of numbers at age 0 (000s), ± 1 standard error, during 1989-93.
F_{94} is the F realized if fishery landings quotas, plus associated discard, are caught in 1994 (commercial landings = 7260 mt, recreational landings = 4840 mt).
F_{tgt} is the target designated by the MAFMC for 1995 (F=0.53) and 1996 (F=0.23). Proportion of F, M before spawning = 0.83 (spawning peak at 1 November).

used in the assessment will be done when the entire revised time series is available.

RESEARCH RECOMMENDATIONS

1. Continue the NEFSC sea sampling program collection of data for summer flounder, with special emphasis on:

   a) improved areal and temporal coverage,
   b) adequate length and age sampling, and
   c) continued sampling after commercial fishery areal and seasonal quotas are reached and fisheries are limited or closed.

   Maintaining adequate sea sampling will be especially important in the next few years, in order to monitor:

   a) the effects of implementation of gear and closed/exempted area regulations, both in terms of the response of the stock and the fishermen,
   b) potential continuing changes in "directivity" in the summer flounder fishery, as a results of changes in stock levels and regulations, and
   c) discards of summer flounder in the otter trawl fishery once quota levels have been attained and the summer flounder fishery is closed or restricted by trip limits.

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

3. Continue the NEFSC winter trawl survey, as

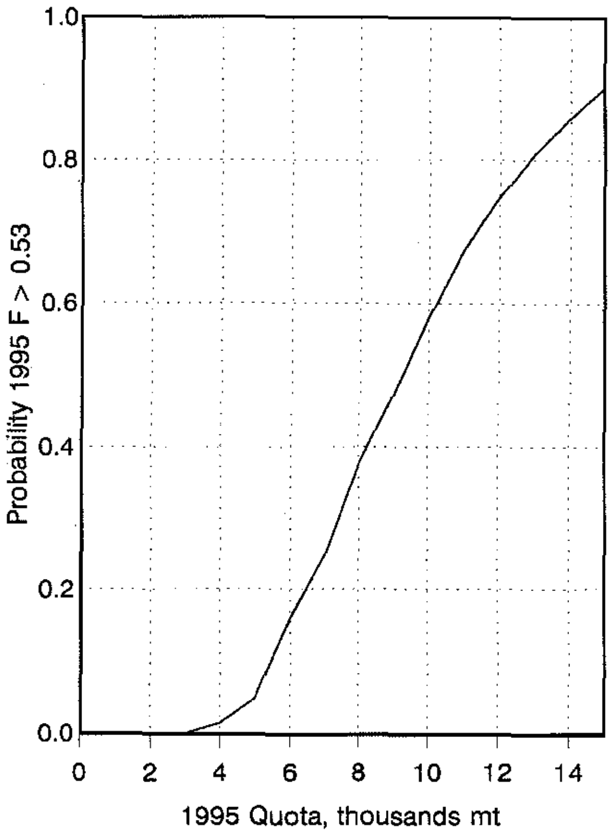

Figure B8. Probability of exceeding 1995 target F level (F = 0.53) under alternative 1995 quota levels, summer flounder.

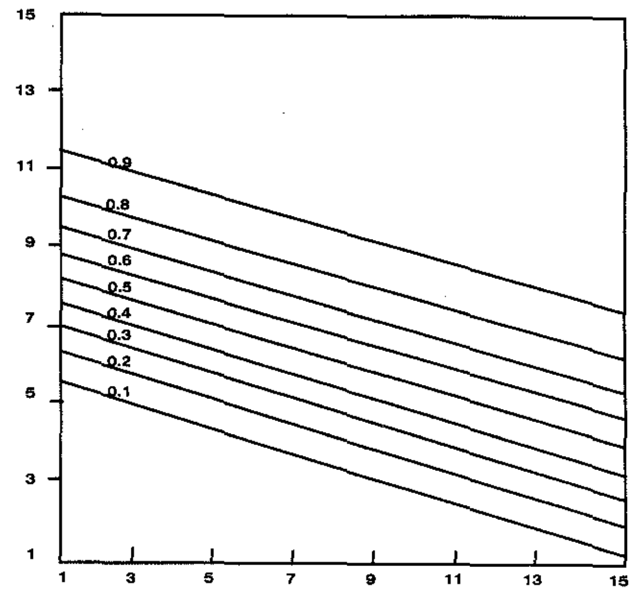

Figure B9. Probability of exceeding 1996 target F level (F = 0.23) in 1996 for different combinations of 1995 and 1996 quota levels (by 10% increments).

initial analyses of winter survey data suggest that this series will provide more reliable and precise indices of abundance for use in mortality estimation and VPA tuning than those provided by the NEFSC spring and autumn survey time series.

4. If the summer flounder assessment remains on a mid-year review schedule, it is critical that data from surveys and the fisheries be made available to the Subcommittee by the end of April. Due to problems in obtaining commercial fishery port (landings) and at sea observer (discard) biological samples during 1994, it is possible that estimates of commercial fishery landings and discard at age will be less reliable than those from previous years.

5. The current VPA does not use the iterative reweighting available in the ADAPT tuning that was used in the last (SARC 16) assessment, because to do so would allow a high degree of influence on results by the NEFSC winter trawl survey, which to date has correlated with VPA estimates of stock numbers very well. The SARC noted that it is important to consider the length of the good fitting survey time series before allowing strong influence on results by such series, to avoid possibly spurious good fits.

6. Consider a coarser level of stratum aggregation in developing estimates of commercial fishery discard from sea sample discard rates and weighout effort (*i.e.*, a coarser level than 2-digit statistical area and quarter stratum), since some of the strata rates must now be substituted for with values from comparable cells.

7. The Methods Subcommittee should investigate alternative ADAPT VPA objective function formulations (*e.g.*, power function), since some of the summer flounder abundance index to VPA stock size estimate relationships may be nonlinear, or have a nonzero intercept (survey values decrease to near zero before stock size estimates approach zero).

8. The partial recruitment of age 1 fish increased dramatically in 1993. If this exploitation pattern persists, then biological reference points should be updated in the next assessment to reflect the different partial recruitment vector.

9. Develop information on optimum length\age at capture and optimum mesh size, and describe potential benefits to be gained in yield per recruit by changing the exploitation pattern to reduce growth overfishing and allow expansion of the age composition of the stock.

10. Update the MD MDR trawl survey recruitment indices through 1993. Also, no data from the New Jersey DFW trawl survey, which began in 1988, are currently used for tuning. The NJ DFW may wish to provide these data to the Subcommittee for use in future assessments.

11. Include information in the report showing how mean weights in the landings and discard were calculated for projections.

12. Conduct further testing of the sensitivity of the analysis to potential sources of bias (*e.g.*, misreporting of landings, systematic error in surveys, incorrect assumptions about discard rates and discard mortality, mis-specification of the objective function in the VPA).

13. Assess the feasibility of extending the historic SSB/recruit time series by calibrating VPA results and survey time series.

14. The present maturity ogive for summer flounder is based on simple gross examination of ovaries, and may not accurately reflect the spawning potential of summer flounder, especially age 0 and age 1 fish. The Subcommittee encourages completion of ongoing work using histological examination of ovaries to better characterize the spawning contribution of young summer flounder. If there are large changes in maturity then biological reference points should be updated.

15. Conduct a systematic review of survey performance, specifically by examining the utility of including a relatively poorly fitting abundance indices in the ADAPT VPA tuning procedure. Consider the costs of including such indices, which increase overall variance, versus the benefits realized by some increase in precision of estimated stock sizes.

16. Consider alternative estimates of the instantaneous natural mortality rate (M) developed by methods such as those of Pauly (1980), Hoenig (1983), and by simple exponential decay (5% rule).

17. Revise recreational catch statistics after the entire Marine Recreational Fisheries Statistics series is revised.

18. Continue development of stochastic projection methods in conjunction with the Methods Subcommittee.

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GULF OF MAINE-GEORGES BANK WITCH FLOUNDER

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Assess the status of witch flounder by updating research vessel survey and commercial landings and sampling data through 1992. Make preliminary estimates of current fishing mortality through catch curve or MULTIFAN based cohort analysis.

b. Initiate efforts to upgrade the assessment from and 'index' assessment to an 'age-structured' assessment.

c. Provide an initial evaluation, based on the NEFSC sea sampling data base, of witch flounder discards.

d. Assess the status of the witch flounder stock, providing historical data on abundance, catch and, if possible, fishing mortality rates.

e. If possible, provide 1994 projections of catch and 1995 SSB options at various levels of F.

ESTIMATION OF DISCARDS

Shrimp Fishery

Estimates of witch flounder discarded in the Gulf of Maine northern shrimp fishery (Figure C1a) were based upon data acquired from four primary data sources: the Northeast Fisheries Science Center (NEFSC) research vessel bottom trawl survey program, the Atlantic States Marine Fisheries Commission (ASMFC) northern shrimp survey, the NEFSC commercial landings weighout and interview database, and the NEFSC Domestic Sea Sampling Program. Important features and relevant limitations of each primary data set are briefly described next.

NEFSC Research Vessel Bottom Trawl Surveys

The all-purpose, multispecies aspect of the survey, coupled with the use of 16 in. roller gear on the footrope to allow fishing on rocky bottom, compromises the capture of some species. In the case of witch flounder, the survey gear is inefficient in catching small fish (Burnett *et al.*, 1992). Wigley (1994) determined that the age at full recruitment for witch flounder to the NEFSC survey is about age 6 or 7 (35-40 cm). In the North Sea, Dahm and Wienbeck (1992) estimated that 91.5% of witch flounder escaped under the footrope of survey trawls. The use of 16 in. rollers in the NEFSC survey suggests that similar escapements may be occurring. Survey indices for witch flounder are thus imprecise, particularly for young fish.

ASMFC Northern Shrimp Survey

Total catch in weight and numbers of all finfish bycatch species has been recorded since 1985; length-frequency samples of bycatch have been taken from 1986 onward. The ASMFC survey is much more efficient in capturing small witch flounder than the NEFSC bottom trawl survey and has been extremely useful in corroborating trends evident from other data sources. However, for estimating discards, the ASMFC summer surveys has two limitations: 1) bycatch information has only been recorded since 1985; and 2) distribution patterns of witch flounder and shrimp in August are not representative of those that occur during the winter and spring shrimp fishery.

NEFSC Commercial Landings Weighout and Interview Database

Limitations in using this database for estimating discards include: 1) not all interviewed

Table C1. Number of sea-sampled trips by month in the Gulf of Maine shrimp fishery conducted by the NEFSC Domestic Sea Sampling Program, 1989-1992

Year	Dec	Jan	Feb	Mar	Apr	May	Total
1989	*	4	9	4	9	4	30
1990	9	8	8	7	2	2	36
1991	4	12	11	11	6	5	49
1992	7	31	26	13	4	0	81
	20	55	54	35	21	11	196

Source: Wigley 1994
* Before Domestic Sea Sampling Program was implemented

trips have discard information; 2) the large spatial scale used to identify trip locations may be too broad to characterize localized discarding events (Murawski and Finn 1988); and 3) interviewed trips may be such a small subsample relative to total weighout trips that estimates may be imprecise or inaccurate (or both). Additionally, discard estimates provided by fisherman may be biased (*i.e.* underestimated) to minimize the perception of a bycatch problem. Thus, the level of detailed information necessary to characterize the discarding of groundfish in the shrimp fishery is not adequately available in this database. However, the weighout database does contain the requisite baseline information on total landings and effort needed to estimate total fishery discards using discard rates derived from more detailed data sources.

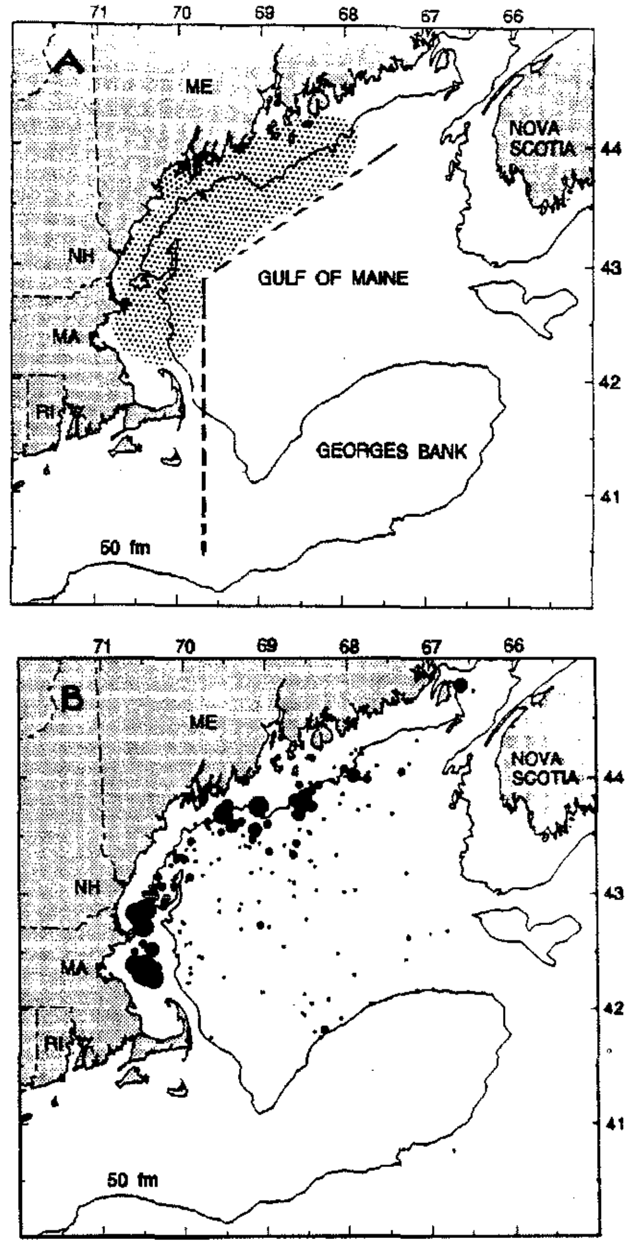

Figure C1. A) The Gulf of Maine-Georges Bank region of the Northwest Atlantic Ocean showing the 50 fathom (92 m) depth contour

NEFSC Domestic Sea Sampling Program

The Domestic Sea Sampling Program (DSSP) was implemented in 1989 to systematically collect information on discarding of commercial species. This program superseded a less-structured NEFSC sea sampling initiative, which was more opportunitistic and targeted situational discarding events (Clark and Wood 1978).

A true statistical protocol does not underlie the allocation of DSSP sea sampling trips. The use of data collected by the NEFSC DSSP to estimate discarding of witch flounder in the Gulf of Maine northern shrimp fishery is predicated upon establishing the adequacy of the DSSP data. During 1989-1992, 196 sea sampling trips were conducted in the shrimp fishery (Table C1). Data from these trips form the basis for the analysis of discard rates and the resulting estimates of total discards of witch flounder in the shrimp fishery.

To evaluate the representativeness of sea sampling data, the adequacy of coverage and similarities in vessel and fishing trip characteristics with respect to non-sampled trips (*i.e.*, interviewed and weighout trips) were examined. The apparent bias in trip allocations by tonnage class, in which ton class 1 vessels were virtually

Table C2. Summary of commercial days fished and number of trips conducted in the Gulf of Maine northern shrimp fishery, 1982-1993

	Days Fished				Percent Days Fished			
Year	**Zone 1**	**Zone 2**	**Zone 3**	**Total**	**Zone 1**	**Zone 2**	**Zone 3**	**Total**
Weighout								
1982	296.9	583.8	119.0	999.7	29.7	58.4	11.9	100.0
1983	512.6	390.3	257.0	1159.9	44.2	33.6	22.2	100.0
1984	547.2	868.3	342.0	1757.5	31.1	49.4	19.5	100.0
1985	495.8	924.8	673.7	2094.3	23.7	44.2	32.2	100.0
1986	365.3	1334.9	700.5	2400.7	15.2	55.6	29.2	100.0
1987	697.9	1653.6	1366.9	3718.4	18.8	44.5	36.8	100.0
1988	256.3	1679.6	890.5	2826.4	9.1	59.4	31.5	100.0
1989	398.2	1682.9	764.7	2845.8	14.0	59.1	26.9	100.0
1990	416.9	1615.5	1206.7	3239.1	12.9	49.9	37.3	100.0
1991	528.0	1163.4	916.2	2607.6	20.2	44.6	35.1	100.0
1992	187.3	1768.2	365.2	2320.7	8.1	76.2	15.7	100.0
1993	528.1	1095.1	282.3	1905.5	27.7	57.5	14.8	100.0
Sea sampled								
1989	1.0	3.4	6.7	11.1	9.0	30.6	60.4	100.0
1990	0.6	4.8	5.9	11.3	5.3	42.5	52.2	100.0
1991	3.3	7.4	8.7	19.4	17.0	38.1	44.8	100.0
1992	5.8	15.4	4.4	25.6	22.7	60.2	17.2	100.0
1993	7.0	13.7	3.9	24.6	28.5	55.7	15.9	100.0

	Number of trips				Percent number of trips			
Year	**Zone 1**	**Zone 2**	**Zone 3**	**Total**	**Zone 1**	**Zone 2**	**Zone 3**	**Total**
Weighout								
1982	1066	1909	348	3323	32.1	57.4	10.5	100.0
1983	2116	1166	803	4085	51.8	28.5	19.7	100.0
1984	2069	3272	1101	6442	32.1	50.8	17.1	100.0
1985	1642	2934	1878	6454	25.4	45.5	29.1	100.0
1986	1165	4523	2086	7774	15.0	58.2	26.8	100.0
1987	2313	5194	3662	11169	20.7	46.5	32.8	100.0
1988	950	5183	2322	8455	11.2	61.3	27.5	100.0
1989	1428	5327	2151	8905	16.0	59.8	24.2	100.0
1990	1518	4653	3065	9236	16.4	50.4	33.2	100.0
1991	1691	3431	2628	7750	21.8	44.3	33.9	100.0
1992	538	5574	1199	7311	7.4	76.2	16.4	100.0
1993	1611	3198	936	5744	28.0	55.7	16.3	100.0
Sea Sampled								
1989	5	14	16	35	14.3	40.0	45.7	100.0
1990	4	23	20	47	8.5	48.9	42.6	100.0
1991	13	25	24	62	21.0	40.3	38.7	100.0
1992	30	62	19	111	27.0	55.9	17.1	100.0
1993	38	53	13	105	36.2	51.4	12.4	100.0

unrepresented in sea-sampled trips, becomes less problematic within the context of fishing zones, since these small vessels fish almost exclusively in fishing zone 1, an area of low juvenile witch flounder abundance (Figure C1b). Furthermore, the dominant vessels in the shrimp fishery, tonnage class 2 and 3 vessels, which operate in the areas and depths associated with witch flounder discarding (fishing zones 2 and 3), are well-represented in DSSP coverage (Table C2).

Vessel characteristics were compared on both an area-wide basis and a fishing zone basis by the proportion of sea-sampled trips in each tonnage class category with respect to the non-sampled trips. The dominant vessel in the shrimp fishery

Table C3. Estimated discard rates by fishing zone obtained from a ratio estimator using the Domestic Sea Sampling Program data, number of days fished by the shrimp fishery, annual mean discard rates, and the annual estimate of discarded weight (metric tons) of witch flounder in the shrimp fishery, 1989-1993

Shrimp Season	Fishing Zone	Trips	Discard Rate (kg/df)	Commercial Days Fished	Weighted Annual Mean Discard Rate	Estimated Discard Weight (kg)
1989	1	5	0.0000	398.2		
	2	14	2.2791	1682.9		
	3	16	18.0870	764.7		
				2845.8	6.21	17,667
1990	1	4	0.0000	416.9		
	2	23	7.0751	1615.5		
	3	20	14.1459	1206.7		
				3239.1	8.80	28,500
1991	1	13	0.9770	528.0		
	2	25	4.4822	1163.4		
	3	24	30.2744	916.2		
				2607.6	12.83	33,468
1992	1	30	2.8399	187.3		
	2	62	8.9270	1768.2		
	3	19	8.1906	365.2		
				2320.7	8.32	19,308
1993	1	38	1.3357	528.1		
	2	53	3.8407	1095.1		
	3	13	12.7515	282.3		
				1905.5	4.47	8,511

Source: Wigley 1994
Note: 1993 data was not used in estimation of discard rates prior to 1989 due to changes in gear regulations (*i.e.*, implementation of Nordmore Grate)

is tonnage class 2 [5-50 gross registered tons (grt)], constituting approximately 50% of the total trips. Tonnage class 1 vessels (< 5 grt), small vessels fishing primarily in fishing zone 1, were under-represented in the sea-sampled trips. This may be due to the physical limitations of these vessel to accommodate an extra person on board (the DSSP observer). In general, sea-sampling coverage of tonnage class 2 and 3 vessels (51-150 grt) fishing in zones 2 and 3 proportionally equalled or exceeded that of non-sampled weighout trips.

The data were considered to be generally representative of the NEFSC commercial weighout database for the purpose of estimating witch flounder discards in the shrimp fishery. However, distribution of effort among fishing zones during 1989-1992 may not represent effort patterns in 1982-1984 (Table C2).

Discard estimates for witch flounder in the Gulf of Maine northern shrimp fishery were derived for 1989-1993 based upon NEFSC Domestic Sea Sampling Program (DSSP) data. As a proxy for depth, fishing zones (defined as distance from shore) were identified as key factors influencing the discarding of juvenile witch flounder. Witch flounder discard rates were estimated using a ratio estimator defined as kilograms of witch flounder discarded divided by the days fished within each fishing zone and year. Fishing zone discard rates were multiplied by the number of days fished by the shrimp fleet in each zone to estimate total discards (in weight) for each year (Table C3).

Ideally, relative abundance data and age composition estimates from the NEFSC bottom trawl surveys post-stratified to coincide with the three fishing zones would provide the best measures of

Table C4. Indices of age 3 witch flounder in the NEFSC autumn survey, discard rates[1], number of days fished by the shrimp fleet, and estimated discarded weight of witch flounder in the Gulf of Maine shrimp fishery

Year	Age 3 Index	Discard Rate (kg/df)	Commercial Days Fished	Estimated Weight (mt)	Rate(kg/df) 95L	Rate(kg/df) 95U	Weight (mt) 95L	Weight (mt) 95U
		Predicted						
1982	0.06	5.805	999.7	5.8	2.768	8.843	2.8	8.8
1983	0.49	10.561	1159.9	12.2	7.864	13.258	9.1	15.4
1984	0.08	6.027	1757.5	10.6	3.044	9.010	5.3	15.8
1985	0.07	5.916	2094.3	12.4	2.906	8.926	6.1	18.7
1986	0.01	5.252	2400.7	12.6	2.065	8.440	5.0	20.3
1987	0.01	5.252	3718.4	19.5	2.065	8.440	7.7	31.4
1988	0.71	12.994	2826.4	36.7	9.759	16.230	27.6	45.9
		Estimated						
1989	0.08	6.208	2845.8	17.7				
1990	0.39	8.7986	3239.1	28.5				
1991	0.67	12.8347	2607.6	33.5				
1992	0.27	8.3198	2320.7	19.3				
1993	0.55	4.466	1905.5	8.5				

Source: Wigley 1994

[1] 1982-1988 rates are predicted from the linear regress and 1989-1993 rates are estimated directly from DSSP

witch flounder abundance. However, too few survey stations occurred in inshore areas, *i.e.* fishing zones 1 and 2, to calculate zone-specific abundance indices. Given this constraint, the zone-specific discard rates during 1989-1992 were aggregated to a spatial scale compatible with the available survey abundance data. This was accomplished by weighting each fishing zone discard rate by the number of days fished in the weighout database in that zone, and calculating a mean rate for all zones combined (Table C3).

To estimate witch flounder discard rates prior to the DSSP program, (*i.e.*, 1982-1988), a simple linear regression was employed using 1989-1992 weighted mean discard rates derived from the DSSP data and annual indices of witch flounder abundance. The NEFSC autumn bottom trawl survey index of age 3 fish was found to be the best predictor ($r^2 = 0.97$, $p = 0.0127$) of annual discard rates (Table C4, Figure C2).

It is logical to expect that discard rates of witch flounder depend upon the number of juvenile witch flounder in the area fished by the shrimp fishery. The selection of a regression model with an intercept acknowledges the imprecision of the survey, *i.e.* some discards would still occur if no age 3 fish were caught in the survey. However, the conclusion with respect to the four-point regression is that no additional data exist, and with the advent of the Nordmore grate regulation in the shrimp fishery in 1993, no additional data from years subsequent to 1992 will be available to strengthen the analysis.

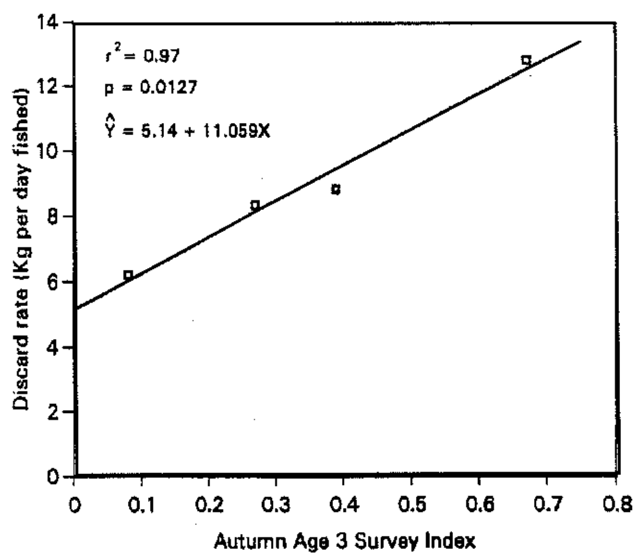

Figure C2. Linear regression of annual mean discard rates of witch flounder in the Gulf of Maine shrimp fishery estimated from the NEFSC Domestic Sea Sampling Program against NEFSC autumn bottom trawl survey witch flounder age 3 index, 1989-1992. (Taken from Wigley 1994b)

Estimated (1989-1993) and predicted (1982-1988) discard rates were multiplied by the total number of days fished by the shrimp fleet to

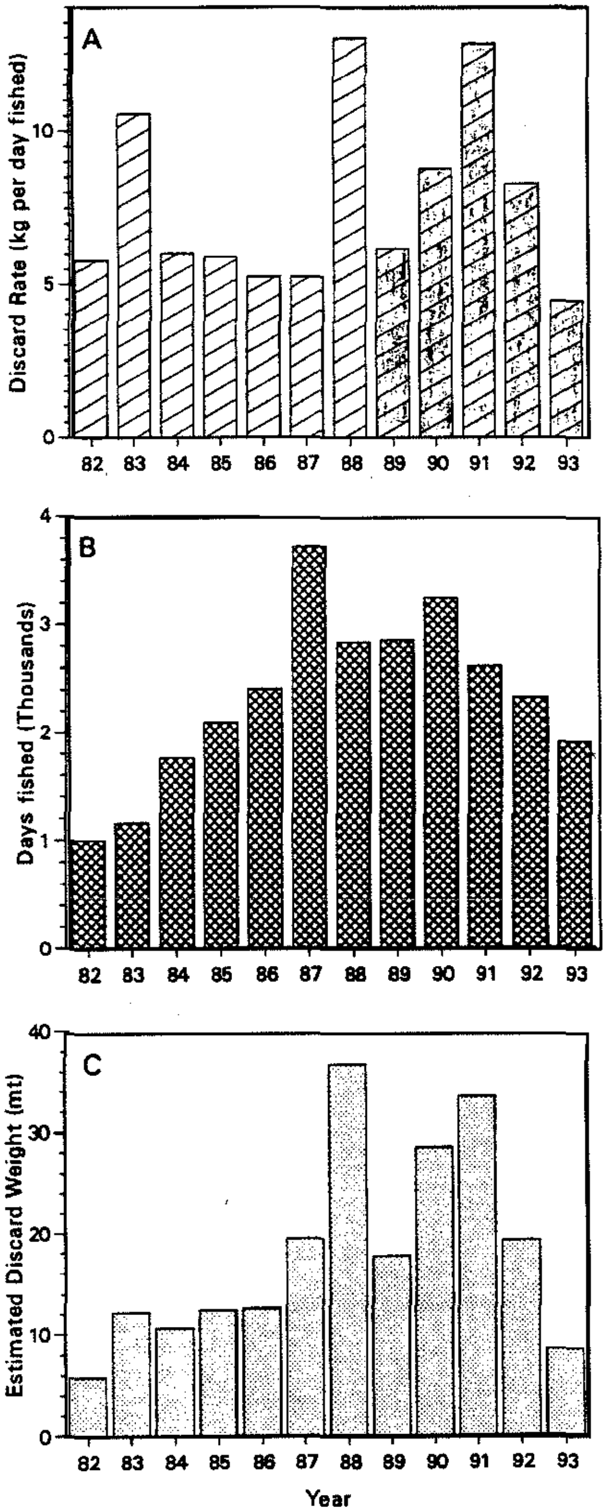

Figure C3. A) Estimates of annual discard rates for witch flounder in the Gulf of Maine shrimp fishery, 1982-1993 (1982-1988 derived via regression estimation, 1989-1993 derived directly from Domestic Sea Sampling Program data); B) number of days fished in the Gulf of Maine shrimp fishery; C) estimated weight (mt) for witch flounder discarded in the Gulf of Maine shrimp fishery. (Taken from Wigley 1994b)

estimate total discards (in weight) for each year (Table C4, Figure C3a). Commercial effort (in days fished) for the shrimp fleet during 1982-1993 is presented in Table C4 and Figure C3b. Effort rose steadily from 1982 to 1987, when it peaked at 3700 days fished (Figure C3b). Subsequent effort has remained relatively high, although a decline is evident (Figure C3b). Estimated discard weight for 1982-1993 is presented in Table C4 and Figure C3c.

No sea sample data were available to directly estimate length/age composition in four years: 1982, 1984, 1986 and 1987. For these years, age compositions were derived using data from adjoining years based upon ancillary information, such as survey age compositions and an *a priori* knowledge of relative year class strengths. Thus, the 1983 length/age compositions were applied to the years of 1982 and 1984, and the length/age compositions for 1985 were applied to the years of 1986 and 1987. The constraint in estimating discards for the years 1982, 1984, 1986, and 1987 may result in a possible bias associated with the samples from 1983 and 1985. In the latter cases, no fish of ages 1 or 2 were present, although these age groups are represented in subsequent years. Applying age compositions for these two years to adjacent years for which no samples were available exacerbates the bias. Additionally, the strong 1985 year class would have most certainly been better represented in 1986 and 1987 and in this sense, discard estimates for age 1 fish in 1986 and age 2 in 1987 may be underestimates.

Estimated discard weight was then translated into discarded numbers at age by applying sea-sampled discard length-frequencies expanded up to the total discard weight and then applying NEFSC spring bottom trawl survey age-length keys. Detailed information on this method can be found in Wigley and Mayo (1994).

Discard rates reported here are based upon discarding per unit effort (days fished) and, as such, are independent of total catch, which may be biased by variable year-class strengths and stock age compositions. Length-frequency information for witch flounder reported by Howell and Langan (1987, 1992) and Brunenmeister and Burns (1987) corresponds closely with that collected by the DSSP, suggesting persistent discarding by size in the shrimp fishery.

Large-Mesh Otter Trawl Fishery

The large-mesh otter trawl fishery has been regulated by a minimum mesh size of 140 mm in

Table C5. Summary of sea sampled witch flounder length frequency samples (number of samples and number of fish measured) from the large-mesh otter trawl fishery in the Gulf of Maine-Georges Bank region, by quarter and kept (K) and discarded (D) fish, 1989-1993

		Quarter 1		Quarter 2		Quarter 3		Quarter 4		Total	
Year		K	D	K	D	K	D	K	D	K	D
1989	Samples	9	1	9	6	8	18	4	6	30	31
	Fish	323	6	264	62	282	494	139	92	1008	654
1990	Samples	5	3	1	0	2	2	0	0	8	5
	Fish	184	20	12	0	39	39	0	0	235	59
1991	Samples	1	1	0	0	3	4	8	3	12	8
	Fish	21	15	0	0	56	147	116	51	193	213
1992	Samples	6	4	1	0	0	0	0	0	7	4
	Fish	62	64	42	0	0	0	0	0	104	64
1993	Samples										
	Fish	DATA NOT AVAILABLE									

the large-mesh regulatory area in the offshore Gulf of Maine and Georges Bank region (Figure C1a) since 1983. Prior to 1983, the regulated mesh in this area was 130 mm. Minimum landed sizes for witch flounder during 1982-1986 and 1987-1993 were 33 and 36 cm, respectively.

The NEFSC DSSP, which began in 1989, has not generated adequate data for estimating the age composition of discards in the large-mesh otter trawl fishery due to low sample sizes (Table C5). The two primary sources of data for the following analyses are: 1) the NEFSC spring and autumn bottom trawl surveys, and 2) the NEFSC commercial weighout database, which includes information on witch flounder commercial landings and length frequencies.

Analyses were performed using a method developed by Mayo *et al.* (1992) to estimate discards of American plaice in the large-mesh otter trawl fishery. This method filters survey length compositions (stratified mean catch per tow at length from the NEFSC bottom trawl surveys) through: 1) selection ogives corresponding to regulated mesh sizes during the study period, and 2) then applies a sorting/culling ogive to approximate the relative composition of the retained and discarded portions of the catch. Proportionality coefficients between survey abundance and commercial landings are then derived semi-annually for each year by regressing the retained portion of the survey length composition against the estimated numbers of landed fish at length in the commercial fishery (spring survey catches are used in conjunction with landings for quarters 1 and 2, and autumn survey catches with landings for quarters 3 and 4, respectively). These coefficients are then applied to the discarded portion of the survey length composition to estimate numbers at length discarded in the commercial fishery for the semi-annual period. Finally, discarded numbers at age are derived by applying spring and autumn survey age-length keys in each year.

The shape of the selection ogive (*i.e.*, the beta value in the logistic regression) for American plaice [originally presented by Smolowitz (1983) and used by Mayo *et al.* (1992)] was assumed to be the same for witch flounder; and mesh selection factors of 2.3 and 2.4 were assumed for witch flounder for regulated mesh sizes of 130 mm and 140 mm, respectively. Resulting proportions retained at length are presented in Table C6 and Figure C4.

Based upon an examination of commercial length frequencies of landed fish, the culling ogive was assumed to be approximately knife-edge with respect to the minimum legal landed sizes. The culling ogive assumed that 1% of fish 3 to 4 cm less than the minimum size, 10% of fish 1 to 2 cm less than the minimum size, 99% of fish at the minimum size, and all fish greater than the minimum size would be landed (see Table C7 for a worksheet example of calculations used in this method).

Seasonal and annual estimated numbers of landed and discarded witch flounder are presented in Table C8 for 1982-1993. Although the r-squared values associated with this estimation procedure are low (Table C8), the general pattern of discarding appears to be appropriate relative to

Table C6. Results from program LOGEST developed to calculate proportion retained at length

Mesh	S.F.	L50	Alpha	Beta	M-L Factor
130.	2.30	29.9	-10.76340	0.35998	1.077
140.	2.40	33.6	-12.09533	0.35998	1.124

LEN1	AGE1	130. PROP	140. PROP
1.0	0.1	0.00003	0.00001
3.0	0.3	0.00006	0.00002
5.0	0.6	0.00013	0.00003
7.0	0.8	0.00026	0.00007
9.0	1.1	0.00054	0.00014
11.0	1.4	0.00111	0.00029
13.0	1.6	0.00227	0.00060
15.0	1.9	0.00466	0.00123
17.0	2.2	0.00953	0.00253
19.0	2.6	0.01938	0.00519
21.0	2.9	0.03902	0.01061
23.0	3.3	0.07700	0.02155
25.0	3.7	0.14630	0.04328
27.0	4.1	0.26039	0.08503
29.0	4.5	0.41971	0.16031
31.0	5.0	0.59772	0.28172
33.0	5.5	0.75323	0.44621
35.0	6.0	0.86246	0.62339
37.0	6.6	0.92797	0.77275
39.0	7.3	0.96359	0.87478
41.0	8.0	0.98194	0.93486
43.0	8.8	0.99113	0.96719
45.0	9.7	0.99566	0.98376
47.0	10.8	0.99788	0.99203
49.0	12.1	0.99897	0.99610
51.0	13.7	0.99950	0.99810

information regarding the strong year classes of 1979-1981, 1985, and 1989-1990.

THE FISHERY

Commercial Landings

United States commercial landings in 1993 equalled 2599 mt, of which 2435 mt were taken from the Gulf of Maine-Georges Bank region (NEFSC Statistical Reporting Areas 511-515, 521-522, 525-526, and 561-562; Figure C5), a 19% increase over 1992 (Table C9); this marked the third consecutive year in which landings increased from the 1990 value of 1467 mt, the lowest harvest of witch flounder since 1964. Canadian landings from this stock were negligible (Table C10). Otter trawl catches accounted for about 94% of 1993 U.S. witch flounder landings. The majority of witch flounder is landed in Maine

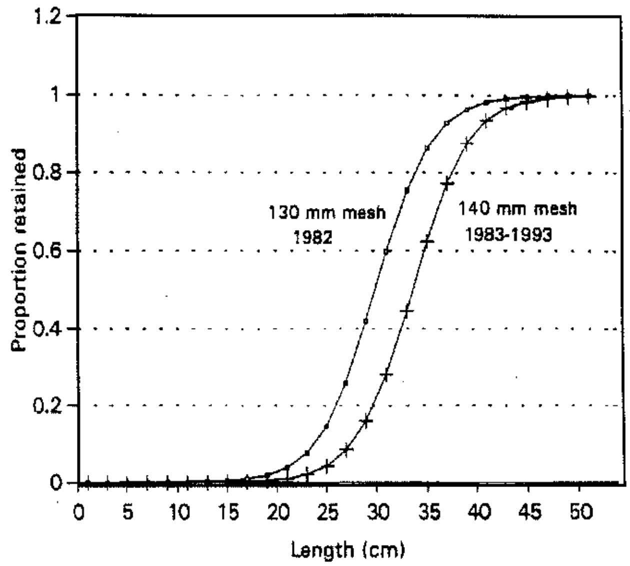

Figure C4. Mesh selection ogives used in filtering NEFSC bottom trawl survey length data.

ports. In 1993, more witch flounder was recorded as landed in Portland, Maine (36% of total landings) than in Rockland (1% of total landings), representing a shift in landing patterns observed in recent years. In 1992 and 1993, witch flounder less than 45 cm ('peewee' and 'small' market categories) made up more that 50% of the total landings (Table C11).

Recreational Catches

There is no recreational fishery for witch flounder due to the species' deep-water offshore distribution and its small mouth size, which precludes the taking of a baited hook.

Discards

The methods used in estimating witch flounder discards in the Gulf of Maine northern shrimp fishery and the large-mesh otter trawl fishery are briefly summarized in Section I of this report. The methodology used for deriving estimates of discards in the shrimp fishery are given in more detail by Wigley and Mayo (1994).

Discard rates in the shrimp fishery ranged from a low of 4.5 k/df in 1993 to a high of 13.0 kg/df in 1988 (Table C4). During 1982-1993, an estimated 3.2 million fish were discarded (217 mt) ranging from age 1 to 6, with ages 3 and 4 fish most commonly discarded and ages 1, 5, and 6 less frequently discarded. Discards in 1992 and 1993 were anomalously represented by age 2 fish, suggesting moderately strong 1990 and

Table C7. Spreadsheet calculations for discards of witch in Gulf of Maine large mesh fishery

1982
USED: BIOSTAT Q3+Q4 AND AUTUMN SURVEY
SUMMER/AUTUMN

Length	Survey Number/ Tow	130 mm Retained	Survey Prop. Retained	Cull Prop. Kept	Survey Kept	Survey Discarded	Numbers Landed	Numbers Discarded	Total Catch
	1	2	3=1*2	4	5=3*4	6=3-5	7	8=6*b	9=7+8
1	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
3	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
5	0.020	0.00	0.000	0.00	0.000	0.000	0	0	0
7	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
9	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
11	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
13	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
15	0.000	0.00	0.000	0.00	0.000	0.000	0	0	0
17	0.000	0.01	0.000	0.00	0.000	0.000	0	0	0
19	0.000	0.02	0.000	0.00	0.000	0.000	0	0	0
21	0.038	0.04	0.001	0.00	0.000	0.001	0	40	40
23	0.013	0.08	0.001	0.00	0.000	0.001	0	27	27
25	0.013	0.15	0.002	0.00	0.000	0.002	0	51	51
27	0.019	0.26	0.005	0.00	0.000	0.005	145	132	277
29	0.000	0.42	0.000	0.01	0.000	0.000	291	0	291
31	0.021	0.60	0.013	0.10	0.001	0.011	585	302	887
33	0.000	0.75	0.000	0.99	0.000	0.000	989	0	989
35	0.064	0.86	0.055	1.00	0.055	0.000	2405	0	2405
37	0.000	0.93	0.000	1.00	0.000	0.000	4530	0	4530
39	0.080	0.96	0.077	1.00	0.077	0.000	4747	0	4747
41	0.115	0.98	0.113	1.00	0.113	0.000	2973	0	2973
43	0.122	0.99	0.121	1.00	0.121	0.000	2442	0	2442
45	0.047	1.00	0.047	1.00	0.047	0.000	2370	0	2370
47	0.038	1.00	0.038	1.00	0.038	0.000	1401	0	1401
49	0.058	1.00	0.058	1.00	0.058	0.000	1626	0	1626
51	0.039	1.00	0.039	1.00	0.039	0.000	1677	0	1677
53	0.048	1.00	0.048	1.00	0.048	0.000	1590	0	1590
55	0.094	1.00	0.094	1.00	0.094	0.000	1729	0	1729
57	0.109	1.00	0.109	1.00	0.109	0.000	1542	0	1542
59	0.033	1.00	0.033	1.00	0.033	0.000	1022	0	1022
61	0.019	1.00	0.019	1.00	0.019	0.000	491	0	491
63	0.000	1.00	0.000	1.00	0.000	0.000	345	0	345
65	0.000	1.00	0.000	1.00	0.000	0.000	93	0	93
67	0.000	1.00	0.000	1.00	0.000	0.000	28	0	28
69	0.000	1.00	0.000	1.00	0.000	0.000	33	0	33
71	0.000	1.00	0.000	1.00	0.000	0.000	0	0	0
TOTAL	0.99						33054	551	33605

1: FROM SURVAN
7: FROM LENGTH BIOSTAT
2:LOGEST PROGRAM USING 130mm IN 1982
4: FROM LOOKING AT L-F, assume knife-edge

Regression Output:	
Constant	0
Std Err of Y Est	1055.918
R Squared	0.063787
No. of Observations	12
Degrees of Freedom	11
b =X Coefficient(s)	26708.6
Std Err of Coef.	4101.139

Table C8. Summarized estimates of witch flounder discards (D) and landings (L, in numbers, thousands) in the large-mesh otter trawl fishery in the Gulf of Maine-Georges Bank region, 1982-1993

Year	Spring			Autumn			Total			Comments
	L	D	r^2	L	D	r^2	L	D	Total	
1982	3480.6	317.8	0.55	3305.0	55.2	0.06	6785.6	373.0	7158.6	
1983	5245.9	530.6	0.53	3350.7	340.0	0.29	8596.6	870.6	9467.2	79-80 strong yc
1984	5702.8	296.4	0.58	4206.6	257.2	0.58	9909.4	553.6	10463.0	81 strong yc
1985	5349.4	193.6	0.44	4485.9	78.2	0.64	9835.3	271.8	10107.1	
1986	5215.8	35.2	0.30	2805.4	36.0	0.49	8021.2	71.2	8092.4	
1987	2873.9	117.2	0.44	2353.3	5.1	0.44	5227.2	122.3	5349.5	81 yc is legal,85 too small for gear
1988	3225.1	55.8	0.85	1364.2	94.2	0.16	4589.3	150.0	4739.3	
1989	1836.5	427.2	0.61	924.0	214.4	0.19	2760.5	641.6	3402.1	85 yc sublegal size
1990	1363.4	158.8	0.92	889.2	247.5	0.36	2252.6	406.3	2658.9	
1991	1166.1	70.5	0.50	1395.6	271.3	0.33	2561.7	341.8	2903.5	
1992	2099.7	257.7	0.33	1440.7	346.0	0.35	3540.4	603.7	4144.1	
1993	2386.1	666.9	0.25	1768.1	463.0	0.76	4154.2	1129.9	5284.1	

Note: r square refers to the regression of survey number per tow at length to numbers landed at length.

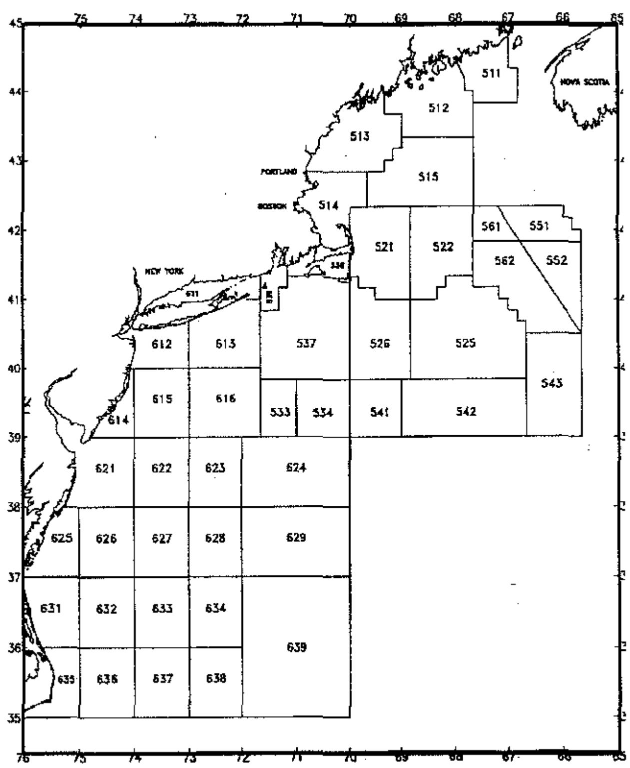

Figure C5. Statistical areas used for reporting U.S. commercial fishery statistics.

1991 year classes, which were detected in the 1992 and 1993 NEFSC autumn surveys (Wigley 1994). The greatest number of discarded fish occurred in 1988, with age 3 fish (the strong 1985 year class) dominating the discards.

A total of 5.5 million witch flounder (908 mt) were estimated to have been discarded in the large-mesh otter trawl fishery during the 1982-1993 period, with a high of 1.1 million discarded in 1993. Witch flounder discarded in this fishery ranged from age 1 to 6, with age 4 fish predominating.

Sampling Intensity

Length frequency and age sampling data for witch flounder landings from the Gulf of Maine-Georges Bank region were minimal and sporadic prior to 1982. During 1982-1988, an average of 48 length-frequency samples were obtained annually over all market categories, representing 1 sample per 102 mt landed. In 1990, sampling requirements were adjusted to 1 sample per 50 mt to obtain more samples from the 'large' market category. Samples for the 'large' market category have been difficult to obtain in recent years due to the sharp decrease in the landings of older fish (Table C12). Sampling intensity during 1990-

Table C9. Summary of U.S. commercial witch flounder landings (metric tons) by Statistical Area, 1973 - 1993

Year	Statistical Areas																				Total
	300	400	465	466	511	512	513	514	515	521	522	523	524	525	526	537	538	539	600 5Y	600 5Ze	
1973	.	27	21	.	102	236	470	349	39	266	412	20	74	192	271	26	0	4	14	2431	2523
1974	.	49	2	4	19	76	319	213	23	334	294	17	104	145	192	41	2	2	3	1736	1839
1975	.	15	18	1	18	150	360	289	92	371	238	10	159	281	105	13	0	3	4	2073	2127
1976	.	22	6	2	25	140	470	365	37	278	209	24	81	144	50	12	2	1	3	1823	1871
1977	.	5	5	2	15	192	756	682	101	257	250	19	62	71	30	13	2	5	2	2435	2469
1978	.	11	5	.	8	330	1370	642	164	366	306	85	86	38	45	20	8	4	10	3440	3498
1979	.	5	1	.	67	270	1025	416	120	367	393	97	35	15	28	21	1	3	14	2833	2878
1980	.	4	7	.	44	278	1320	386	258	317	231	67	26	38	111	19	1	6	15	3076	3128
1981	.	7	34	.	66	317	1410	419	322	390	183	68	62	48	40	39	0	9	28	3325	3442
1982	.	22	34	.	155	759	1432	427	760	558	289	120	52	69	96	51	6	12	64	4717	4906
1983	.	31	145	.	252	1233	1460	479	1045	555	322	121	46	63	104	88	2	14	40	5680	6000
1984	.	15	147	.	158	750	1564	788	1322	800	430	155	67	118	181	99	1	8	57	6333	6660
1985	255	5	68	.	234	752	1474	658	1263	735	468	128	62	99	106	34	1	2	41	5979	6385
1986	539	12	66	.	204	765	1213	468	787	481	298	100	20	33	77	31	2	2	50	4446	5148
1987	346	5	15	.	103	441	1039	364	720	344	214	55	20	25	47	16	0	1	43	3372	3798
1988	359	.	11	.	94	288	958	352	617	450	207	53	35	96	47	13	1	1	39	3197	3621
1989	297	.	2	.	32	175	517	223	381	304	135	39	28	52	129	17	2	1	31	2015	2365
1990	2	5	2	.	24	135	429	182	188	164	82	35	36	55	77	28	0	2	23	1407	1469
1991	.	2	1	.	19	168	470	197	281	146	138	43	54	36	87	65	1	2	67	1639	1777
1992	.	1	.	.	13	235	520	226	332	152	188	46	39	63	219	124	0	4	62	2033	2224
1993	.	12	.	.	14	175	580	419	422	180	270	82	65	94	134	94	0	2	56	2435	2599

Note: United States portions of SA 523 and 524 were renamed 561 and 562, respectively, in 1985. Gulf of Maine-Georges Bank region (5Y&5Ze) comprises SA 511-515,521-526. Landings data from Unk, state, and canvass not included.

1993 averaged 35 samples annually, representing 1 sample per 56 mt landed; however, even with this increased sampling intensity, inadequate numbers of samples were obtained for some market categories and quarter combinations. This required pooling the length frequency samples across quarters when only one or no sample existed.

Commercial Catch at Age

Commercial age data for the years 1982 to 1993 were available for this assessment. Quarterly age-length keys (ALKs) were applied to corresponding length frequency data from the commercial landings; resulting estimates of annual age compositions are presented in Table C13. Estimates of age compositions of discarded witch flounder from both the shrimp fishery and the large-mesh otter trawl fishery are presented in Tables C14 and C15, respectively. Estimates of total catch at age compositions (including commercial landings, discards from the northern shrimp fishery and the large-mesh otter trawl fishery) of witch flounder from the Gulf of Maine - Georges Bank region are presented in Table C16.

Examination of age compositions from the commercial landings revealed strong 1979-1981 year classes, with the 1980 year class being the strongest (Table C13). More recently, the 1985 year class appeared to be of moderate strength; however, this cohort was heavily discarded in both the shrimp and large-mesh otter trawl fisheries (Tables C14 and C15). High levels of discarding were also noted for the 1988 and 1989 year classes which, although not completely recruited to the large-mesh fishery, appear to be of strengths comparable to year classes of the late 1970s and early 1980s (Table C16).

Mean Weights at Age

Mean weights and lengths at age (ages 1 to 11+) of witch flounder discarded in the shrimp and large-mesh otter trawl fisheries, in commercial landings, and total catch for the years 1982-1993 are presented in Tables C13-C16. There did not appear to be any discernible changes in growth during 1982-1993. The mean weights at age of fish discarded in the shrimp fishery were lower than those discarded or landed in the large-mesh otter trawl fishery, reflecting the selectivity patterns and seasonal differences between these fisheries. Mean weights and lengths at age of discarded fish in the large-mesh fishery were lower than those of landed fish. Since witch flounder landings are highest during March-July, these means more closely represent mid-year weights. Mean weights at age for January

Table C10. Nominal catches[1] of witch flounder (metric tons, live) from all areas and catches in the Gulf of Maine-Georges Bank region (NAFO Subareas 5Y and 5Ze), and Subarea 6, by country, 1960-1993

Year	Subarea/Division													Total
	5Y[2]			5Z USA[5]				6[3]			Totals			
	Can	USA	Other[4]	Can	Ze	Zw	Other[4]	Can	USA	Other[4]	Can	USA	Other	
1960	-	601	-	-	654		-	-	-	-	-	1255	-	1255
1961	-	524	-	2	498		-	-	-	-	2	1022	-	1024
1962	-	463	-	1	513		-	-	-	-	1	976	-	977
1963	-	641	-	27	585		121	-	-	-	27	1226	121	1374
1964	6	703	-	31	678		-	-	-	-	37	1381	-	1418
1965	-	730	-	22	1410		502	-	-	-	22	2140	502	2664
1966	31	744	-	37	2149		311	-	42	-	68	2935	311	3314
1967	16	895	-	47	2433		249	-	42	-	63	3370	249	3682
1968	4	1040	-	52	1541	208	191	-	18	-	56	2807	191	3054
1969	0	1138	-	0	1263	112	1291	-	29	19	-	2542	1310	3852
1970	10	978	14	9	1598	383	114	-	153	2	19	3112	130	3261
1971	19	1072	-	16	1955	131	2736	-	62	124	35	3220	2860	6115
1972	1	1121	3	12	1758	29	2530	-	26	35	13	2934	2568	5515
1973	1	1176	-	9	1223	24	621	-	11	8	10	2434	629	3073
1974	3	640	-	6	1079	37	264	-	11	28	9	1767	292	2068
1975	5	909	-	8	1167	17	125	-	13	92	13	2106	217	2336
1976	1	1041	-	4	787	14	6	-	11	-	5	1853	6	1864
1977	-	1756	-	11	688	20	-	-	14	13	11	2478	13	2502
1978	3	2552	-	15	926	30	4	-	12	2	18	3520	6	3544
1979	2	2031	-	15	936	24	-	-	23	-	17	3014	-	3031
1980	-	2532	-	18	796	28	-	-	18	1	18	3374	1	3393
1981	-	2534	-	7	806	48	-	-	34	-	7	3422	-	3429
1982	4	3826	-	5	1196	70	-	-	71	-	9	5163	-	5172
1983	11	4470	-	34	1214	110	-	-	43	-	45	5837	-	5882
1984	10	4584	-	5	1755	108	-	-	85	-	15	6532	-	6547
1985	4	4380	-	42	1598	37	-	-	50	-	46	6065	-	6111
1986	12	3036	-	55	972	44	-	-	62	-	67	4114	-	4181
1987	-	2668	-	23	705	18	-	-	44	-	23	3435	-	3458
1988	-	2349	-	45	903	22	-	-	61	-	45	3335	-	3380
1989	-	1329	-	13	686	24	-	-	31	-	13	2070	-	2083
1990	-	958	-	12	448	30	-	-	31	-	12	1467	-	1479
1991	-	1134	-	7	505	68	-	-	86	-	7	1793	-	1800
1992	1	707	-	6	1326	128	-	-	62	-	7	2223	-	2230
1993	2	1610	-	8	825	96	-	-	56	-	10	2587	-	2597

Note: This table includes landings from UNK, state and canvass that are not included in Table C9

1. As reported to ICNAF/NAFO for 1960-1982 (Burnett and Clark 1983)
2. NK landings for SA5 assigned to Div. 5Y.
3. Statistics not available prior to 1963.
4. Includes West Germany, East Germany, Poland, Spain, Japan, and the USSR.
5. Div 5Z was divided into 5Ze and 5Zw in 1968.

1 (necessary for computing stock biomass in the VPA) were calculated from procedures developed by Rivard (1980).

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial LPUE

Commercial catch rates (landings per unit effort, LPUE, expressed as landings in mt per day fished) were derived for vessel tonnage classes 2-4. LPUE indices were computed for: 1) all trips landing witch flounder, and 2) trips in which 40% or more of the total landings comprised witch flounder (Table C17). These '40% trips' may represent effort that is 'directed' towards witch flounder, a species normally taken as bycatch.

For all trips landing witch flounder, increases in LPUE occurred in 1977-1978 for tonnage classes 2 and 3 and in 1982 for tonnage class 4.

Table C11. United States commercial witch flounder landings (metric tons) from the Gulf of Maine-Georges Bank region, (SA 511-515,521-526) by market category, 1973 - 1993

Year	Peewee	Small	Medium	Large	Jumbo	Uncl.	Total
1973	0	327	0	1115	0	989	2431
1974	0	456	0	1282	0	0	1738
1975	0	545	0	1530	0	0	2075
1976	0	391	0	1429	0	2	1822
1977	0	558	0	1878	0	0	2436
1978	0	1041	0	2401	0	0	3442
1979	0	871	0	1961	0	0	2832
1980	0	720	0	2338	0	17	3075
1981	0	1001	0	2271	0	52	3324
1982	12	1243	255	3020	0	190	4720
1983	82	1419	835	3318	0	24	5678
1984	213	1594	1212	3275	0	37	6331
1985	460	1661	1389	2418	6	42	5976
1986	226	1499	1127	1541	2	53	4448
1987	121	1254	876	1046	18	58	3373
1988	89	1095	927	981	18	86	3196
1989	67	601	629	635	23	61	2016
1990	77	367	429	458	10	62	1403
1991	108	542	418	508	22	39	1637
1992	269	794	412	508	2	49	2034
1993	431	957	450	526	0	71	2435

and remained high during the early 1980s; however, LPUE indices declined steadily for all tonnage classes beginning in 1986, and 1993 values are among the lowest values observed in the time series (Table C17, Figure C6a). Indices for 40% trips exhibited similar trends, with sharp declines in LPUE noted since the mid-1980s (Table C17, Figure C6a). Effort (days fished) associated with all trips and 40% trips increased during the late 1970s and early 1980s, peaked during 1985-1988, decreased in 1990, and increased slightly since then (Figure C6b). Total effort from all trips was divided into landings at age to derive age-disaggregated LPUE indices (Table C18) for calibrating VPA for ages 7 to 9.

Research Vessel Survey Indices

Surveys conducted by the NEFSC, Massachusetts' Division of Marine Fisheries (DMF), and Atlantic States Marine Fisheries Commission (ASMFC) were used in this assessment. While NEFSC spring survey indices tend to be more variable due to the prespawning aggregations of witch flounder, spring and autumn indices generally display similar trends (Table C19, Figures C7a and C7b). Abundance and biomass remained fairly stable from 1963 until the late 1970s (Table C19); autumn indices declined steadily throughout the 1980s until 1987, reaching the lowest values observed in the time series. Biomass remained low through 1993, while abundance increased due to above-average 1990 and 1991 year classes. Abundance sharply increased in 1993, apparently due to a strong 1993 year class as indicated by the 1993 autumn NEFSC survey (Table C19, Figure C7a). Preliminary analyses of the 1994 NEFSC spring survey corroborates this event with evidence of young fish within the length range encompassed by the 1992-1993 year classes. Improved recruitment is also apparent in the ASMFC survey, where several strong year classes are present in recent years.

Estimates of survey age composition for spring and autumn 1980-1993 are presented in Table C20. Declining survey catches in recent years have resulted in reduced numbers of age samples and highly variable estimates of numbers at age. Additionally, the age composition has contracted, and the low levels of older fish do not allow adequate tracking of individual cohorts. The poor catchability of young fish (ages 0-3) in the bottom trawl survey noted above for this species is evident in the survey catch at age (Table C20).

MORTALITY

Natural Mortality

Burnett (1987) estimated M to be 0.16 from a regression of survey-derived instantaneous total

Table C12. Summary of U.S. commercial witch flounder landings (metric tons), number of length samples (n), number of fish measured (len) and number of age samples (age) by market category and quarter from the Gulf of Maine-Georges Bank region (SA 511-515,521-526) for all gear types from 1980 - 1993

Year		Quarter 1			Quarter 2			Quarter 3			Quarter 4			Total
		Sm	Med	Lg	Sm	Med	Lg	Sm	Med	Lg	Sm	Med	Lg	All
1981	mt	260	7	517	269	32	694	242	13	607	230	0	453	3324
	n	.	.	.	.	1	1	.	1	.	1	.	1	5
	len	.	.	.	.	101	103	.	89	.	105	.	100	498
	age	.	.	.	.	.	26	.	25	.	25	.	25	101
1982	mt	348	1	726	342	73	886	287	170	739	278	201	669	4720
	n	5	2	6	1	2	2	2	2	6	3	4	2	37
	len	527	194	626	126	209	216	189	210	514	307	393	189	3700
	age	128	55	150	30	55	50	50	50	150	81	105	50	954
1983	mt	475	250	910	471	286	1037	298	154	758	257	169	613	5678
	n	5	2	3	5	1	5	8	3	8	6	3	.	49
	len	680	232	265	685	96	520	1008	123	981	677	344	.	5611
	age	135	30	55	131	16	125	152	0	159	180	75	.	1058
1984	mt	462	322	1036	513	393	1000	403	248	653	429	286	586	6331
	n	5	9	4	7	1	7	8	1	2	4	2	1	51
	len	804	1112	400	970	117	775	1045	106	191	615	243	91	6469
	age	154	250	76	186	25	180	210	28	53	105	44	25	1336
1985	mt	465	377	613	697	453	850	526	291	553	433	310	408	5976
	n	12	1	2	5	4	7	7	7	6	8	2	4	65
	len	1530	105	229	657	426	698	795	800	684	824	264	349	7361
	age	319	29	50	106	77	153	97	138	113	161	25	29	1297
1986	mt	384	309	356	654	421	595	375	238	354	312	212	238	4448
	n	6	3	5	5	4	5	4	3	4	5	3	2	49
	len	662	307	515	558	410	413	302	364	406	416	337	233	4923
	age	123	60	89	106	97	129	63	75	100	87	75	52	1056
1987	mt	349	211	228	432	317	387	296	203	247	298	203	202	3373
	n	1	1	2	4	2	3	5	5	4	2	3	2	34
	len	85	145	200	323	228	316	354	583	400	204	261	178	3277
	age	25	25	50	77	47	76	78	113	95	48	64	51	749
1988	mt	424	304	271	436	393	389	184	176	208	140	140	131	3196
	n	5	4	5	5	5	3	5	4	3	3	4	3	49
	len	335	407	465	344	544	429	396	359	295	229	402	356	4561
	age	70	89	106	71	110	77	70	100	75	61	95	69	993
1989	mt	230	174	148	255	264	251	98	145	156	85	107	103	2016
	n	1	2	2	2	2	1	2	2	1	1	2	.	18
	len	94	201	222	230	236	27	150	206	100	125	202	.	1793
	age	25	50	49	50	46	25	40	51	25	25	47	.	433
1990	mt	113	125	107	147	168	147	100	119	129	84	79	85	1403
	n	1	2	3	6	3	1	6	2	2	7	2	.	35
	len	134	199	199	335	296	100	349	247	145	381	201	.	2586
	age	15	40	45	81	70	25	69	41	50	103	48	.	587
1991	mt	71	56	58	219	151	167	192	142	184	168	108	121	1637
	n	5	2	3	7	2	1	4	2	3	5	4	3	41
	len	262	224	401	537	239	125	212	165	249	300	410	274	3398
	age	53	50	80	93	45	25	49	49	52	66	97	58	717
1992	mt	180	86	82	466	163	174	205	115	138	212	97	116	2034
	n	4	2	2	7	1	2	7	1	1	2	.	1	30
	len	259	241	185	501	125	235	477	121	117	129	.	46	2436
	age	42	46	52	78	25	25	86	25	25	27	.	23	454
1993	mt	350	112	110	442	192	161	263	122	150	331	96	106	2435
	n	7	1	.	7	1	1	9	1	5	.	.	.	32
	len	830	100	.	741	107	100	728	85	499	.	.	.	3190
	age	55	25	.	56	27	26	74	.	73	.	.	.	336

Table C13. Landings at age in numbers, weight, mean weight, and mean length (centimeters) at age of witch flounder from the Gulf of Maine-Georges Bank region (SAR 511-515, 521-526, 561, 562), 1982 - 1993

Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Total
						Commercial Landings in Numbers (Thousands) at Age						
1982	0.00	0.00	113.40	794.80	1076.80	1398.30	639.60	630.70	384.10	230.20	1517.70	6785.60
1983	0.00	0.00	208.10	727.60	978.50	1483.70	1505.40	925.60	698.30	483.20	1586.20	8596.60
1984	0.00	0.00	86.20	962.70	1720.00	1649.20	1413.60	1424.00	662.50	356.70	1634.50	9909.40
1985	0.00	0.00	0.00	960.80	1976.80	1886.10	1487.30	1217.10	591.00	390.50	1325.70	9835.30
1986	0.00	0.00	6.10	288.00	1390.70	2674.80	1511.60	805.40	398.10	214.90	731.60	8021.20
1987	0.00	0.00	0.00	79.70	314.40	1247.40	1539.40	851.40	469.80	246.70	478.40	5227.20
1988	0.00	0.00	0.00	49.80	172.40	641.50	1354.70	1130.80	393.40	261.30	585.40	4589.30
1989	0.00	0.00	0.00	7.10	48.40	306.20	739.70	859.30	340.60	120.20	339.00	2760.50
1990	0.00	0.00	0.00	174.10	550.70	245.10	262.60	451.70	320.20	78.00	170.20	2252.60
1991	0.00	0.00	0.00	165.70	676.40	479.40	217.60	225.70	269.60	289.40	237.90	2561.70
1992	0.00	0.00	0.00	465.00	766.40	854.10	654.60	184.10	162.40	109.60	344.20	3540.40
1993	0.00	0.00	0.00	395.60	958.50	859.90	559.60	548.70	205.00	261.00	365.90	4154.20
						Commercial Landings in Weight (Metric Tons) at Age						
1982	0.00	0.00	24.49	218.57	371.50	592.88	351.78	458.52	340.31	226.29	2133.31	4717.64
1983	0.00	0.00	40.58	186.99	315.08	608.32	779.80	567.39	555.15	472.09	2153.22	5678.61
1984	0.00	0.00	18.27	258.00	595.12	695.96	761.93	945.54	541.26	328.88	2189.16	6334.12
1985	0.00	0.00	0.00	243.08	614.78	809.14	840.32	841.02	497.62	376.44	1757.24	5979.65
1986	0.00	0.00	0.51	65.38	425.55	1091.32	805.68	544.45	339.58	209.53	966.37	4448.37
1987	0.00	0.00	0.00	21.68	107.52	541.37	863.60	584.06	388.99	241.77	623.38	3372.38
1988	0.00	0.00	0.00	15.44	63.27	279.05	728.83	755.37	322.19	256.07	776.03	3196.27
1989	0.00	0.00	0.00	1.85	16.65	130.14	424.59	586.04	278.61	116.35	460.27	2014.50
1990	0.00	0.00	0.00	53.62	177.88	107.35	153.88	310.77	271.85	81.82	247.50	1404.68
1991	0.00	0.00	0.00	47.39	250.94	212.37	125.77	158.44	225.39	281.88	337.77	1639.95
1992	0.00	0.00	0.00	152.52	293.53	392.03	401.92	136.05	133.49	96.67	427.87	2034.09
1993	0.00	0.00	0.00	115.52	348.89	371.48	299.39	365.43	180.81	267.00	488.59	2437.11
						Mean Weight (Kilograms) at Age						
1982	0.000	0.000	0.216	0.275	0.345	0.424	0.550	0.727	0.886	0.983	1.406	0.695
1983	0.000	0.000	0.195	0.257	0.322	0.410	0.518	0.613	0.795	0.977	1.357	0.661
1984	0.000	0.000	0.212	0.268	0.346	0.422	0.539	0.664	0.817	0.922	1.339	0.639
1985	0.000	0.000	0.000	0.253	0.311	0.429	0.565	0.691	0.842	0.964	1.326	0.608
1986	0.000	0.000	0.084	0.227	0.306	0.408	0.533	0.676	0.853	0.975	1.321	0.555
1987	0.000	0.000	0.000	0.272	0.342	0.434	0.561	0.686	0.828	0.980	1.303	0.645
1988	0.000	0.000	0.000	0.310	0.367	0.435	0.538	0.668	0.819	0.980	1.326	0.696
1989	0.000	0.000	0.000	0.260	0.344	0.425	0.574	0.682	0.818	0.968	1.358	0.730
1990	0.000	0.000	0.000	0.308	0.323	0.438	0.586	0.688	0.849	1.049	1.454	0.624
1991	0.000	0.000	0.000	0.286	0.371	0.443	0.578	0.702	0.836	0.974	1.420	0.640
1992	0.000	0.000	0.000	0.328	0.383	0.459	0.614	0.739	0.822	0.882	1.243	0.575
1993	0.000	0.000	0.000	0.292	0.364	0.432	0.535	0.666	0.882	1.023	1.335	0.587
						Mean Length (Centimeters) at Age						
1982	0.0	0.0	32.3	35.0	37.5	39.8	42.9	46.5	49.3	50.9	56.3	44.3
1983	0.0	0.0	31.7	34.3	36.8	39.4	42.2	44.2	47.7	50.7	55.0	35.9
1984	0.0	0.0	32.6	34.9	37.6	39.8	42.7	45.3	48.2	49.9	55.5	43.6
1985	0.0	0.0	0.0	34.2	36.3	40.0	43.3	45.9	48.6	50.6	55.3	42.9
1986	0.0	0.0	25.0	33.2	36.2	39.4	42.5	45.6	48.8	50.7	55.3	42.0
1987	0.0	0.0	0.0	35.0	37.4	40.1	43.2	45.8	48.4	50.8	55.1	44.3
1988	0.0	0.0	0.0	36.4	38.2	40.1	42.7	45.4	48.2	50.8	55.3	45.3
1989	0.0	0.0	0.0	34.6	37.5	39.9	43.5	45.6	48.1	50.6	55.7	46.0
1990	0.0	0.0	0.0	36.2	36.8	40.2	43.7	45.8	48.7	51.8	56.8	43.5
1991	0.0	0.0	0.0	35.4	38.3	40.3	43.3	46.1	48.5	50.6	56.5	43.8
1992	0.0	0.0	0.0	37.0	38.7	40.7	44.3	46.8	48.3	49.2	54.2	42.7
1993	0.0	0.0	0.0	35.8	38.1	40.0	42.6	45.3	49.3	51.5	55.5	42.8

Table C14. Discards at age in numbers, weight, mean weight, and mean length at age witch flounder from the Gulf of Maine-Georges Bank region (SAR 511-515, 521-526, 561, 562), 1982-1993

Shrimp Discards	Age											Total
Year	1	2	3	4	5	6	7	8	9	10	11+	
					Shrimp Fishery Discards in Numbers (Thousands) at Age							
1982	0.00	0.00	24.76	21.29	11.56	3.22	0.00	0.00	0.00	0.00	0.00	60.83
1983	0.00	0.00	52.28	44.91	24.43	6.77	0.00	0.00	0.00	0.00	0.00	128.39
1984	0.00	0.00	45.18	38.86	21.09	5.88	0.00	0.00	0.00	0.00	0.00	111.02
1985	0.00	2.99	6.94	50.46	30.15	2.82	0.00	0.00	0.00	0.00	0.00	93.36
1986	0.00	3.04	7.03	51.40	30.69	2.85	0.00	0.00	0.00	0.00	0.00	95.01
1987	0.00	4.71	10.89	79.62	47.53	4.42	0.00	0.00	0.00	0.00	0.00	147.16
1988	15.62	141.80	565.53	46.65	44.14	3.33	0.00	0.00	0.00	0.00	0.00	817.07
1989	2.85	8.76	62.79	85.36	18.68	0.00	0.00	0.00	0.00	0.00	0.00	178.44
1990	4.89	53.75	266.93	114.20	37.69	0.00	0.00	0.00	0.00	0.00	0.00	477.46
1991	8.29	7.71	335.15	122.74	13.84	6.35	0.00	0.00	0.00	0.00	0.00	494.07
1992	40.14	147.28	129.11	89.54	0.62	0.00	0.00	0.00	0.00	0.00	0.00	406.69
1993	45.36	113.43	41.40	15.12	5.37	0.49	0.00	0.00	0.00	0.00	0.00	221.16
					Shrimp Fishery Discards in Weight (Metric Tons) at Age							
1982	-	-	1.00	2.09	1.89	0.82	0.00	0.00	0.00	0.00	0.00	5.80
1983	-	-	2.10	4.41	4.00	1.73	0.00	0.00	0.00	0.00	0.00	12.25
1984	-	-	1.82	3.82	3.46	1.50	0.00	0.00	0.00	0.00	0.00	10.59
1985	-	0.05	0.31	5.99	5.39	0.65	0.00	0.00	0.00	0.00	0.00	12.39
1986	-	0.05	0.31	6.11	5.48	0.66	0.00	0.00	0.00	0.00	0.00	12.61
1987	-	0.08	0.48	9.46	8.49	1.02	0.00	0.00	0.00	0.00	0.00	19.53
1988	0.09	2.14	19.17	5.25	9.12	0.94	0.00	0.00	0.00	0.00	0.00	36.72
1989	0.01	0.10	2.69	10.22	4.64	0.00	0.00	0.00	0.00	0.00	0.00	17.67
1990	0.05	0.76	9.90	12.00	5.78	0.00	0.00	0.00	0.00	0.00	0.00	28.50
1991	0.04	0.09	14.55	14.36	3.07	1.39	0.00	0.00	0.00	0.00	0.00	33.45
1992	0.14	2.96	5.42	10.64	0.14	0.00	0.00	0.00	0.00	0.00	0.00	1932
1993	0.14	2.54	2.34	2.06	1.27	0.16	0.00	0.00	0.00	0.00	0.00	8.51
					Mean Weight (Kilograms) at Age							
1982	-	-	0.040	0.098	0.164	0.256	-	-	-	-	-	0.095
1983	-	-	0.040	0.098	0.164	0.256	-	-	-	-	-	0.095
1984	-	-	0.040	0.098	0.164	0.256	-	-	-	-	-	0.095
1985	-	0.017	0.044	0.119	0.179	0.231	-	-	-	-	-	0.133
1986	-	0.017	0.044	0.119	0.179	0.231	-	-	-	-	-	0.133
1987	-	0.017	0.044	0.119	0.179	0.231	-	-	-	-	-	0.133
1988	0.006	0.015	0.034	0.113	0.207	0.282	-	-	-	-	-	0.045
1989	0.004	0.011	0.043	0.120	0.249	0.000	-	-	-	-	-	0.099
1990	0.010	0.014	0.037	0.105	0.153	0.000	-	-	-	-	-	0.060
1991	0.004	0.011	0.043	0.117	0.222	0.218	-	-	-	-	-	0.068
1992	0.004	0.020	0.042	0.119	0.220	0.000	-	-	-	-	-	0.048
1993	0.003	0.022	0.057	0.136	0.237	0.317						0.039
					Mean Length (Centimeters) at Age							
1982	-	-	20.3	26.3	30.6	34.9	-	-	-	-	-	25.1
1983	-	-	20.3	26.3	30.6	34.9	-	-	-	-	-	25.1
1984	-	-	20.3	26.3	30.6	34.9	-	-	-	-	-	25.1
1985	-	15.7	20.7	27.8	31.4	33.9	-	-	-	-	-	28.3
1986	-	15.7	20.7	27.8	31.4	33.9	-	-	-	-	-	28.3
1987	-	15.7	20.7	27.8	31.4	33.9	-	-	-	-	-	28.3
1988	10.6	15.3	19.2	27.4	32.8	36.0	-	-	-	-	-	19.6
1989	10.2	14.0	20.6	27.9	34.6	0.0	-	-	-	-	-	25.1
1990	13.6	15.0	19.8	26.9	30.1	0.0	-	-	-	-	-	21.7
1991	10.5	13.7	20.7	27.6	33.6	33.4	-	-	-	-	-	22.7
1992	9.7	16.5	20.4	27.9	33.5	0.0	-	-	-	-	-	19.6
1993	9.3	16.9	22.1	28.9	34.2	37.3	-	-	-	-	-	17.6

Note: 1982-1988 derived from regression estimation.
1989-1993 directly estimated (ratio estimator) from DSSP data.

Table C15. Discards at age in numbers, weight, mean weight, and mean length at age of witch flounder from the Gulf of Maine-Georges Bank region (SAR 511-515, 521-526, 561, 562), 1982 - 1993

Large Mesh Otter Trawl Discards					**Age**						**Total**
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**	
				Large-mesh Otter Trawl Fishery Discards in Numbers (Thousands) at Age								
1982	0.20	0.10	36.60	238.20	82.40	15.50	0.00	0.00	0.00	0.00	0.00	373.00
1983	0.00	0.30	39.40	408.30	421.20	1.40	0.00	0.00	0.00	0.00	0.00	870.60
1984	0.00	0.10	6.10	378.00	169.10	0.30	0.00	0.00	0.00	0.00	0.00	553.60
1985	0.00	0.10	7.60	101.10	152.10	10.90	0.00	0.00	0.00	0.00	0.00	271.80
1986	0.00	0.00	1.20	23.70	46.00	0.30	0.00	0.00	0.00	0.00	0.00	71.20
1987	0.00	0.10	4.30	19.40	98.20	0.30	0.00	0.00	0.00	0.00	0.00	122.30
1988	0.00	0.00	59.80	35.10	54.30	0.80	0.00	0.00	0.00	0.00	0.00	150.00
1989	0.10	0.20	7.30	538.50	95.50	0.00	0.00	0.00	0.00	0.00	0.00	641.60
1990	0.30	0.90	53.80	191.90	159.40	0.00	0.00	0.00	0.00	0.00	0.00	406.30
1991	0.00	3.50	96.40	95.20	102.10	44.60	0.00	0.00	0.00	0.00	0.00	341.80
1992	0.20	8.40	147.00	410.50	31.60	6.00	0.00	0.00	0.00	0.00	0.00	603.70
1993	1.30	7.30	172.70	696.10	250.50	2.00	0.00	0.00	0.00	0.00	0.00	1129.90
				Large-mesh Otter Trawl Fishery Discards in Weight (Metric Tons) at Age								
1982	0.00	0.00	1.98	32.59	10.86	2.78	0.00	0.00	0.00	0.00	0.00	48.21
1983	0.00	0.01	3.59	57.94	70.85	0.31	0.00	0.00	0.00	0.00	0.00	132.70
1984	0.00	0.00	0.50	58.33	29.03	0.07	0.00	0.00	0.00	0.00	0.00	87.93
1985	0.00	0.00	0.76	15.24	26.72	1.61	0.00	0.00	0.00	0.00	0.00	44.33
1986	0.00	0.00	0.13	3.18	8.25	0.07	0.00	0.00	0.00	0.00	0.00	11.62
1987	0.00	0.00	0.48	2.55	21.67	0.08	0.00	0.00	0.00	0.00	0.00	24.78
1988	0.00	0.00	5.58	6.10	11.12	0.21	0.00	0.00	0.00	0.00	0.00	23.01
1989	0.00	0.01	0.53	86.38	20.06	0.00	0.00	0.00	0.00	0.00	0.00	106.98
1990	0.01	0.03	6.19	31.05	31.88	0.00	0.00	0.00	0.00	0.00	0.00	69.16
1991	0.00	0.19	10.08	14.26	20.60	9.86	0.00	0.00	0.00	0.00	0.00	55.00
1992	0.00	0.52	20.32	69.37	7.98	1.65	0.00	0.00	0.00	0.00	0.00	99.85
1993	0.02	0.39	23.66	124.32	55.19	0.65	0.00	0.00	0.00	0.00	0.00	204.23
					Mean Weight (Kilograms at Age							
1982	0.002	0.016	0.054	0.137	0.132	0.179	-	-	-	-	-	0.129
1983	-	0.034	0.091	0.142	0.168	0.220	-	-	-	-	-	0.152
1984	-	0.016	0.082	0.154	0.172	0.220	-	-	-	-	-	0.159
1985	-	0.034	0.100	0.151	0.176	0.148	-	-	-	-	-	0.163
1986	-	-	0.112	0.134	0.179	0.220	-	-	-	-	-	0.163
1987	-	0.016	0.112	0.131	0.221	0.268	-	-	-	-	-	0.203
1988	-	-	0.093	0.174	0.205	0.265	-	-	-	-	-	0.153
1989	0.016	0.029	0.073	0.160	0.210	-	-	-	-	-	-	0.167
1990	0.021	0.032	0.115	0.162	0.200	-	-	-	-	-	-	0.170
1991	-	0.054	0.105	0.150	0.202	0.221	-	-	-	-	-	0.161
1992	0.020	0.062	0.138	0.169	0.253	0.276	-	-	-	-	-	0.165
1993	0.016	0.053	0.137	0.179	0.220	0.324	-	-	-	-	-	0.181
					Mean Length (Centimeters) at Age							
1982	8.5	15.5	22.0	28.9	28.7	31.6	-	-	-	-	-	28.3
1983	-	19.5	25.6	29.3	30.9	33.5	-	-	-	-	-	29.9
1984	-	15.5	24.6	30.1	31.1	33.5	-	-	-	-	-	30.4
1985	-	19.5	26.5	29.9	31.4	29.8	-	-	-	-	-	30.6
1986	-	-	27.5	28.9	31.6	33.5	-	-	-	-	-	30.6
1987	-	15.5	27.5	28.7	33.5	35.5	-	-	-	-	-	32.5
1988	-	-	26.0	31.1	32.9	35.5	-	-	-	-	-	29.7
1989	15.5	18.5	24.1	30.4	33.0	-	-	-	-	-	-	30.7
1990	16.8	18.9	27.6	30.5	32.5	-	-	-	-	-	-	30.9
1991	-	22.0	26.7	29.8	32.6	33.5	-	-	-	-	-	30.2
1992	16.5	23.1	29.0	30.9	34.9	35.8	-	-	-	-	-	30.5
1993	15.4	21.9	29.0	31.4	33.5	37.5	-	-	-	-	-	31.4

Note: 1982-1988 derived from regression estimation.
1989-1993 directly estimated (ratio estimator) from DSSP data.

Table C16. Total catch at age in numbers, weight, mean weight, and mean length at age of witch flounder from the Gulf of Maine-Georges Bank region (SAR 511-515, 521-526, 561, 562), 1982-1993

Total Catch Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Total
Commercial Catch in Numbers (Thousands) at Age												
1982	0.20	0.10	174.76	1054.29	1170.76	1417.02	639.60	630.70	384.10	230.20	1517.70	7219.43
1983	0.00	0.30	299.78	1180.81	1424.13	1491.87	1505.40	925.60	698.30	483.20	1586.20	9595.59
1984	0.00	0.10	137.48	1379.56	1910.19	1655.38	1413.60	1424.00	662.50	356.70	1634.50	10574.02
1985	0.00	3.09	14.54	1112.36	2159.05	1899.82	1487.30	1217.10	591.00	390.50	1325.70	10200.46
1986	0.00	3.04	14.33	363.10	1467.39	2677.95	1511.60	805.40	398.10	214.90	731.60	8187.41
1987	0.00	4.81	15.19	178.72	460.13	1252.12	1539.40	851.40	469.80	246.70	478.40	5496.66
1988	15.62	141.80	625.33	131.55	270.84	645.63	1354.70	1130.80	393.40	261.30	585.40	5556.37
1989	2.95	8.96	70.09	630.96	162.58	306.20	739.70	859.30	340.60	120.20	339.00	3580.54
1990	5.19	54.65	320.73	480.20	747.79	245.10	262.60	451.70	320.20	78.00	170.20	3136.36
1991	8.29	11.21	431.55	383.64	792.34	530.35	217.60	225.70	269.60	289.40	237.90	3397.57
1992	40.34	155.68	276.11	965.04	798.62	860.10	654.60	184.10	162.40	109.60	344.20	4550.79
1993	46.66	120.73	214.10	1106.82	1214.37	862.39	559.60	548.70	205.00	261.00	365.90	5505.26
Commercial Catch in Weight (Metric Tons) at Age												
1982	0.00	0.00	27.47	253.25	384.25	596.48	351.78	458.52	340.31	226.29	2133.31	4771.66
1983	0.00	0.01	46.27	249.35	389.92	610.36	779.80	567.39	555.15	472.09	2153.22	5823.56
1984	0.00	0.00	20.59	320.15	627.61	697.53	761.93	945.54	541.26	328.88	2189.16	6432.64
1985	0.00	0.05	1.06	264.31	646.90	811.40	840.32	841.02	497.62	376.44	1757.24	6036.37
1986	0.00	0.05	0.96	74.66	439.29	1092.04	805.68	544.45	339.58	209.53	966.37	4472.60
1987	0.00	0.08	0.96	33.68	137.69	542.47	863.60	584.06	388.99	241.77	623.38	3416.69
1988	0.09	2.14	24.75	26.78	83.51	280.20	728.83	755.37	322.19	256.07	776.03	3256.00
1989	0.01	0.11	3.22	98.44	41.36	130.14	424.59	586.04	278.61	116.35	460.27	2139.14
1990	0.06	0.79	16.10	96.67	215.54	107.35	153.88	310.77	271.85	81.82	247.50	1502.34
1991	0.04	0.27	24.63	76.01	274.61	223.62	125.77	158.44	225.39	281.88	337.77	1728.40
1992	0.15	3.48	25.74	232.53	301.65	393.69	401.92	136.05	133.49	96.67	427.87	2153.26
1993	0.16	2.93	26.00	241.90	405.35	372.28	299.39	365.43	180.81	267.00	488.59	2649.85
Mean Weight (Metric Tons) at Age												
1982	0.002	0.016	0.157	0.240	0.328	0.421	0.550	0.727	0.886	0.983	1.406	0.661
1983	-	0.034	0.154	0.211	0.274	0.409	0.518	0.613	0.795	0.977	1.357	0.607
1984	-	0.016	0.150	0.232	0.329	0.421	0.539	0.664	0.817	0.922	1.339	0.608
1985	-	0.017	0.073	0.238	0.300	0.427	0.565	0.691	0.842	0.964	1.326	0.592
1986	-	0.017	0.067	0.206	0.299	0.408	0.533	0.676	0.853	0.975	1.321	0.547
1987	-	0.017	0.063	0.188	0.299	0.433	0.561	0.686	0.828	0.980	1.303	0.621
1988	0.006	0.015	0.040	0.204	0.308	0.434	0.538	0.668	0.819	0.980	1.326	0.586
1989	0.004	0.012	0.046	0.156	0.254	0.425	0.574	0.682	0.818	0.968	1.358	0.598
1990	0.011	0.014	0.050	0.201	0.288	0.438	0.586	0.688	0.849	1.049	1.454	0.479
1991	0.004	0.024	0.057	0.198	0.347	0.422	0.578	0.702	0.836	0.974	1.420	0.509
1992	0.004	0.022	0.093	0.241	0.378	0.458	0.614	0.739	0.822	0.882	1.243	0.474
1993	0.003	0.024	0.121	0.219	0.334	0.432	0.535	0.666	0.882	1.023	1.335	0.482
Mean Length (Centimeters) at Age												
1982	8.5	15.5	28.5	33.5	36.8	39.7	42.9	46.5	49.3	50.9	56.3	43.3
1983	-	19.5	28.9	32.3	34.9	39.4	42.2	44.2	47.7	50.7	55.0	35.2
1984	-	15.5	28.2	33.3	36.9	39.7	42.7	45.3	48.2	49.9	55.5	42.7
1985	-	15.8	23.7	33.6	35.9	39.9	43.3	45.9	48.6	50.6	55.3	42.5
1986	-	15.7	23.1	32.2	36.0	39.3	42.5	45.6	48.8	50.7	55.3	41.8
1987	-	15.7	22.6	31.1	35.9	40.1	43.2	45.8	48.4	50.8	55.1	43.6
1988	10.6	15.3	19.8	31.8	36.3	40.1	42.7	45.4	48.2	50.8	55.3	41.1
1989	10.4	14.1	21.0	30.1	34.5	39.9	43.5	45.6	48.1	50.6	55.7	42.2
1990	13.8	15.1	21.1	31.7	35.5	40.2	43.7	45.8	48.7	51.8	56.8	38.5
1991	10.5	16.3	22.0	31.5	37.5	39.6	43.3	46.1	48.5	50.6	56.5	39.3
1992	9.7	16.8	25.0	33.5	38.5	40.7	44.3	46.8	48.3	49.2	54.2	39.0
1993	9.5	17.2	27.7	32.9	37.1	40.0	42.6	45.3	49.3	51.5	55.5	39.4

Table C17. United States commercial landings (L), days fished (DF), and landings per day fished (L/DF), by vessel

Year	Class 2				Class 3				Class4				Total			
	L	DF	L\DF	TRIPS	L	DF	L\DF	TRIPS	L	DF	L\DF	TRIP	L	DF	L\DF	TRIPS
								All Trips								
1973	802	2620	0.31	2475	1284	6236	0.21	2305	234	859	0.27	316	2320	9715	0.25	5096
1974	497	2478	0.20	2612	1029	7092	0.15	2440	157	1004	0.16	356	1683	10574	0.16	5408
1975	679	2354	0.29	2488	1126	7728	0.15	2421	153	1178	0.13	395	1957	11260	0.19	5304
1976	756	2826	0.27	2507	913	6373	0.14	2131	97	860	0.11	313	1765	10059	0.19	4951
1977	1074	3183	0.34	2774	1070	6025	0.18	2479	157	872	0.18	341	2302	10080	0.25	5594
1978	1372	4033	0.34	3329	1658	7053	0.24	2920	277	1225	0.23	541	3307	12310	0.28	6790
1979	946	4465	0.21	3450	1467	6757	0.22	3240	283	1570	0.18	686	2696	12792	0.21	7376
1980	1062	4932	0.22	3149	1428	7120	0.20	3501	376	1997	0.19	755	2866	14049	0.20	7405
1981	1069	3748	0.29	4325	1637	7015	0.23	3405	423	2595	0.16	810	3129	13358	0.24	8540
1982	1162	4430	0.26	4672	2346	8626	0.27	3868	905	3559	0.25	979	4413	16615	0.27	9519
1983	1203	3930	0.31	4577	2796	9581	0.29	4155	1308	4544	0.29	1127	5307	18056	0.29	9859
1984	1281	4069	0.31	4912	3245	12157	0.27	4942	1423	4769	0.30	1110	5949	20994	0.28	10964
1985	1195	3794	0.31	4503	2765	12664	0.22	4845	1600	5530	0.29	1305	5560	21988	0.26	10653
1986	806	3289	0.25	3366	2031	10525	0.19	4091	1177	5287	0.22	1264	4015	19101	0.21	8721
1987	647	2833	0.23	2506	1623	9593	0.17	3370	845	5035	0.17	1167	3114	17461	0.18	7043
1988	560	2986	0.19	2476	1463	8948	0.16	3447	951	4871	0.20	1121	2973	16805	0.18	7044
1989	283	2269	0.12	1933	959	8538	0.11	2862	618	4292	0.14	985	1860	15099	0.12	5780
1990	265	2649	0.10	1761	661	7736	0.09	2375	347	4172	0.08	1003	1274	14557	0.09	5139
1991	316	3135	0.10	2153	830	9076	0.09	2531	383	4681	0.08	988	1529	16892	0.09	5672
1992	352	3589	0.10	2478	148	10720	0.11	2745	414	5005	0.08	897	1914	19314	0.10	6120
1993	380	3321	0.11	2312	1347	10872	0.12	2950	530	4711	0.11	841	2257	18904	0.12	6103
								40%Trips								
1973	306	208	1.47	150	392	271	1.45	109	96	58	1.66	18	793	536	1.48	277
1974	134	99	1.34	121	169	112	1.50	69	21	16	1.25	7	323	228	1.42	197
1975	292	171	1.71	307	208	168	1.24	92	4	4	1.09	2	504	343	1.51	401
1976	211	144	1.47	258	137	90	1.54	67	3	1	3.38	1	352	234	1.51	326
1977	151	93	1.62	166	129	84	1.53	58	1	4	0.26	1	281	182	1.57	225
1978	214	162	1.33	137	197	82	2.39	76	7	2	3.58	2	418	246	1.87	215
1979	93	79	1.17	87	103	69	1.49	47	7	2	3.45	1	203	151	1.41	135
1980	93	82	1.14	76	107	40	2.66	28	54	25	2.17	13	254	147	2.00	117
1981	101	54	1.87	94	239	108	2.21	82	22	13	1.69	8	362	175	2.08	184
1982	172	112	1.53	147	289	136	2.13	106	55	31	1.75	11	516	279	1.89	264
1983	183	140	1.30	162	519	279	1.86	159	48	30	1.59	12	750	450	1.70	333
1984	234	210	1.12	367	705	595	1.18	404	176	98	1.80	28	1115	903	1.27	799
1985	266	277	0.96	382	465	580	0.80	307	177	143	1.24	44	909	1000	0.93	733
1986	185	236	0.78	279	499	785	0.64	372	127	169	0.75	42	811	1190	0.69	693
1987	155	195	0.79	215	377	569	0.66	239	86	109	0.78	25	617	873	0.71	479
1988	137	176	0.78	181	517	905	0.57	344	202	254	0.79	54	856	1335	0.66	579
1989	45	67	0.67	85	128	256	0.50	129	77	112	0.69	223	250	435	0.59	437
1990	36	57	0.63	72	49	85	0.58	39	9	16	0.54	3	94	158	0.60	114
1991	35	76	0.46	74	55	106	0.52	35	1	1	0.83	1	92	183	0.50	110
1992	42	65	0.65	59	181	382	0.48	96	25	7	3.32	5	248	454	0.79	160
1993	76	140	0.54	103	266	538	0.49	166	30	42	0.71	10	372	720	0.52	279

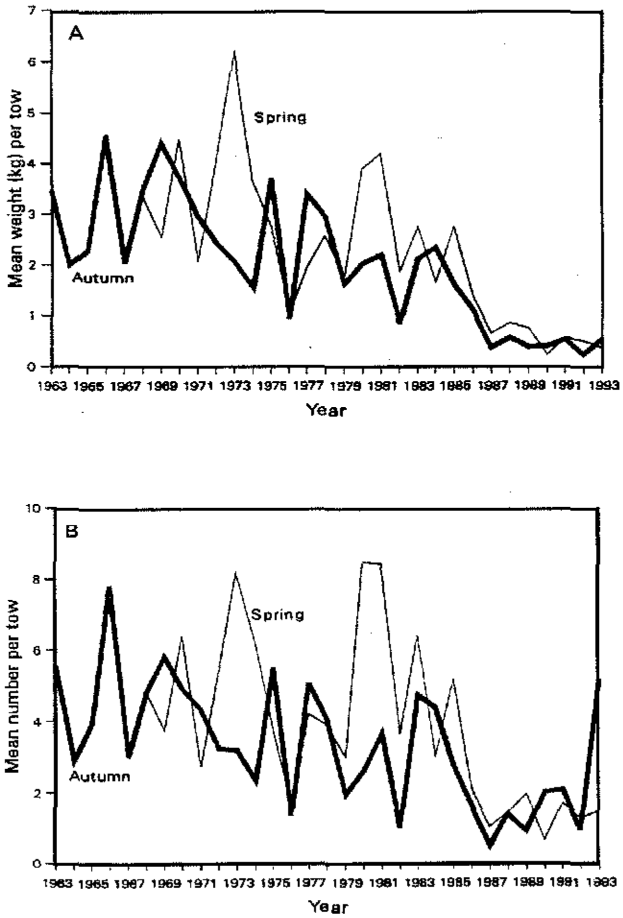

Figure C6. Trends in U.S. landings per day fished (A) and effort (B) of witch flounder, 1973-1993. Data are based on all otter trawl trips that caught witch flounder (all trips), and for otter trawl trips for which the trip catch by weight was 40% or more witch flounder (directed trips).

Table C18. Landings per unit effort (LPUE) age-specific indices used in the VPA calibration

Year	Age 7	Age 8	Age 9
1982	0.0385	0.0380	0.0231
1983	0.0834	0.0513	0.0387
1984	0.0677	0.0682	0.0317
1985	0.0694	0.0568	0.0276
1986	0.0799	0.0426	0.0210
1987	0.0895	0.0495	0.0273
1988	0.0812	0.0677	0.0236
1989	0.0496	0.0576	0.0228
1990	0.0181	0.0312	0.0221
1991	0.0129	0.0134	0.0160
1992	0.0343	0.0096	0.0085
1993	0.0297	0.0291	0.0109

Table C19. Stratified mean catch per tow in number and weight of witch flounder from the NEFSC offshore spring and autumn bottom trawl surveys in Gulf of Maine-Georges Bank region, strata 22-30, 36-40), 1963-1993

	Spring		Autumn	
	Weight	Numbers	Weight	Numbers
1963	-	-	3.46	5.52
1964	-	-	2.00	2.89
1965	-	-	2.27	3.94
1966	-	-	4.56	7.80
1967	-	-	2.02	3.01
1968	3.34	4.76	3.49	4.82
1969	2.53	3.74	4.40	5.81
1970	4.49	6.39	3.71	4.89
1971	2.06	2.74	2.95	4.32
1972	4.01	5.35	2.42	3.24
1973	6.21	8.20	2.05	3.18
1974	3.62	6.23	1.54	2.34
1975	2.75	3.72	3.70	5.50
1976	1.03	1.66	0.94	1.34
1977	1.96	4.20	3.38	5.06
1978	2.56	3.87	2.94	4.04
1979	1.77	3.01	1.62	1.94
1980	3.89	8.46	2.04	2.62
1981	4.18	8.40	2.19	3.66
1982	1.87	3.64	0.83	0.99
1983	2.74	6.41	2.12	4.72
1984	1.66	3.00	2.34	4.37
1985	2.75	5.18	1.59	2.76
1986	1.35	2.07	1.09	1.59
1987	0.65	1.01	0.37	0.48
1988	0.85	1.43	0.57	1.38
1989	0.74	1.95	0.38	0.89
1990	0.24	0.63	0.40	2.00
1991	0.57	1.68	0.54	2.08
1992	0.50	1.26	0.24	0.94
1993	0.36	1.47	0.54	5.15

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

mortality estimates on commercial fishing effort. Halliday (1973) used a value of M = 0.15 for females and M = 0.2 for males in an assessment for Scotian Shelf witch flounder. All analyses were performed in the present study assuming M = 0.15.

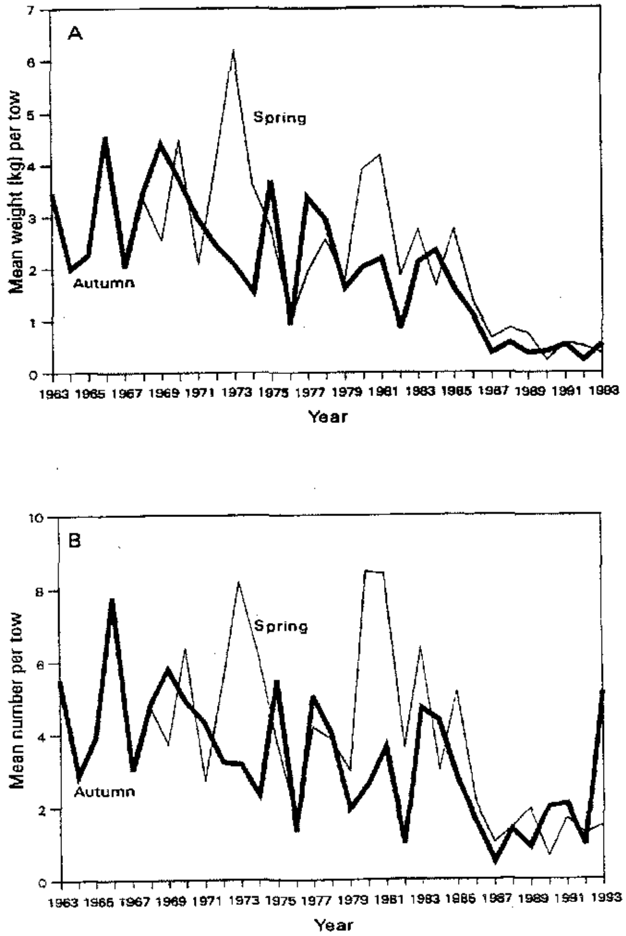

Figure C7. Stratified (A) mean catch per tow (kilograms) and (B) mean number per tow of witch flounder in NEFSC spring and autumn research vessel bottom trawl surveys in the Gulf of Maine - Georges Bank region, 1963-1993.

Total Mortality

Estimates of instantaneous total mortality (Z) were computed from NEFSC spring and autumn research vessel bottom trawl survey catch per tow at age data by combining cohorts over the following time periods: 1981-1984, 1985-1988, and 1989-1992. Given the variability in age at full recruitment to the survey gear observed during the time series (Table C20), estimates were derived for each time period and each season by taking the natural logarithm of the ratio of pooled age 7+ to pooled 8+. Because the estimates from each season exhibited similar trends and there was no basis to select one season over the other, total mortality was calculated by taking the geometric mean of the spring and autumn estimates for each time period. Total mortality increased from 0.34 during 1981-1984 to 0.71 during 1985-1988, and subsequently declined to 0.53 during 1989-1993 (Table C21).

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Virtual Population Analysis and Tuning

The ADAPT (Parrack 1986, Gavaris 1988, Conser and Powers 1990) calibration method was applied to derive estimates of terminal F values in 1993. Calibration formulations included both age-aggregated and age-disaggregated indices. Several exploratory formulations were conducted using the catch-at-age estimates (landings plus discards from the shrimp and large-mesh otter trawl fishery; Table C16). Estimates of stock sizes, their associated statistics, and F in the terminal year are summarized in Table C22.

The baseline formulation was performed to estimate stock sizes for ages 3 to 9 (Table C22; RUN A) using NEFSC spring and autumn abundance indices for ages 3 to 10 and an aggregate index of age 7+, DMF inshore spring and autumn abundance indices (age-aggregated), and an age-aggregated commercial LPUE index as tuning indices. All indices were given equal weighting. Autumn survey indices were lagged forward one year and age to equate autumn indices with beginning year population sizes of the subsequent year. A flat-top partial recruitment pattern was used, with full fishing mortality on ages 8 and older as indicated by the separable VPA. Spawning stock biomass (SSB) was calculated at spawning time by applying the witch flounder maturity ogive from O'Brien *et al.* (1993).

Baseline results indicated that the coefficient of variation (CV) for age 3 was 96%; consequently this age was excluded from subsequent formulations. The CVs for survey catchability coefficients (q) were consistent, ranging from 25% to 32%, with higher CVs associated with younger ages.

Exploratory formulations included varying the ages to be estimated, including LPUE age-specific indices, excluding age-aggregated indices, excluding survey indices on older ages, and lowering the age of full recruitment to age 7. Results indicate a consistent increase in F in the terminal year, an unexpected jump in F between the fully-recruited age (7 or 8) and the previous age in the terminal year, and extremely low

Table C20. Stratified mean number per tow at age of witch flounder in the NEFSC bottom trawl spring and autumn surveys (Strata 22-30, 36-40), 1980-1993

Year	Age Group															Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	
								SPRING								
1980	0.00	0.06	0.23	0.95	1.52	0.72	1.20	1.02	0.38	0.40	0.31	0.30	0.12	0.16	1.10	8.46
1981	0.00	0.00	0.05	0.82	0.93	2.00	1.02	0.76	0.67	0.42	0.13	0.20	0.24	0.22	0.90	8.40
1982	0.00	0.04	0.01	0.56	0.57	0.34	0.21	0.64	0.41	0.08	0.26	0.15	0.03	0.03	0.30	3.64
1983	0.00	0.00	0.03	0.58	1.25	1.33	0.55	0.64	0.67	0.48	0.20	0.09	0.08	0.11	0.41	6.41
1984	0.00	0.00	0.01	0.10	0.33	0.73	0.42	0.26	0.28	0.24	0.11	0.12	0.09	0.02	0.29	3.00
1985	0.00	0.00	0.00	0.02	0.43	1.11	1.19	0.86	0.45	0.13	0.06	0.14	0.09	0.04	0.67	5.18
1986	0.00	0.00	0.00	0.00	0.04	0.24	0.53	0.43	0.17	0.18	0.07	0.04	0.08	0.05	0.25	2.07
1987	0.00	0.00	0.00	0.00	0.06	0.12	0.12	0.26	0.17	0.03	0.06	0.03	0.00	0.00	0.15	1.01
1988	0.00	0.02	0.02	0.06	0.00	0.07	0.31	0.38	0.25	0.16	0.08	0.04	0.02	0.00	0.02	1.43
1989	0.00	0.02	0.01	0.04	0.98	0.12	0.07	0.10	0.31	0.07	0.03	0.05	0.05	0.02	0.06	1.95
1990	0.00	0.01	0.00	0.04	0.09	0.32	0.02	0.02	0.02	0.06	0.01	0.00	0.01	0.00	0.03	0.63
1991	0.00	0.04	0.00	0.78	0.11	0.11	0.19	0.02	0.09	0.10	0.14	0.02	0.02	0.00	0.07	1.68
1992	0.00	0.05	0.01	0.19	0.37	0.08	0.12	0.15	0.05	0.14	0.02	0.01	0.05	0.00	0.02	1.26
1993	0.00	0.15	0.11	0.14	0.46	0.33	0.06	0.08	0.00	0.02	0.02	0.00	0.06	0.00	0.04	1.47
								AUTUMN								
1980	0.04	0.00	0.02	0.00	0.20	0.26	0.28	0.36	0.17	0.15	0.27	0.04	0.16	0.12	0.57	2.62
1981	0.03	0.07	0.03	0.24	0.44	0.61	0.46	0.27	0.26	0.18	0.21	0.17	0.04	0.13	0.48	3.66
1982	0.02	0.00	0.00	0.06	0.01	0.02	0.08	0.25	0.13	0.01	0.03	0.03	0.00	0.06	0.29	0.99
1983	0.00	0.01	0.01	0.49	1.60	0.78	0.51	0.47	0.11	0.10	0.12	0.09	0.02	0.00	0.42	0.47
1984	0.00	0.00	0.00	0.08	0.97	1.01	0.58	0.54	0.32	0.14	0.12	0.06	0.04	0.14	0.38	4.37
1985	0.00	0.00	0.01	0.07	0.06	0.60	0.62	0.58	0.24	0.13	0.09	0.01	0.03	0.10	0.22	2.76
1986	0.01	0.00	0.00	0.01	0.04	0.27	0.36	0.31	0.15	0.11	0.02	0.02	0.01	0.05	0.23	1.59
1987	0.00	0.00	0.02	0.01	0.00	0.02	0.05	0.18	0.07	0.00	0.01	0.00	0.02	0.00	0.08	0.48
1988	0.00	0.00	0.00	0.71	0.07	0.00	0.03	0.22	0.06	0.05	0.03	0.06	0.02	0.03	0.08	1.38
1989	0.17	0.02	0.02	0.08	0.30	0.01	0.02	0.04	0.05	0.09	0.01	0.00	0.03	0.00	0.04	0.89
1990	0.48	0.12	0.11	0.39	0.52	0.17	0.05	0.02	0.02	0.05	0.00	0.00	0.01	0.04	0.03	2.00
1991	0.22	0.02	0.17	0.67	0.35	0.27	0.15	0.09	0.06	0.02	0.04	0.03	0.00	0.00	0.00	2.08
1992	0.09	0.03	0.11	0.27	0.22	0.06	0.05	0.00	0.00	0.02	0.01	0.02	0.00	0.01	0.04	0.94
1993	2.54	0.67	0.11	0.55	0.76	0.23	0.06	0.03	0.08	0.00	0.02	0.04	0.00	0.01	0.01	5.15

Note: 2 cm intervals

values of F on age 4 and 5 (due to high estimates of age 5 and 6 stock sizes in 1994) (Table C22). These stock size estimates eventually translated into record-high age 2 recruitment estimates for the 1988 and 1989 year classes in 1990 and 1991. Residuals showed a pattern of high positive residuals (forming a ridge), which appears to be caused by the strong 1985 year class (only weakly detected in the NEFSC surveys) and improved recruitment since 1990.

Because of these problems with the formulations, a final formulation was developed whereby the F on ages 4 and 5 in 1993 was estimated directly from the input partial recruitment pattern, the plus group was extended from 11+ to 10+, and the age at full recruitment was shortened from 8 to 7 (approximately 85-90% fully recruited). This formulation yielded a relatively smooth F pattern in the terminal year and a smoother annual trend in the fully recruited F. The input PR for this calibration was obtained from a separable analysis, but the final calibration employed a PR derived from the 1988-1992 F pattern derived from the penultimate calibration run.

Table C23 give results of the final VPA calibration, including estimates of F, stock size, and spawning stock biomass at age. The final calibration exhibited very low correlations (< 0.10) among estimates of slopes (q), but some moderate correlations (0.20-0.30) were evident between stock sizes and q's. The CVs on age 4 and 7-9 abundance estimates ranged from 0.4 to 0.6.

Fishing Mortality Estimates

Average (ages 7-9, unweighted) fishing mortality increased rapidly from 0.19 in 1982 to 0.55 in 1985, declined to 0.24 in 1990 and 1991, and increased in 1993 to 0.45 (Table C23, Figure C8).

Table C21. Estimates of instantaneous total mortality (Z) for witch flounder in the Gulf of Maine-Georges Bank region, 1980-1993, derived from NEFC offshore spring and autumn bottom trawl survey data

Year	Age						Time	LN(7+/8+)		Geometric
	3+	4+	5+	6+	7+	8+	Period	Spring	Autumn	Mean
						Spring				
1980	8.13	7.17	5.74	4.95	3.76	2.82				
1981	8.25	7.52	6.43	4.60	3.54	2.88	1981-1984	0.48	0.24	0.34
1982	3.55	2.95	2.46	2.09	1.85	1.24				
1983	6.34	5.81	4.55	3.26	2.72	2.00				
1984	2.91	2.90	2.60	1.83	1.43	1.15				
1985	5.19	5.17	4.71	3.65	2.45	1.54	1985-1988	0.77	0.65	0.71
1986	2.06	2.06	2.02	1.78	1.25	0.84				
1987	0.99	0.99	0.93	0.82	0.69	0.43				
1988	1.39	1.33	1.33	1.26	0.96	0.58				
1989	1.91	1.88	0.88	0.77	0.70	0.62	1989-1992	0.58	0.49	0.53
1990	0.62	0.58	0.49	0.17	0.17	0.13				
1991	1.64	0.86	0.75	0.66	0.45	0.42	1981-1986	0.61	0.38	0.48
1992	1.21	1.02	0.65	0.56	0.45	0.30	1987-1992	0.45	0.55	0.50
1993	1.21	1.07	0.61	0.28	0.22	0.14				
						Autumn				
1980	2.55	2.55	2.34	2.07	1.75	1.43				
1981	3.50	3.29	2.83	2.24	1.71	1.46				
1982	0.99	0.93	0.91	0.88	0.80	0.56				
1983	4.68	4.18	2.58	1.82	1.27	0.83				
1984	4.35	4.26	3.32	2.33	1.73	1.20				
1985	2.73	2.69	2.61	2.00	1.32	0.84				
1986	1.58	1.58	1.53	1.26	0.91	0.60				
1987	0.45	0.44	0.44	0.42	0.37	0.18				
1988	1.36	0.63	0.58	0.57	0.54	0.33				
1989	0.68	0.60	0.30	0.29	0.27	0.25				
1990	1.29	0.91	0.40	0.18	0.16	0.14				
1991	1.66	1.00	0.67	0.38	0.24	0.17				
1992	0.79	0.52	0.31	0.26	0.20	0.20				
1993	1.79	1.24	0.48	0.25	0.19	0.16				

Stock Size and Spawning Stock Biomass Estimates

Spawning stock biomass declined from 26,000 tons in 1982 to about 7,000 tons in 1989 and has fluctuated about this level through 1993 (Table C23, Figure C9).

Recruitment Estimates

Since 1982 recruitment at age 2 has ranged from approximately 4 million (1983 and 1984 year classes) to 26 million (1990 year class) with most estimates between 7 and 15 million fish (Table C23, Figure C9). Over the 1982-1993 period, geometric mean recruitment for the 1980-1991 year classes equalled 9.8 million fish. The 1988 and 1989 year classes were slightly above average, the 1990 year class was well above average and the 1992 year class was below average.

Precision of F and SSB

The uncertainty associated with the estimates of stock size and fishing mortality from the final VPA was evaluated using a bootstrap procedure (Efron 1982). Two hundred bootstrap iterations were performed to derive standard errors, coefficients of variation (CVs) and bias estimates for

Table C22. Parameter estimates (with associated statistics) and estimates of terminal F from trial ADAPT calibrations for witch flounder

RUN A BASELINE AGES 3-9, ALL INDICES

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
N 3	3.72012E4	3.57656E4	1.04014E0	0.96	3 · 0.01
N 4	2.25709E4	1.25490E4	1.79862E0	0.56	4 · 0.06
N 5	1.78868E4	8.03158E3	2.22706E0	0.45	5 · 0.09
N 6	1.13401E4	4.60169E3	2.46434E0	0.41	6 · 0.42
N 7	1.54324E3	7.05706E2	2.18680E0	0.46	7 · 0.77
N 8	4.44382E2	2.87043E2	1.54814E0	0.65	8 · 1.58
N 9	1.32088E2	1.03345E2	1.27812E0	0.78	9 · 1.58
					10 · 1.58
					11 . 1.58

RUN B AGES 4-9, ALL INDICES

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 · 0.01
N 4	2.35172E4	1.30432E4	1.80302E0	0.55	4 · 0.05
N 5	1.83630E4	8.22455E3	2.23270E0	0.45	5 · 0.09
N 6	1.15679E4	4.68032E3	2.47161E0	0.40	6 · 0.41
N 7	1.56761E3	7.11368E2	2.20365E0	0.45	7 · 0.77
N 8	4.47535E2	2.87286E2	1.55781E0	0.64	8 · 1.71
N 9	1.12077E2	8.52046E1	1.31538E0	0.76	9 · 1.71
					10 · 1.71
					11 · 1.71

RUN CAGES 4-9, WITHOUT NEFC AUTMUN AGE 5 AND NEFC AUTUMN AGE 6

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
			3 · 0.01		
N 4	2.41499E4	1.22552E4	1.97058E0	0.51	4 · 0.06
N 5	1.76054E4	8.19530E3	2.14824E0	0.47	5 · 0.07
N 6	1.66369E4	7.21513E3	2.30583E0	0.43	6 · 0.42
N 7	1.54535E3	6.90111E2	2.23928E0	0.45	7 · 0.97
N 8	3.15666E2	2.11747E2	1.49077E0	0.67	8 · 1.68
N 9	1.17115E2	8.03816E1	1.45699E0	0.69	9 · 1.68
					10 · 1.68
					11 · 1.68

RUN DAGES 4-9, ALL INDICES, ITERATIVE RE-WEIGHT BY INDEX (chi)

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 · 0.01
N 4	2.52698E4	1.36540E4	1.85073E0	0.54	4 · 0.05
N 5	2.12724E4	1.01033E4	2.10548E0	0.47	5 · 0.08
N 6	1.27431E4	5.32528E3	2.39295E0	0.42	6 · 0.49
N 7	1.26640E3	6.14919E2	2.05946E0	0.49	7 · 0.60
N 8	6.26531E2	2.83496E2	2.21002E0	0.45	8 · 1.69
N 9	1.14709E2	7.57249E1	1.51481E0	0.66	9 · 1.69
					10 · 1.69
					11 · 1.69

RUN EAGES 4-9 USING LPUE AGE-SPECIFIC (ages 7-10), omitting all age-agregated indices

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 · 0.01
N 4	2.38702E4	1.27472E4	1.87259E0	0.53	4 · 0.05
N 5	1.85870E4	8.01576E3	2.31880E0	0.43	5 · 0.09
N 6	1.17086E4	4.56061E3	2.56732E0	0.39	6 · 0.48
N 7	1.30854E3	6.97114E2	1.87708E0	0.53	7 · 0.64
N 8	5.78943E2	3.27880E2	1.76572E0	0.57	8 · 1.33
N 9	1.81839E2	1.00912E2	1.80196E0	0.55	9 · 1.33
					10 · 1.33
					11 · 1.33

Table C22. Continued.

RUN FAGES 4-9, SPR 3-9, AUT 3-9, LPUE AGE-SPECIFIC 7-9

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 0.01
N 4	2.39708E4	1.31487E4	1.82305E0	0.55	4 0.05
N 5	1.86547E4	8.26323E3	2.25755E0	0.44	5 0.09
N 6	1.17522E4	4.70143E3	2.49972E0	0.40	6 0.47
N 7	1.31589E3	7.19093E2	1.82993E0	0.55	7 0.64
N 8	5.82787E2	3.38553E2	1.72141E0	0.58	8 1.28
N 9	1.95265E2	1.20349E2	1.62249E0	0.62	9 1.28
					10 1.28
					11 1.28

RUN GAGES 5-9, SPR 5-9, AUT 5-6, LPUE AGE-SPECIFIC 7-10

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 0.02
					4 0.04
N 5	2.28591E4	1.96439E4	1.16367E0	0.86	5 0.19
N 6	5.36427E3	3.00842E3	1.78308E0	0.56	6 0.70
N 7	7.84935E2	7.86020E2	9.98619E-1	1.00	7 0.35
N 8	1.24014E3	7.45398E2	1.66373E0	0.60	8 1.17
N 9	2.29581E2	1.62985E2	1.40860E0	0.71	9 1.17
					10 1.17
					11 1.17

RUN HAGES 5-9, SPR 5-6, AUT 5-6, LPUE AGE-SPECIFIC 7-10

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 · 0.01
N 4					4 · 0.04
N 5	2.35158E4	2.07298E4	1.13440E0	0.88	5 · 0.18
N 6	5.54434E3	3.18333E3	1.74168E0	0.57	6 · 0.67
N 7	8.43961E2	8.35110E2	1.01060E0	0.99	7 · 0.27
N 8	1.67165E3	1.07211E3	1.55922E0	0.64	8 · 0.95
N 9	3.22786E2	2.22490E2	1.45078E0	0.69	9 · 0.95
					10 · 0.95
					11 · 0.95

RUN IAGES 4-8, P-R FULL AT AGE 7, SPR 3-6, AUT 3-6, LPUE AGE-SPECIFIC 7-10

PARAMETER	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.	F in 1993
					3 0.01
N 4	2.50275E4	1.39350E4	1.79601E0	0.56	4 0.05
N 5	1.93627E4	8.70885E3	2.22333E0	0.45	5 0.09
N 6	1.22113E4	4.95918E3	2.46237E0	0.41	6 0.44
N 7	1.45033E3	9.51660E2	1.52400E0	0.66	7 0.86
N 8	3.83877E2	2.20836E2	1.73829E0	0.58	8 0.86
					9 0.86
					10 0.86
					11 0.86

Table C23. Stock size, fishing mortality, and spawning stock biomass obtained from VPA calibration with NEFSC spring and autumn indices and U.S. commercial LPUE at age indices for the Georges Bank-Gulf of Maine witch flounder

Stock Numbers (Jan 1) in Thousands - WIT94R

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	19358.3	10994.4	5168.2	4279.5	10975.6	8716.3	7833.7	13818.9	14964.7	30422.5	8649.2	11386.0	0.0
2	21452.4	16661.6	9462.9	4448.4	3683.4	9446.8	7502.2	6728.0	11891.3	12875.4	26177.2	7407.0	9800.0
3	15429.5	18464.2	14340.5	8144.7	3825.9	3167.5	8126.4	6325.6	5782.5	10184.3	11071.6	22386.5	6263.3
4	12345.6	13118.1	15614.1	12215.4	6996.7	3279.7	2712.2	6414.3	5379.5	4679.5	8365.3	9273.3	19069.6
5	9339.3	9647.8	10195.2	12159.3	9481.9	5685.3	2657.0	2212.4	4935.4	4184.7	3671.8	6304.8	6954.7
6	7907.2	6952.2	6982.6	7002.9	8462.4	6799.8	4466.4	2035.7	1753.4	3554.2	2866.7	2419.4	4300.0
7	4330.1	5491.2	4599.8	4474.2	4264.9	4799.2	4691.0	3245.3	1468.0	1281.8	2567.1	1669.4	1282.3
8	3542.6	3133.6	3329.7	2647.6	2471.1	2268.5	2702.6	2780.8	2107.0	1019.9	901.4	1602.2	917.7
9	2372.6	2464.0	1838.4	1544.8	1149.7	1379.7	1162.6	1277.0	1596.2	1394.4	668.5	605.0	870.0
10	10760.8	7262.1	5486.7	4452.1	2715.0	2115.5	2485.9	1712.8	1232.4	2716.8	1859.1	1838.0	1334.7
1+	106838.4	94189.1	77018.1	61368.9	54026.6	47658.2	44340.0	46550.8	51110.5	72313.5	66797.8	64891.6	50792.3

Summaries for ages 3 -7

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
3	55266.9	59271.0	56900.3	48188.9	36652.7	27379.7	26518.3	24291.0	23022.1	26298.8	30112.3	44260.6	39657.6
4	39837.4	40806.9	42559.8	40044.2	32826.8	24212.2	18391.8	17965.4	17239.5	16114.5	19040.7	21874.1	33394.3
5	27491.8	27688.7	26945.6	27828.7	25830.1	20932.6	15679.6	11551.1	11860.1	11435.0	10675.4	12600.8	14324.7
6	18152.5	18041.0	16750.4	15669.5	16348.2	15247.3	13022.6	9338.7	6924.6	7250.3	7003.6	6296.1	7370.0
7	10245.3	11088.8	9767.8	8666.6	7885.7	8447.4	8556.2	7303.1	5171.2	3696.1	4136.9	3876.7	3070.0

Fishing Mortality - WIT94R

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.02
3	0.01	0.02	0.01	0.00	0.00	0.01	0.09	0.01	0.06	0.05	0.03	0.01
4	0.10	0.10	0.10	0.10	0.06	0.06	0.05	0.11	0.10	0.09	0.13	0.14
5	0.15	0.17	0.23	0.21	0.18	0.09	0.12	0.08	0.18	0.23	0.27	0.23
6	0.21	0.26	0.30	0.35	0.42	0.22	0.17	0.18	0.16	0.18	0.39	0.48
7	0.17	0.35	0.40	0.44	0.48	0.42	0.37	0.28	0.21	0.20	0.32	0.45
8	0.21	0.38	0.62	0.68	0.43	0.52	0.60	0.41	0.26	0.27	0.25	0.46
9	0.19	0.36	0.49	0.53	0.47	0.46	0.45	0.34	0.24	0.23	0.30	0.45
10	0.19	0.36	0.49	0.53	0.47	0.46	0.45	0.34	0.24	0.23	0.30	0.45

Ave F for ages 3-7

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
3	0.15	0.24	0.31	0.33	0.29	0.25	0.26	0.20	0.18	0.18	0.24	0.32
4	0.17	0.27	0.36	0.39	0.34	0.30	0.29	0.23	0.19	0.20	0.28	0.37
5	0.19	0.31	0.41	0.44	0.40	0.34	0.34	0.26	0.21	0.22	0.31	0.42
6	0.20	0.34	0.45	0.50	0.45	0.41	0.40	0.30	0.22	0.22	0.32	0.46
7	0.19	0.37	0.50	0.55	0.46	0.47	0.48	0.34	0.24	0.24	0.29	0.45

SSB at the Start of the Spawning Season - Males & Females (Metric Tons)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	203.61	89.22	99.63	27.21	12.73	10.10	20.19	16.21	13.58	28.37	51.33	113.59
4	960.01	824.97	1020.17	795.33	298.84	127.92	109.02	173.46	178.63	161.32	337.15	454.19
5	2430.80	2180.17	2346.10	2806.54	2225.18	1259.90	583.73	457.95	920.49	965.41	871.53	1559.97
6	2767.02	2330.53	2157.82	2366.95	2637.39	2255.83	1544.58	700.63	544.32	1137.76	1022.55	861.29
7	2137.48	2358.95	1970.00	1977.40	1885.79	2085.92	2140.30	1556.47	689.46	608.16	1194.45	747.70
8	2318.20	1664.74	1718.10	1406.02	1401.10	1263.37	1447.99	1583.33	1236.03	609.67	547.47	925.41
9	1798.71	1719.25	1169.02	1030.98	791.18	943.15	779.31	862.90	1137.48	992.01	470.80	438.62
10	13725.57	8453.28	6233.03	4942.06	3046.74	2280.94	2727.06	1982.80	1531.21	2995.05	1992.26	2002.62
1+	26341.4	19621.1	16713.9	15352.5	12299.0	10227.1	9352.2	7333.8	6251.2	7497.8	6487.57	103.4

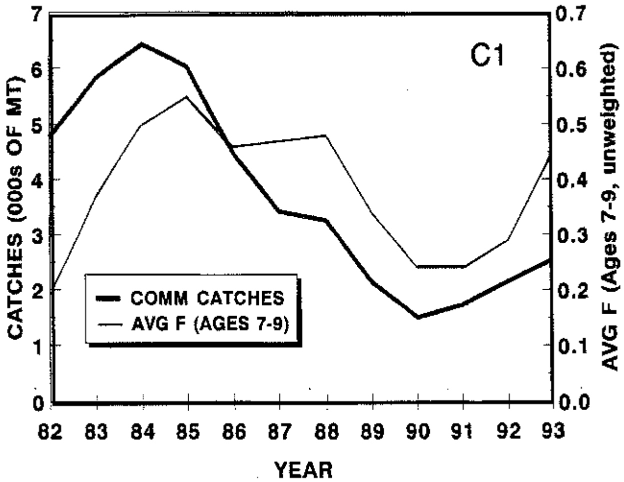

Figure C8. Gulf of Maine - Georges Bank witch flounder commercial catches (thousand metric tons) and fishing mortality, 1982-1993.

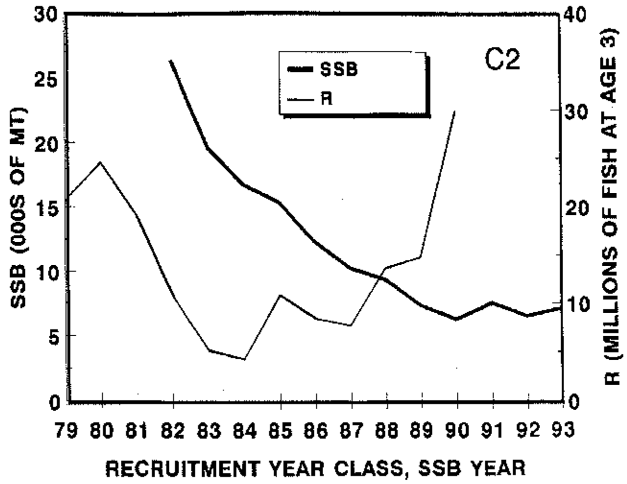

Figure C9. Gulf of Maine - Georges Bank witch flounder spawning stock biomass, 1972-1993, and recruitment 1982-1990.

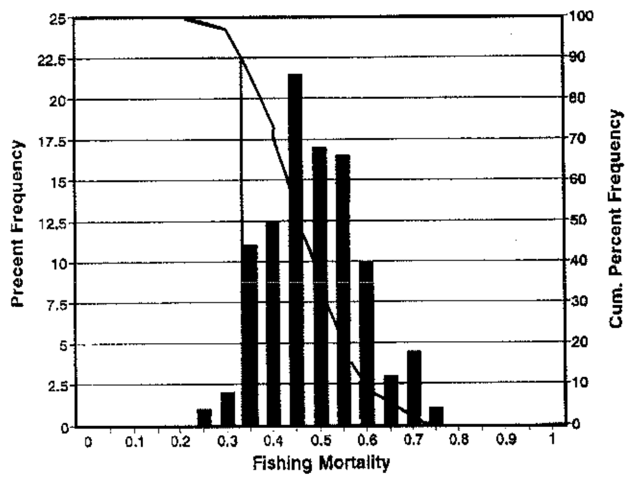

Figure C10. Gulf of Maine - Georges Bank witch flounder fishing mortality.

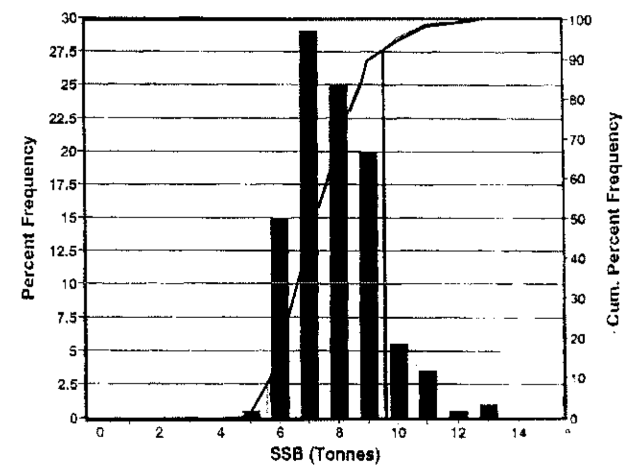

Figure C11. Gulf of Maine - Georges Bank witch flounder spawning stock biomass.

the ages 4 and 7-9 stock size estimates at the start of 1994, the catchability estimates (q) for each index of abundance used in calibrating the VPA, and the age 7-9 Fs in 1993. Frequency distributions of the 1993 age 7-9 mean fishing mortality and spawning stock biomass bootstrap estimates were generated and cumulative probability curves were produced (Figures C10 and C11).

The bootstrap results indicate that age-specific stock sizes in 1994 were moderately well estimated with CVs ranging from 0.43 to 0.73. CVs on the catchability estimates of the indices of abundance used in the final ADAPT calibration generally ranged from 0.25 to 0.30 for the spring and autumn bottom trawl survey indices and for the commercial LPUE indices.

Except for ages 3 and 6, the age-specific F's in 1993 were reasonably well estimated with CVs ranging from 0.22 to 0.34, as was the mean (ages 7-9) fully recruited fishing mortality (CV = 0.22). The age 3 and 6 F's derived from the VPA were 15-16% higher than the bootstrap estimate. The corrected values are 0.087 (*vs* 0.104) for age 3 and 0.405 (*vs* 0.485) for age 6. The corrected estimates produce a slightly smoother exploitation pattern in the terminal year.

The mean bootstrap estimate of the fully recruited F in 1993 (0.465) was slightly higher than the VPA point estimate (0.455). Based on the cumulative probability curve (Figure C10), there is an 80% probability that the 1993 F lies between 0.33 and 0.59. These results also imply that there is a 77% probability that the 1993 F was greater than 0.39 (the overfishing definition of $F_{20\%}$).

Table C24. Yield and SSB per recruit results for Gulf of Maine-Georges Bank witch flounder

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- 6-1994; Time: 13:29:03.20

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .150
Initial age is: 1; Last age is: 10
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:==> WIT94R.DAT

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Prop Mat	Proportion of F Lndgs	Proportion of F LMO	Proportion of F Shmp	Average Weights Catch	Average Weights Lndgs	Average Weights LMDsc	Average Weights ShDsc
1	.0001	1.0000	.00	.00	.02	.98	.006	.000	.019	.005
2	.0390	1.0000	.02	.00	.04	.96	.021	.000	.050	.017
3	.1060	1.0000	.10	.16	.24	.60	.080	.000	.124	.045
4	.3030	1.0000	.36	.57	.35	.08	.215	.304	.165	.119
5	.5120	1.0000	.93	.85	.13	.02	.337	.360	.219	.208
6	.6730	1.0000	.98	.99	.01	.00	.437	.443	.274	.268
7	1.0000	1.0000	1.00	1.00	.00	.00	.578	.578	.000	.000
8	1.0000	1.0000	1.00	1.00	.00	.00	.699	.699	.000	.000
9	1.0000	1.0000	1.00	1.00	.00	.00	.847	.847	.000	.000
10+	1.0000	1.0000	1.00	1.00	.00	.00	1.269	1.269	.000	.000

Summary of Yield per Recruit Analysis for:Witch flounder 1994 - revised

Slope of the Yield/Recruit Curve at F=0.00: —> 3.1156
F level at slope=1/10 of the above slope (F0.1): ——> .149
Yield/Recruit corresponding to F0.1: ——> .1775
F level to produce Maximum Yield/Recruit (Fmax): ——> .271
Yield/Recruit corresponding to Fmax: ——> .1918
F level at 20 % of Max Spawning Potential (F20): ——> .388
SSB/Recruit corresponding to F20: ————> .6878

Listing of Yield per Recruit Results for: Witch flounder 1994 - revised

	FMORT	ALL COMPONENTS NUMBER	ALL COMPONENTS WEIGHT	LANDINGS ONLY NUMBER	LANDINGS ONLY WEIGHT	LM OT DISCARD NUMBER	LM OT DISCARD WEIGHT	SHRIMP DISCARD NUMBER	SHRIMP DISCARD WEIGHT
	.000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.050	.13414	.10776	.12370	.10587	.00580	.00102	.00464	.00026
	.100	.21619	.15834	.19560	.15464	.01138	.00199	.00921	.00051
F0.1	.149	.27140	.18290	.24108	.17749	.01666	.00291	.01366	.00076
	.150	.27212	.18316	.24165	.17772	.01674	.00292	.01373	.00076
	.200	.31306	.19509	.27298	.18801	.02189	.00381	.01819	.00100
	.250	.34460	.20018	.29516	.19153	.02684	.00466	.02259	.00123
Fmax	.271	.35568	.20108	.30244	.19180	.02884	.00500	.02440	.00133
	.300	.36983	.20153	.31128	.19138	.03161	.00547	.02694	.00146
	.350	.39060	.20081	.32318	.18924	.03619	.00625	.03124	.00168
F20%	.388	.40430	.19945	.33021	.18683	.03958	.00683	.03450	.00185
	.400	.40812	.19896	.33204	.18602	.04059	.00700	.03548	.00190
	.450	.42316	.19652	.33865	.18228	.04483	.00771	.03968	.00211
	.500	.43628	.19380	.34355	.17833	.04891	.00839	.04382	.00232
	.550	.44788	.19099	.34713	.17435	.05283	.00904	.04792	.00252
	.600	.45824	.18820	.34967	.17043	.05660	.00966	.05197	.00271
	.650	.46759	.18547	.35137	.16663	.06024	.01026	.05598	.00290
	.700	.47608	.18284	.35241	.16299	.06373	.01083	.05993	.00309
	.750	.48385	.18033	.35290	.15950	.06710	.01137	.06385	.00327
	.800	.49101	.17793	.35295	.15617	.07034	.01190	.06772	.00345
	.850	.49764	.17564	.35263	.15300	.07346	.01240	.07155	.00362
	.900	.50381	.17345	.35200	.14998	.07646	.01287	.07534	.00379
	.950	.50957	.17137	.35112	.14710	.07936	.01333	.07909	.00396
	1.000	.51497	.16937	.35003	.14435	.08215	.01377	.08280	.00412

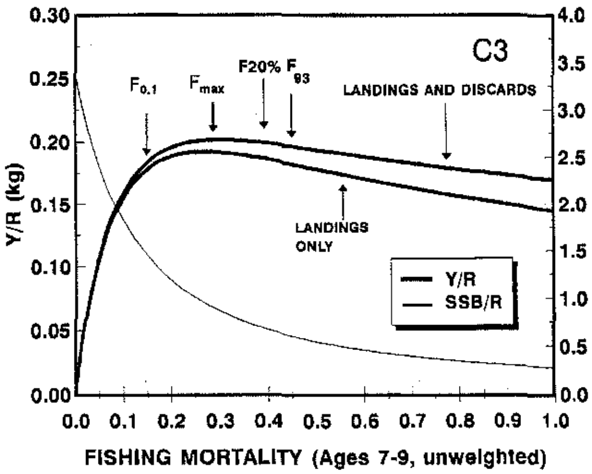

Figure C12. Gulf of Maine - Georges Bank witch flounder yield and spawning stock biomass per recruit.

The bootstrap mean of spawning stock biomass in 1993 (7400 mt) was rather precise (CV = 0.21) and slightly higher than the VPA point estimate (7100 mt). Based on the cumulative probability curve (Figure C11), there is an 80% probability that the 1993 SSB was between 5800 tons and 9000 mt.

BIOLOGICAL REFERENCE POINTS

Yield and Spawning Stock Biomass per Recruit

Yield-per-recruit (Y/R), total stock biomass per recruit, and spawning stock biomass per recruit (SSB/R) analyses were performed using the Thompson and Bell (1934) method. The exploitation pattern for input to the yield and SSB per recruit analyses and short-term projections was computed from the most recent five years of the F matrix derived from the VPA (Table C24). Geometric mean F at age was computed for the 1988-1992 period and divided by the geometric mean of the 7-9 unweighted F to derive the partial recruitment vector. The final exploitation pattern was smoothed, applying full exploitation on ages 7 and older. The final exploitation pattern was as follows:

Age 1: 0.0001	Age 2: 0.0390,
Age 3: 0.1060	Age 4 : 0.3030,
Age 5: 0.5120	Age 6: 0.6730,
	Ages 7+: 1.0000

This exploitation pattern was used in the Y/R and SSB/R analyses and for the catch and stock size projections for 1994 and 1995.

Mean weights at age used in the Y/R analyses were computed as a 4-year arithmetic average of landings mean weights at age (Table C13) over the 1990-1993 period. Mean weights at age for use in the SSB/R analyses were computed as the four-year arithmetic average of catch mean weights at age (Table C16) over the period 1990-1993. The maturation ogive was taken from O'Brien *et al.* (1993). The input data for the Y/R and SSB/R analyses are given in Table C24, and the results are presented in Table C24 and in Figure C12. The results indicate that $F_{0.1}$ = 0.15, F_{max} = 0.27, and $F_{20\%}$ = 0.39.

SHORT-TERM PROJECTIONS

Recruitment

Because of the uncertainty regarding quantitative predictions of recruitment from trawl survey indices, the long-term geometric mean recruitment (9.8 million fish), covering the 1982-1993 period was assumed for the 1992 and 1993 year classes in 1994 and 1995. Input data for the projections are listed in Table C25 The forecasts for 1994/1995 were run under the single recruitment scenario described earlier. The 1994 F scenarios used in the forecasts included: $F_{0.1}$, F_{max}, $F_{20\%}$, $0.9F_{93}$, and F_{93} given F in 1993 equalled 0.45. The smoothed partial recruitment pattern obtained from the VPA was applied to the fully recruited 1993 F (0.45) using 1993 VPA-calibrated stock sizes.

Catch and Stock Size Projections

Continued fishing at the 1993 level (F = 0.45) will lead to catches in 1994 remaining at the 1993 level (Table C25). Due to continued growth and maturation of the strong 1990 year class, SSB is expected to increase to about 10,000-11,000 mt in 1995, but will begin to decline in 1996 unless F is reduced in 1995 to $F_{20\%}$ (0.39) or less (Figure C13).

CONCLUSIONS

The Gulf of Maine-Georges Bank witch flounder stock is at a low biomass level and is overexploited. There is a high probability that fishing mortality in 1993 was at or above the $F_{20\%}$ level.

Table C25. Projection results for Gulf of Maine-Georges Bank witch flounder

The NEFC/PDB Catch and Stock Size Prediction Program - PDBPRED
Run Date: 22- 6-1994; Time: 12:46:15.76; Projection # 1
Witch flounder 1994 - revised

Input for Projections:

Number of Years: 3; Initial Year: 1994; Final Year: 1996
Number of Ages : 8; Age at Recruitment: 3; Last Age: 10
Natural Mortality is assumed Constant over time at: .150
Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file: ==> WITPRED.DAT

Year-specific Input data for Projection # 1

Year	Recruits at Age 3	Reference F	Natural Mortality	Target Catch
1994	9052.	.450	.150	N/A
1995	9052.	.450	.150	N/A
1996	9052.	.450	.150	N/A

Age-specific Input data for Projection # 1

Age	Stock Size in 1994	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Catch	Weights Stock
3	9052.	.1060	1.0000	.1000	.080	.080
4	19070.	.3030	1.0000	.3600	.215	.215
5	6955.	.5120	1.0000	.9300	.337	.337
6	4300.	.6730	1.0000	.9800	.437	.437
7	1282.	1.0000	1.0000	1.0000	.578	.578
8	918.	1.0000	1.0000	1.0000	.699	.699
9	870.	1.0000	1.0000	1.0000	.847	.847
10+	1335.	1.0000	1.0000	1.0000	1.269	1.269

Year	F(ref)	Recruits	Total Stock		Spawning Stock		Catch	
			Number	Weight	Number	Weight	Number	Weight
1994	.450	9052.	43782.	12861.	21385.	8681.	6524.	2715.
1995	.450	9052.	40708.	13260.	24908.	10369.	6918.	3017.
1996	.450	9052.	37699.	12796.	22485.	10053.	6706.	3084.
1994	.450	9052.	43782.	12861.	21385.	8681.	6524.	2715.
1995	.410	9052.	40708.	13260.	25007.	10418.	6375.	2786.
1996	.410	9052.	38199.	13067.	23018.	10345.	6308.	2923.
1994	.450	9052.	43782.	12861.	21385.	8681.	6524.	2715.
1995	.390	9052.	40708.	13260.	25057.	10442.	6099.	2669.
1996	.390	9052.	38453.	13205.	23291.	10495.	6097.	2836.
1994	.450	9052.	43782.	12861.	21385.	8681.	6524.	2715.
1995	.270	9052.	40708.	13260.	25357.	10590.	4371.	1926.
1996	.270	9052.	40047.	14077.	25015.	11451.	4656.	2215.
1994	.450	9052.	43782.	12861.	21385.	8681.	6524.	2715.
1995	.150	9052.	40708.	13260.	25662.	10739.	2515.	1116.
1996	.150	9052.	41761.	15027.	26901.	12510.	2862.	1392.

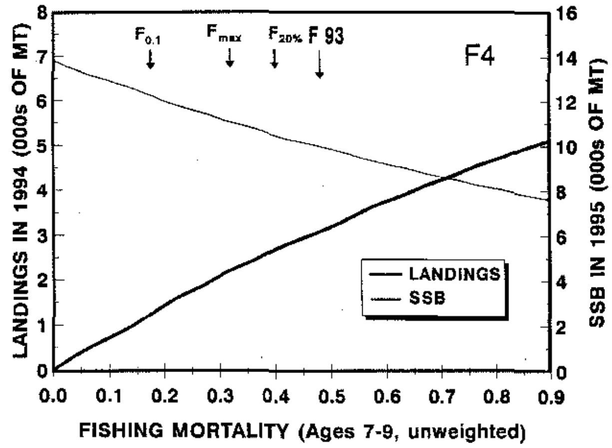

Figure C13. Gulf of Maine - Georges Bank witch flounder short-term landings and spawning stock biomass.

SSB has continually declined since the early 1980s, and all fishery-independent survey indices suggest a very substantial decline in biomass of witch flounder in recent years. Except for the very strong 1990 year class, recent year classes have been about average. Spawning stock biomass may be expected to increase in the short term, as the 1990 year class matures and recruits to the fishery, but will begin to decline in 1996 unless fishing mortality is reduced from the present level. It is also clear that, despite the variability in the survey indices, the age range of the stock has been greatly reduced (< age 7) since 1985-86 and that ages 2-4 in the catch are almost entirely fish discarded in the shrimp and large mesh otter trawl fisheries. Prospects for recruitment, however, appear to have improved in recent years as both a 1992 and possible 1993 year class are indicated to be above average.

SUBCOMMITTEE COMMENTS

Shortcomings in data requirements for the last witch flounder assessment (16th SAW/SARC Northern Demersal Subcommittee meeting 24-28 May, 1993) were overcome with the inclusion of a completed landings at age matrix, derived using yearly age-length keys, and augmented to account for discards in both the large mesh and shrimp fisheries. Different approaches to estimating discards in the large mesh and shrimp fisheries were used, although both relied on the NEFSC surveys.

For the shrimp fishery, a ratio estimator (kg/df) was derived by season and fishing zone (zone 1, 0-3 miles; zone 2, 3-12 miles; and zone 3, 12+ miles) and expanded to a fishery wide rate by averaging over fishing zone and weighting by the days fished for vessels in the shrimp fishery. These weighted mean annual discard rates (1989-1992) were then regressed on the 1989-1992 age 3 autumn bottom trawl survey index of witch flounder abundance to derive a regression equation (estimation period) to predict discard rates in past years (prediction period). Because the regression analysis was critical to deriving past discard estimates, the subcommittee noted the following concerns: 1) the regression analysis was based on only four observations giving rise to concerns about the accuracy (bias) and precision (variability) of the estimated regression coefficients; 2) the independent variable, age 3 witch flounder in the autumn, is itself quite variable; and 3) two annual indices in earlier years (1986-1987) were extrapolated beyond the range of observed *X*-values used in the regression.

The regression analysis assumed that the stock-wide age 3 autumn index was representative of the availability of witch flounder to the shrimp fishery, occurring primarily in the western Gulf of Maine during the winter months. To make historical predictions from the regression, it was further assumed that the distribution of fleet effort among fishing zones during the prediction period (1982-1988) was similar to the estimation period (1989-1992). Some disparity in the distribution of fleet effort for the 1989-1992 period was observed during earlier years (1982-1984); higher effort in zone 1 *vs* lower effort in zone 3). The subcommittee noted that fishing zone-specific discard estimates would have been more appropriate, but recognized that they could not be computed due to lack of survey coverage within specific zones.

The subcommittee then examined the relationship between the discard rate *vs* age 3 fall survey index within each of the fishing zones. Of these, only fishing zone 3 data appeared to exhibit a relationship between discard rate and age 3 abundance, in contrast to the weighted average discard rate, which yielded highly significant coefficients. The subcommittee concluded that there was sufficient biological rationale, based on distribution of shrimp fleet effort and age 3 witch flounder, and accepted the regression results. It was noted, however, that the prediction limits for the regression equation are probably wider than estimated because the random variation associated with the fishing zone-specific discard estimates are subsumed into the error among the weighted mean discard rates for a given age 3 index. Further, because discards in the shrimp fishery were derived from the age 3 autumn survey indices the subcommittee recognized potential autocorrelation between the catch at age 3 (mostly discards) and the survey indices when calibrating the VPA.

For the large mesh otter trawl fishery, the sea sampling database could not be used to derive a length-based discard estimator as had been done for the shrimp fishery, because too few trips occurred in which witch flounder length samples (both kept and discarded) were taken. Instead, for this approach, witch flounder size compositions from spring and autumn surveys were first filtered through retention ogives (130 and 140 mm mesh size) to estimate the proportion at length retained in the large mesh fishery, and then filtered through a culling ogive to determine the proportions at length kept and discarded. The slope coefficients from the regression analyses (for each season and year) of kept proportions to numbers landed at length in the large mesh fishery were used to estimate numbers discarded at length.

The subcommittee noted that rather large age to length variability in survey indices tended to propagate into large variation in the estimated proportions kept after filtering, and suggested that smoothing of the survey length indices may produce better results. In addition, it was noted that this approach tended to apportion the numbers discarded into a very narrow range of age classes (mostly age 4). Because of the close linkage between discarded fish in the catch at age and the survey length/age compositions from which the discard estimates were derived, the subcommittee recognized the potential for substantial autocorrelation when calibrating the VPA.

An initial ADAPT run was performed to estimate age 3-9 stock sizes and calibrated with equal weighting for the following indices: 1) disaggregated age 3-10 NEFSC spring and fall surveys; 2) age-aggregated commercial CPUE, Massachusetts DMF spring and fall surveys, and ages 7+ NEFSC spring and fall surveys (Table C22, run A). The age-aggregated indices were all tuned to age 7+ stock sizes. Because of very high CVs on age 3 stock sizes, various other formulations of ADAPT were performed which omitted the estimation of age 3 stock sizes (Table C22, run A). The subcommittee noted that all ADAPT runs produced inordinately high Fs on the fully recruited age (age 8) in the terminal year (1993) relative to the previous year and age and stock sizes on ages 8-10 in 1994 were some of the lowest observed. It was noted that there were no significant changes in landings or fleet effort that would account for F more than doubling. The subcommittee also noted a non-random pattern of model residual errors in recent years (1988-1993) which appeared to represent a sloped plane going from high negative to high positive values, particularly on the 1985 year class as it tracked through the matrix.

The subcommittee felt that if residual problems were associated with survey indices, then using age-aggregated survey indices would magnify their effect, but results from an additional ADAPT run eliminating the age-aggregated NEFSC survey indices were not appreciably different from previous attempts (Table C22, run E). Further, because of the potentially high likelihood of autocorrelation between the catch at age and the age 3-4 NEFSC survey indices, another run which excluded these indices from the calibrations was attempted. These results, however, were very unstable (high CVs) due to the limited number of indices used for calibrating (Table C22, runs G and H). A final attempt, using the age 3-4 survey indices but adjusting the PR to full recruitment at age 7, did not show any appreciable improvement over other runs (Table C22, run I).

Because of these problems with the formulations, a final formulation was developed whereby the F on ages 4 and 5 in 1993 was estimated directly from the input partial recruitment (PR) pattern, the plus group was extended from 11+ to 10+, and the age at full recruitment was shortened from 8 to 7 (approximately 85-90% fully recruited). Results from this formulation yielded a relatively smooth F pattern in the terminal year and a smoother annual trend in the fully recruited F. The input PR for this calibration was obtained from a separable analysis, but the final calibration employed a PR derived from the 1988-1992 F pattern derived from the penultimate calibration run. Results from this run was deemed acceptable by the subcommittee.

SARC COMMENTS

The committee noted that the age range of the stock has been greatly reduced (< age 7) since 1985-86 and that research survey indices were quite variable, although some year class effects were noticeable. Prospects for recuritment appear to have improved in recent years, and the committee noted that protection of pre-recruits should be considered a priority. The 1992 year class is above average and research survey indices show the possibility of a strong 1993 year class. Since fish of ages 2-4 are often discarded in the shrimp and large mesh otter trawl fisheries, effects of these strong year classes on SSB could be diminished, if significant discarding of these pre-recruits occur. discarding in the large mesh otter trawl fishery on age 3 and 4 witch flounder may continue to be problematic; however, the use of the Nordmore grate is expected to ameliorate the effect of discarding mortality in the shrimp fishery. The impact of the grate, however, may not be directly observed in the fishery until the 1992 and 1993 year classes become fully recruited. An evaluation of discarding with the use of the Nordmore grate was not possible at this time due to its incomplete use in the shrimp fishery in 1993.

The partial recruitment pattern used for 1995 catch and SSB projections were based on estimated 1988-1992 Fs from VPA results. It was noted that the PR may, however, change due to effects of the use of the Nordmore grate in the Gulf of Maine shrimp fishery, changes in the minimum mesh size used in the large mesh otter trawl fishery, and targeting by the fishery on the large 1992 and possibly 1993 year class. Consensus was also reached with regard to using age 3 stock sizes as the age of recruitment for short term projections.

SOURCES OF UNCERTAINTY

1. NEFSC spring and autumn bottom trawl survey indices were highly variable, particularly for those older age groups of witch flounder (>age 7) that are fully recruited into the fishery. Because of this, year classes did not track well through the abundance at age tuning indices, and age-disaggregated commercial LPUE indices had to be used for older age groups.

2. Although port sampling coverage was adequate, overall length and age sampling for the large market category was low, often only one sample per quarter. In addition, length samples for peewee and small market categories were combined when generating the catch at age matrix. If samples were not taken in proportion to landings within a market category then a misallocation of fish to younger or older ages may occur, depending upon which was sampled in greater proportion. Further, samples from the peewee market category in recent years spanned a broad range of ages (2-7).

3. There is a rather high likelihood that substantial autocorrelation exists between ages 3-5 in the catch at age matrix (which are mostly discarded fish) and the NEFSC survey indices for those ages, because discards from the shrimp and large mesh otter trawl fisheries were derived from the survey indices. The effect of the autocorrelation in calibrating the VPA, if significant, is unclear but would probably result in artificially greater precision associated with age 3-5 stock sizes.

4. The partial recruitment pattern used for 1995 catch and SSB projections were based on estimated 1988-1992 Fs from VPA results. The PR may, however, change due to effects of the use of the Nordmore grate in the Gulf of Maine shrimp fishery, changes in the minimum mesh size used in the large mesh otter trawl fishery, and targeting by the fishery on the large 1992 year class.

RESEARCH RECOMMENDATIONS

1. Evaluate effectiveness of the Nordmore grate in reducing witch flounder discards in the Gulf of Maine northern shrimp fishery as data become available. Further, assess the survival of fish that pass through the grate.

2. Examine the reason for the problematic residual patterns resulting from VPA calibrations.

3. Mesh selection studies to determine the L_{50} and L_{25} for 6-in. square and diamond meshes for witch flounder.

4. Compute F_{rep} from S/R relationship.

5. Consider incorporating Canadian witch flounder catches from 4X into this assessment.

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D. SPINY DOGFISH

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Summarize historical patterns of landings, CPUE, and size composition for the coastwide stock of spiny dogfish.

b. Provide time-series fishery independent abundance data, disaggregated by sex, size, and subarea.

c. Explore calculations of biological reference points for management, specifically addressing sustainable harvest rates for the stock.

BASIC LIFE HISTORY INFORMATION

Spiny dogfish (*Squalus acanthias*) are distributed in Northwest Atlantic waters between Labrador and Florida, are considered to be a unit stock in NAFO Subareas 2-6 (Figure D1), but are most abundant from Nova Scotia to Cape Hatteras.

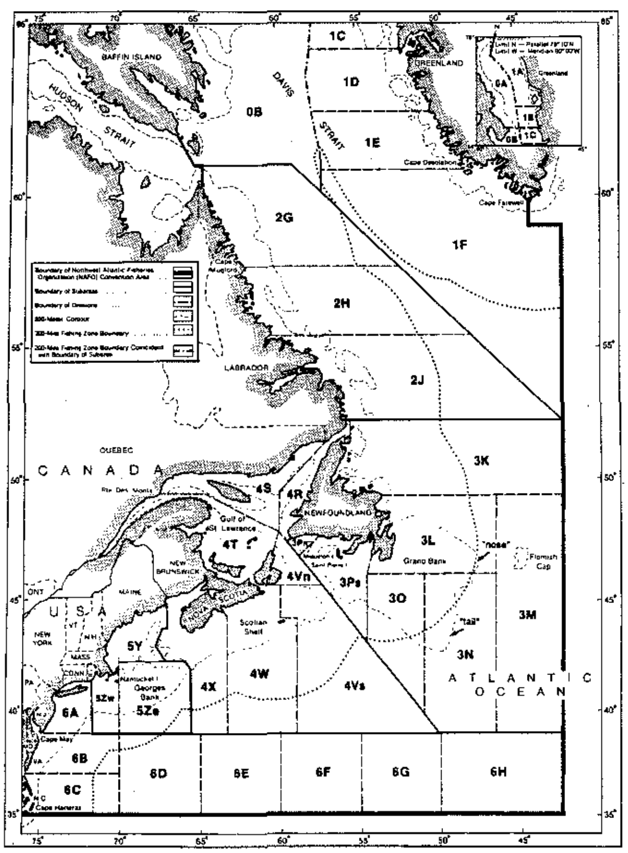

Figure D1. Map of NAFO Subareas 0-6.

Seasonal migrations occur northward in the spring and summer and southward in the fall and winter and preferred temperatures range from 7.2° to 12.8°C (Jensen 1965). Dogfish tend to school by size and, for large, mature individuals, by sex. They are known to attack schools of herring and mackerel and concentrations of haddock, cod, sand lance, and other species. Maximum reported ages for males and females in the Northwest Atlantic were estimated by Nammack (1982) to be 35 and 40 years, respectively, whereas ages as old as 70 years have been determined for spiny dogfish off British Columbia (McFarlane and Beamish 1987). In this report, a maximum age of 50 years was assumed. Sexual maturity occurs at a length of about 60 cm for males and 75 cm for females (Jensen 1965). Reproduction occurs offshore in the winter (Bigelow and Schroeder 1953), and female dogfish bear live offspring. The gestation period ranges from 18 to 22 months with 2 to 15 pups (average of 6) produced. Females attain a greater size than males, reaching maximum lengths and weights of about 125 cm and 10 kg, respectively.

FISHERY DATA

Commercial Landings

U.S. Landings

United States commercial landings of dogfish from NAFO Subareas 2-6 were around 500 mt in the early 1960s (Table D1, Figure D2), dropped to levels as low as zero during 1963-1975 while averaging about 90 mt, and remained less than

Table D1. Total spiny dogfish landings

Year	Canada	U.S.	USSR	Other For.	U.S. Rec.	Total
1960	-	455	-	64	na	519
1961	-	438	-	-	na	438
1962	-	296	-	-	na	296
1963	-	1	-	1	na	1
1964	-	102	-	16	na	118
1965	9	181	188	10	na	388
1966	39	261	9389	-	na	9689
1967	-	90	2436	-	na	2526
1968	-	158	4404	-	621	5183
1969	-	112	8827	363	453	9755
1970	19	3	4924	716	705	6367
1971	4	<1	10802	764	561	12131
1972	3	9	23302	689	820	24823
1973	20	16	14219	4574	890	19719
1974	36	102	20444	4069	969	25620
1975	1	168	22331	192	789	23481
1976	3	549	16681	107	707	18047
1977	1	929	6942	257	563	8692
1978	84	852	577	45	700	2258
1979	1331	4751	105	82	426	6695
1980	670	4171	351	248	284	5723
1981	564	6865	516	458	1856	10257
1982	953	6633	27	337	700	8647
1983	-	4906	359	105	745	6115
1984	4	4451	291	100	663	5509
1985	13	4031	694	318	1591	6647
1986	21	2665	214	154	1438	4492
1987	280	2735	116	23	1053	4207
1988	-	3257	574	73	1336	5103
1989	166	4603	169	87	1829	6854
1990	1316	14870	383	10	1662	18222
1991	292	13353	218	16	1677	15831
1992	829	17160	26	41	1197	19012
1993	1000[1]	20360	-	-	1212	22572

[1]Estimate of Canadian landings.

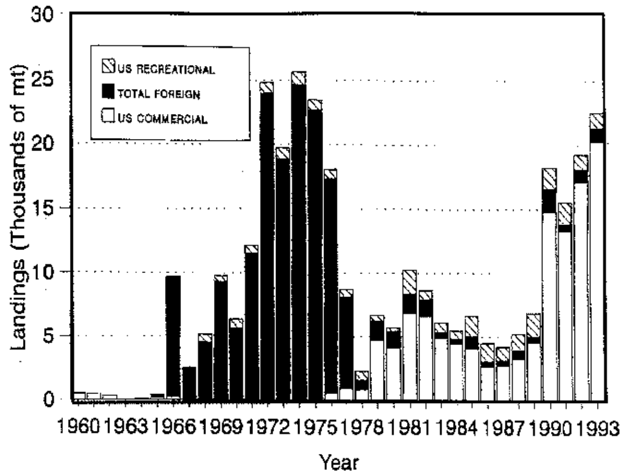

Figure D2. Landings (metric tons) of spiny dogfish from NAFO Sunareas 2-6, 1960-1993.

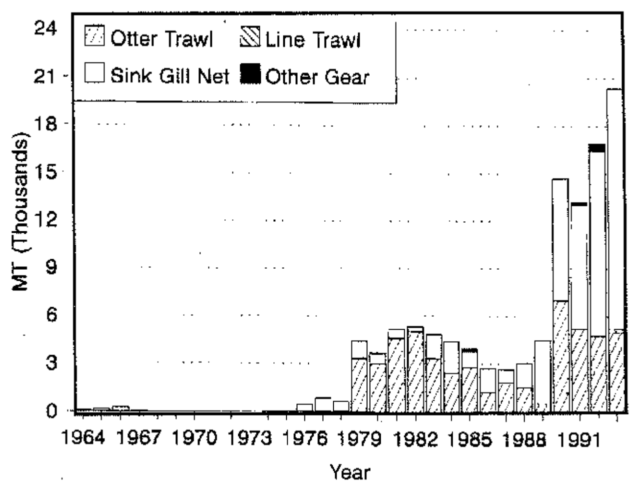

Figure D3. United States commercial landings (metric tons) of spiny dogfish by major gear type.

1000 mt until the late 1970s. Landings increased to about 4800 mt in 1979 and remained fairly steady for the next ten years averaging about 4,500 mt annually. Landings increased sharply to 14,900 mt in 1990, dropped slightly in 1991, but increased to 16,900 mt in 1992 and 20,400 mt in 1993.

Historical records dating back to 1931 indicate levels of U.S. commercial landings of dogfish in Subareas 5 and 6 of less than 100 mt in most years prior to 1960 (NEFSC 1990).

Foreign Landings

A substantial foreign harvest of dogfish occurred mainly during 1966-1977 in Subareas 5 and 6. Landings, the bulk of which were taken by the former USSR, averaged 13,000 mt per year and reached a peak of about 24,000 mt in 1972 and 1974 (Table D1). In addition to the former USSR, other countries that reported significant amounts of landings include Poland, the former German Democratic Republic, Japan, and Canada. Since 1978, landings have averaged only about 900 mt annually and, except for those taken by Japan and Poland, have come primarily from Subareas 4 and 3. Canadian landings, insignificant until 1979 when 1300 mt were landed, have been sporadic, but again totalled about 1300 mt in 1990. The 1992 Canadian landings were about 800 mt, and probably increased in 1993 (Hunt, pers. comm.).

Table D2. Spiny dogfish landings (metric tons) by month

Year	Month												Unk	Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1964	7	1	1	-	13	32	-	5	36	-	-	8	-	103
1965	<1	4	-	15	5	35	23	27	31	12	23	6	-	181
1966	2	2	8	7	2	69	83	49	27	6	8	-	-	261
1967	-	4	-	4	6	16	43	5	7	1	3	1	-	90
1968	-	-	-	-	<1	-	-	<1	-	-	-	-	-	<1
1969	-	-	-	-	-	-	-	-	-	-	-	-	-	0
1970	-	-	-	-	-	-	<1	1	<1	1	<1	<1	-	3
1971	<1	-	-<1	-	-<1	-	-	-	-	-	-	-	-	<1
1972	-	-	-	<1	<1	<1	-	-	-	2	5	2	-	9
1973	3	<1	-	1	2	4	2	<1	-	2	1	<1	-	16
1974	<1	-	1	-	1	<1	1	<1	1	<1	<1	<1	-	5
1975	<1	<1	<1	3	<1	<1	<1	<1	-	<1	4	3	-	11
1976	<1	1	-	<1	<1	24	127	71	120	92	<1	<1	-	436
1977	<1	-	-	-	30	262	121	170	138	99	4	17	-	841
1978	<1	1	6	<1	1	85	296	103	55	134	9	2	-	691
1979	-	-	-	-	17	294	641	505	1049	1144	392	392	-	4435
1980	27	3	82	<1	113	808	544	824	1094	53	92	61	-	3701
1981	1	<1	-	1	108	951	1128	1164	1011	703	99	1	-	5166
1982	144	372	1296	221	135	835	825	414	520	258	237	120	-	5377
1983	4	4	-	<1	56	142	714	969	749	405	170	1667	-	4879
1984	-	-	-	<1	1	562	2090	1118	360	169	104	25	-	4429
1985	-	-	1	2	277	695	757	790	592	647	177	43	-	3979
1986	1	6	3	12	146	486	471	477	626	379	94	50	-	2751
1987	5	2	4	9	18	399	559	387	443	708	177	4	-	2713
1988	1	116	28	4	387	570	536	506	512	404	10	1	-	3072
1989	<1	-	2	21	299	1140	718	967	930	377	42	7	16	4518
1990	292	209	282	321	496	1145	2899	2836	2092	1174	966	2055	50	14817
1991	1619	1111	665	1306	1144	628	1430	969	845	356	971	1993	215	13252
1992	2124	1623	1405	706	792	1090	2341	1559	814	1371	1899	889	323	16936
1993	1516	1632	835	262	518	2001	3423	3227	2587	1983	1074	1302	-	20360

Sources: NMFS weighout, including most unclassified dogfish plus North Carolina landings.
Note: 1993 Landings are preliminary.

Gear Types

The primary gear used by U.S. fishermen to catch spiny dogfish has been otter trawls and sink gill nets (Figure D3). The latter accounted for more than 50% of the total U.S. landings during the 1960s, while the former was the predominant gear through the 1970s and into the early 1980s. Since the late 1980s, sink gill nets have again taken most of the landings, accounting for about 70% in 1993.

Spiny dogfish taken by the distant-water fleets were caught almost entirely by otter trawl. Recent Canadian landings have been mainly by gill nets and longlines.

Temporal and Spatial Distribution

United States dogfish landings have been reported in all months of the year, but most have traditionally occurred from June through September (Table D2). In recent years, however, as total landings have increased sharply, substantial amounts have also been taken during autumn and winter months.

During the 1980s, when U.S. landings averaged about 4500 mt per year, most landings originated from statistical area 514, Massachusetts Bay (Table D3). Following the recent intensification of the fishery in 1990, statistical areas 537 (Southern New England) and 621 (off Delmarva and southern New Jersey) have produced substantial quantities. In 1992 and 1993, large landings were reported from statistical areas 631 and 635 (North Carolina).

In most years since 1979, the bulk of the landings have occurred in Massachusetts (Table D4). Since 1989, important landings have also been made in Maine, New Jersey, Maryland, Rhode Island, and North Carolina ports. In 1992 and 1993, North Carolina landings ranked second to those in Massachusetts.

Table D3. Landings of spiny dogfish by statistical area

Year	Statistical Area																					Total
	3	4	511	512	513	514	515	52	53	611	612	613	614	615	616	621	622	625	626	63[1]	6	
1964	-	-	-	-	102	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	102
1965	-	<1	-	-	171	1	<1	3	1	-	-	-	-	-	-	-	-	-	-	-	5	176
1966	-	-	-	8	251	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	260
1967	-	-	5	-	77	5	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	89
1968	-	-	-	-	-	-	<1	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1
1969	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
1970	-	-	-	-	<1	2	-	-	<1	-	-	<1	-	-	-	-	-	-	-	-	-	3
1971	-	-	-	-	<1	<1	-	-	<1	-	-	-	-	-	<1	-	-	-	-	-	-	<1
1972	-	-	-	-	<1	1	-	-	8	1	-	<1	-	-	-	-	-	-	-	-	-	9
1973	-	-	-	-	-2	4	-	<1	9	1	-	<1	-	-	-	-	-	-	-	-	-	16
1974	-	-	-	-	<1	3	<1	<1	1	<1	-	-	-	-	-	-	-	-	-	-	-	5
1975	-	-	-	-	-	2	-	-	8	<1	-	-	<1	-	-	-	-	-	-	-	-	11
1976	-	-	4	415	3	12	<1		1-	-	<1	-	-	-	-	-	-	-	-	-	-	435
1977	-	-	-	-	793	17	4	<1	25	1	-	<1	-	-	-	-	-	-	-	-	-	841
1978	-	-	-	32	620	29	<1	3	1	<1	<1	<1	-	-	6	-	-	-	-	-	-	692
1979	-	-	10	74	1086	2796	6	66	2			1	89	1	<1	304	-	-	-	-	-	4435
1980	<1	-	1	10	617	2773	<1	12	<1	-	-3	<1	<1	1	<1	259	-	-	-	1	-	3700
1981	-	-	-	-	550	4510	1	8	2	-	23	<1	<1	-	<1	70	-	-	-	2	-	5166
1982	1	<1	-	10	234	2891	41	10	1	-	1	<1	1	-	<1	830	23	39	546	747	-	5377
1983	-	-	-	<1	224	4557	3	<1	-	-	<1	-	<1	-	-	89	-	3	4	<1	-	4880
1984	-	-	-	-	569	3725	-	-	11	-	3	-	19	-	-	100	-	2	-	-	-	4430
1985	-	-	-	14	405	3322	154	-	1	-	3	2	-	<1	-	78	<1	1	<1	1	-	3980
1986	-	-	-	-	389	2037	<1	104	3	38	23	93	1	-	3	59	<1	<1	<1	<1	-	2751
1987	-	-	-	3	274	2303	<1	43	19	27	7	28	1	-	4	4	<1	<1	<1	1	-	2713
1988	-	-	-	11	228	2549	6	85	<1	2	2	37	2	-	<1	11	-	-2	-	137	-	3073
1989	1	1	-	54	2165	2204	36	10	2	15	7	3	2	<1	<1	8	-	9	-	<1	-	4518
1990	-	20	-	84	2819	6455	32	69	2210	14	2	22	51	<1	8	2301	682	5	23	21	-	14818
1991	-	-	-	24	923	3079	2	38	4912	21	183	11	105	185	17	2593	75	66	346	676	-	13253
1992	-	-	-	38	1007	4236	44	751	4216	24	492	34	42	35	69	1048	147	74	736	3942	-	16842
1993	-	-	-	39	2198	6530	218	3921	2199	12	206	29	6	25	14	906	5	24	14	4015	-	20360

Sources: Landings from NEFSC weighout data and from North Carolina.

[1] North Carolina landings may occur in area 700

Table D4. Dogfish landings by state

Year	State											Total
	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	
1964	103	-	-	<1	-	-	-	-	-	-	-	103
1965	172	-	8	1	-	-	-	-	-	-	-	181
1966	261	-	-	<1	-	-	-	-	-	-	-	261
1967	83	-	7	1	-	-	-	-	-	-	-	90
1968	-	-	-	<1	-	-	-	-	-	-	-	<1
1969	-	-	-	-	-	-	-	-	-	-	-	0
1970	-	-	-	2	1	-	-	-	-	-	-	3
1971	-	-	-	<1	<1	-	-	-	-	-	-	<1
1972	-	-	-	1	8	-	-	-	-	-	-	9
1973	-	-	-	5	10	-	-	-	-	-	-	16
1974	-	-	-	3	1	-	-	-	-	-	-	5
1975	-	-	-	2	9	-	-	-	-	-	-	11
1976	431	-	3	2	-	-	-	-	-	-	-	436
1977	798	-	18	26	-	-	-	-	-	-	-	841
1978	651	-	32	3	-	-	7	-	-	-	-	692
1979	1056	-	2983	2	-	-	395	-	-	-	-	4435
1980	623	-	2811	1	-	-	265	-	-	-	1	3700
1981	519	-	4550	2	-	-	93	-	-	-	2	5166
1982	284	-	2903	1	-	-	3	-	900	1283	3	5377
1983	226	<1	4557	-	-	-	<1	-	89	7	<1	4879
1984	569	<1	3725	11	-	-	4	-	118	2	-	4430
1985	412	-	3484	1	-	-	4	-	76	2	1	3979
1986	351	-	2179	2	-	135	24	-	59	1	-	2751
1987	273	-	2349	14	-	71	2	-	4	2	-	2713
1988	220	<1	2659	<1	-	39	4	-	11	2	137	3072
1989	2227	-	2247	2	<1	22	10	-	<1	9	-	4517
1990	2905	85	8125	593	11	8	2074	-	995	3	19	14818
1991	920	-	6611	1442	4	35	1239	3	2254	79	664	13251
1992	785	184	8385	925	10	71	1157	-	1398	105	3917	16935
1993	1599	743	11896	874	-	43	349	-	815	47	3994	20360

Size and Sex Compositions

Since 1982, more than 95% of the sampled landings of spiny dogfish have been females longer than 84 cm. Males have composed a small fraction of the landings and have rarely been observed to have obtained lengths greater than 90 cm (Figure D4). Length frequencies (Figure D4) show the marked increase in landings since 1989. The average size of landed females appears to have decreased by about 5 cm since 1982 (Figure D5). The average size of males has not changed appreciably. Decreases in average size are consistent with increased fishing mortality, but could also be due to changes in the mix of otter trawl and sink gill net catches. Potential causes of the decreased size of landed dogfish need to be investigated. The implications of sex-specific removals are considered further in the section on Mechanistic Models, page 127.

Landings Per Unit Effort

Landings per day fished (LPUE) were determined for 1976-1993 for otter trawls and sink gill nets fished by tonnage class vessels 2, 3, and 4 based on trips in which 50% or more of the landed catch consisted of spiny dogfish (Table D5). Data used in this analysis represented all of Subareas 5 and 6, but were primarily from trips in Subarea 5. There was considerable year-to-year variability in LPUE for each of the data sets, but for nearly each of the gear/tonnage class categories there was a decrease since 1990 accompanying the sharp increase in landings (Figure D6).

Recreational Landings

Estimates of recreational catch and landings of dogfish were obtained from the NMFS Marine

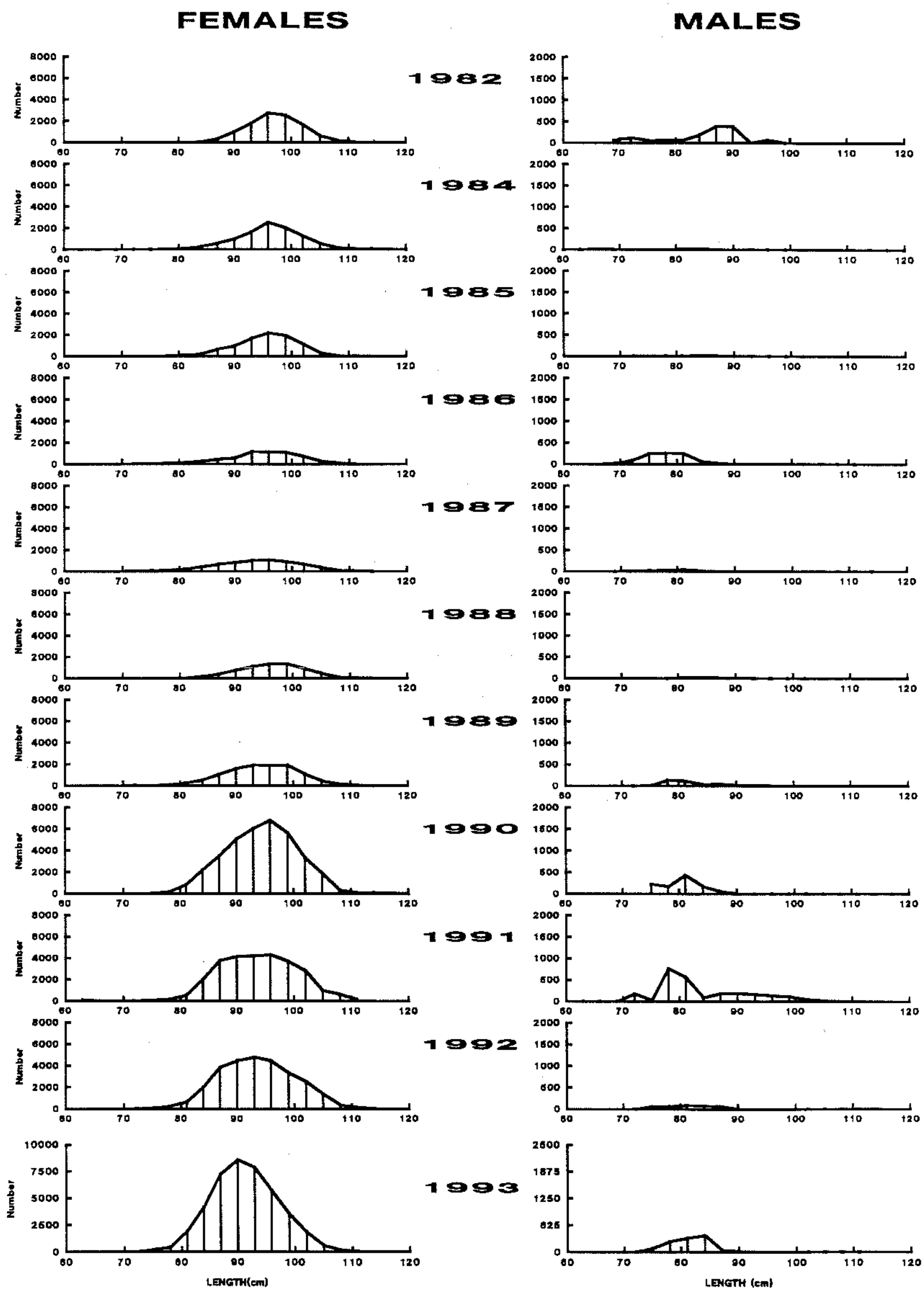

Figure D4. Length frequencies (total number landed) for female and male spiny dogfish, 1982-1993. Sample data were not availalbe for 1983. Note that the y-axis scale for females is four times greater than that for males.

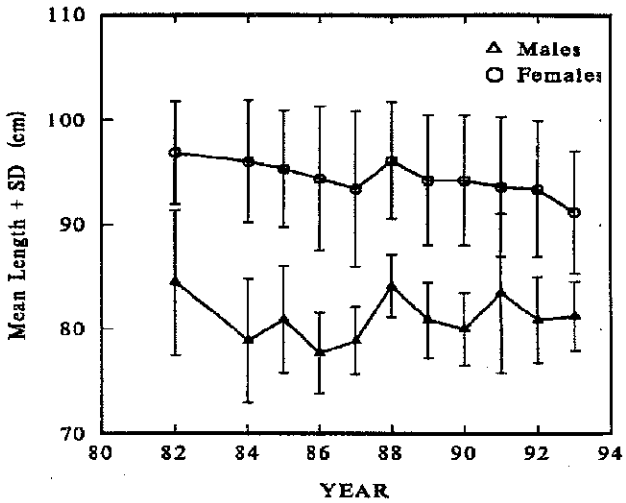

Figure D5. Mean length of male and female spiny dogfish landed beween 1982 and 1993. Sample data were not available for 1983. Error bars represent plus or minus one standard deviation.

Recreational Fishery Statistics Survey (MRFSS). Recreational catch data have been collected in a consistent fashion since 1979. Methodological differences between the current survey and intermittent surveys before 1979 preclude the use of the earlier data. The MRFSS consists of two complementary surveys of anglers *via* on-site interviews and households *via* telephone. The angler-intercept survey provides catch data and biological samples while the telephone survey provides a measure of overall effort. Surveys are stratified by state, type of fishing (mode), and sequential two-month periods (waves). For the purposes of this assessment, annual catches pooled over all waves and modes and grouped by subregion (Maine to Connecticut, New York to Virginia, and North Carolina to Florida) were examined.

Catches are partitioned into three categories: A, B1, and B2. Type A catches represent landed fish enumerated by the interviewer, while B1 are landed catches reported by the angler. Type B2 catches are those fish caught and returned to the water. Inasmuch as dogfish are generally caught with live bait and are often mishandled by anglers, 100% discard mortality was assumed. The MRFSS provides estimates of landings in terms of numbers of fish. Biological information on dogfish is generally scanty, resulting in wide annual fluctuations in mean weights. To compute total catch in metric tons, an average weight of 2.5 kg per fish was assumed for all years.

Total recreational catches increased from an average of about 350 mt per year in 1979-1980 to about 1700 mt in 1989-1991 (Table D1). The 1993 estimate was 1200 mt. Catch estimates for 1968-1978 were estimated from a regression between recreational catch estimates and spring survey catch per tow (weight) indices for 1979-1993.

Total catches (Type A + B1 +B2) have increased nearly five fold since the survey began (Figure D7). In the northern states (Maine-Connecticut), catches peaked in 1988 at nearly 400,000 fish and declined to fewer than 250,000 in 1993. Peak catches in excess of 500,000 fish occurred in the Mid-Atlantic states (New York-Virginia) in 1990. Numbers caught in 1993 were about 250,000. Catches of spiny dogfish from North Carolina to Florida increased dramatically after 1979, but are an order of magnitude lower than observed in the Mid-Atlantic and New England states. Historically, less than 4% of the spiny dogfish catch comes from North Carolina to Florida. Most dogfish are released after capture (Type B2) and since 1979, the B2 proportion of the catch has increased to more than 90% in recent years.

The possibility that recreational catches may simply reflect increased reporting by anglers was considered. If so, there should be no relation between catch and fishery-independent indices of abundance. The log of total catch was significantly correlated ($r = 0.62$; $P = 0.015$) with the log of average weight per tow from the NEFSC spring research vessel survey. Thus, increases in recreational catches roughly parallel increases in abundance and the hypothesis of an increased reporting rate is not supported. Recreational CPUE, however, was not significantly correlated with spring ($r = 0.386$, $P = 0.155$) or autumn survey mean weight per tow ($r = 0.291$, $P = 0.292$). The possibility that the estimate of Type B1 catch in 1981 was incorrect in the MRFSS data base could not be verified. If the 1981 value is excluded, the correlation between the spring survey index (weight/tow) and recreational CPUE increases to 0.589 ($P = 0.027$).

Even if all of the Type B2 catch died after release, recreational catches have constituted only about 8% of the total landings. Therefore, the imprecision in the estimation of recreational landings is inconsequential relative to the commercial landings and discards.

Table D5. Landings(metric tons), effort (days fished), and lpue(metric tons/days fished) of trips landing more than 50% dogfish

Otter Trawl Fishery

	Ton Class 2			Ton Class 3			Ton Class 4		
	mt	df	lpue	mt	df	lpue	mt	dF	lpue
1977	1.4	0.7	2.06	11.7	0.5	23.34	-	-	-
1978	21.7	2.2	9.87	5.9	1.2	4.90	-	-	-
1979	1563.5	37.4	41.81	1422.8	36.8	38.66	171.0	6.4	26.72
1980	682.8	17.0	40.17	2206.5	35.8	61.63	57.9	2.4	24.13
1981	698.6	13.6	51.37	3821.1	47.1	81.13	0.5	0.2	2.50
1982	309.5	11.7	26.45	3115.7	57.0	54.66	1565.9	28.9	54.18
1983	389.7	6.0	64.94	2913.4	43.9	66.36	-	-	-
1984	101.1	14.3	7.07	2335.4	33.5	69.71	-	-	-
1985	26.9	2.2	12.23	2691.5	27.2	98.95	46.3	4.6	10.06
1986	749.7	34.1	21.98	292.2	17.3	16.89			
1987	1305.5	77.9	16.76	361.6	16.7	21.65	0.5	0.2	2.70
1988	1170.8	57.2	20.47	127.7	9.9	12.90	-	-	-
1989	296.0	21.1	14.03	49.7	7.1	7.00	-	-	-
1990	2069.2	88.1	23.49	3904.7	92.6	42.17	785.9	14.5	54.20
1991	1165.9	68.8	16.95	3345.9	112.5	29.74	318.3	10.5	30.32
1992	1202.9	123.1	9.78	2863.2	169.0	16.94	152.7	12.4	12.32
1993	681.3	98.3	6.93	3053.0	216.0	14.13	654.6	39.8	16.45

Sink Gill Net Fishery

	Ton Class 2			Ton Class 3			Ton Class 4		
	mt	df	lpue	mt	df	lpue	mt	dF	lpue
1976	119.1	84.4	1.41	-	-	-	-	-	-
1977	455.7	215.8	2.11	-	-	-	-	-	-
1978	206.5	132.4	1.56	-	-	-	-	-	-
1979	431.9	182.3	2.37	1.6	2.0	0.79	-	-	-
1980	228.6	133.1	1.72	-	-	-	-	-	-
1981	198.9	108.4	1.84	-	-	-	-	-	-
1982	88.6	65.0	1.36	-	-	-	-	-	-
1983	991.8	92.5	10.72	-	-	-	-	-	-
1984	1659.0	244.0	6.79	-	-	-	-	-	-
1985	640.9	168.0	3.81	54.3	18.9	2.87	-	-	-
1986	798.1	333.9	2.39	272.5	62.1	4.39	-	-	-
1987	441.3	258.0	1.71	48.2	37.1	1.30	-	-	-
1988	924.1	314.5	2.94	375.0	65.7	5.71	-	-	-
1989	3240.6	1107.5	2.93	62.9	31.2	2.02	-	-	-
1990	4409.2	1573.3	2.80	1119.1	159.1	7.03	-	-	-
1991	4551.4	1564.5	2.91	529.5	145.5	3.64	-	-	-
1992	5202.9	1914.4	2.72	588.3	113.9	5.17	-	-	-
1993	6412.0	2619.1	2.45	365.9	97.8	3.74	40.2	10.9	3.69

Discards

Introduction

Spiny dogfish have been caught and discarded during fishing operations both in the past and at present. Unfortunately, information on which to base quantitative estimates of discard has only been collected in recent years. Previous qualitative information has, however, suggested that the amounts discarded have been substantial and constitute an important source of mortality.

Recent information on the catch, discards, landings, and size composition of spiny dogfish taken on sea sampling trips aboard U.S. fishing vessels from 1989 to early 1994 are summarized

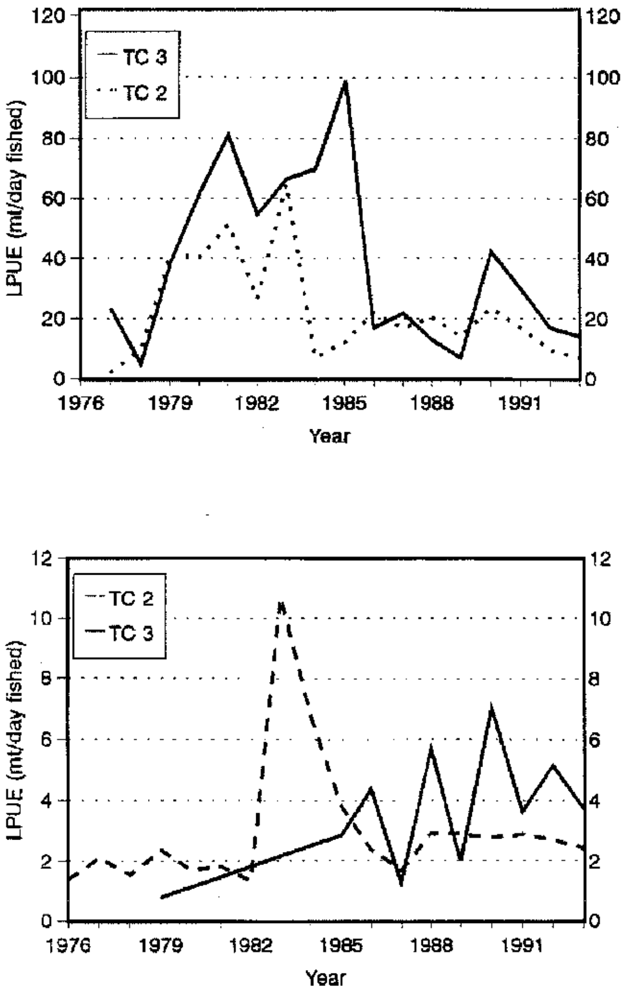

Figure D6. Landings (metric tons) per day fished (LPUE) for U.S. otter trawlers and sink gill nets landing ≥50% dogfish.

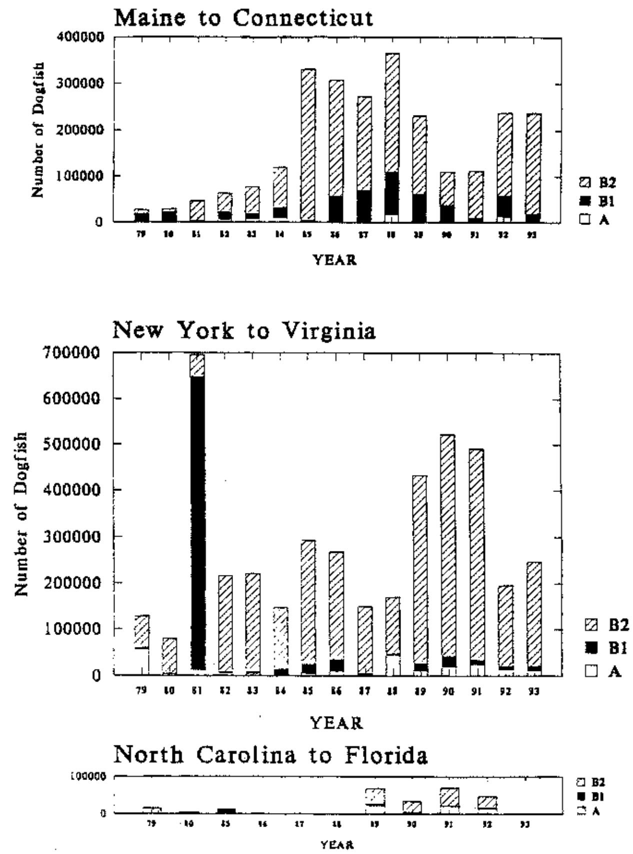

Figure D7. Estimated total recreational catch of spiny dogfish (numbers of fish) by geographical area. Type A and B1 catches represent landings; type B2 cates are fish released after capture. The veracity of the type B1 catch in 1981 has not yet been verified. Data are from the Marine Recreational Fisheries Statistics Survey (MRFSS) data base.

by year, gear type, and primary species sought (= target species). Data are presented on the catch, disposition and catch rate (CPUE) of spiny dogfish, as well as information on the species compositions of target fisheries, reasons for discards, and the size and sex compositions of the spiny dogfish catches by fishery. A preliminary estimate of the 1993 spiny discards and discard mortalities is made.

It should be noted that, even though sea sampling data were available, greater coverage of this type of sampling is needed to provide more reliable estimates of dogfish discards by area, gear type, and target species.

Summary of Sea Sampling

The NEFSC sea sampling program has operated since 1989. The data base structure and access to information are described in Anderson (1992). Species catch, effort, and associated biological and fishery data can be summarized in a variety of ways. An important attribute collected during each trip, determined from skipper interviews, is the "primary species sought". Data on the gear used, time spent fishing, mesh size, *etc.* are also collected.

Gill Net Trips

Gill net trips predominate in the sea sampling data collected owing to the objective of sampling at least 10% of the gill net trips for marine mammal bycatch estimation. Dogfish catch information from gill net sampling (primarily in the Gulf of Maine) is summarized in Tables D6-D9.

Table D6. Summary of spiny dogfish catch (pounds) and effort data from sea sampled gill net trips in the Gulf of Maine designating dogfish as the primary species sought

Year	Dogfish Catch			Number	Number	Hours	Catch Per		
	Landings	Discards	Total	Trips	Sets	Soaked	Trip	Set	Hour
1993	83,474	9,214	92,688	18	60	3116	5,149	1,545	29.7
1992	406,989	51,904	458,893	84	283	10,666	5,463	1,622	43.0
1991	609,873	104,947	714,820	125	378	14,733	5,719	1,891	48.5
1990	43,655	11,066	54,721	7	20	890	7,817	2,736	61.5
1989	17,000	900	17,900	1	3	72	17,900	5,967	248.6

Table D7. Species composition of sea sampled catches (pounds) from the Gulf of Maine gill net fishery, for trips with dogfish as the primary species sought, 1989-1993

Species	Year									
	1989		1990		1991		1992		1993	
	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept	Disc	Kept
Spiny dogfish	900	17,000	11,066	43,655	104,947	09,873	51,904	406,989	9,214	83,474
Atlantic cod	0	30	60	1,261	985	11,302	176	4,985	170	1,846
Pollock	0	0	10	135	34	553	16	195	34	512
White hake	0	0	2	24	82	388	0	150	48	457
American plaice	4	0	16	11	291	206	188	182	5	10
Witch	0	0	7	37	17	413	1	118	0	7
Other groundfish[1]	0	1	80	163	777	925	105	453	130	102
Other species	125	445	1,044	734	7,461	16,995	7,778	8,092	572	1,775
Total	1,029	17,476	12,285	46,020	114,594	640,655	60,168	421,164	10,173	88,183
% Discarded	5.6		21.1		15.2		12.5		10.3	

[1] Yellowtail flounder, winter flounder, red hake, silver hake, haddock, redfish, ocean pout, windowpane flounder

During 1989-1993, 235 gill net trips designating dogfish as the main species sought were sampled. The average catch per trip, set, and hour fished have all declined slightly over the time period (Table D6). In general, discards of spiny dogfish were low, averaging 13% of the weight of the dogfish catch. Spiny dogfish accounted for about 95% of the catch of all species in the directed gill net fishery (Table D7), other species included primarily groundfish species such as cod, pollock, and white hake. In the directed gill net fishery, the major reason for discarding dogfish that they were too small to be sold (Table D8). Other reasons for discarding in this fishery included poor quality, no market, and damage due to hagfish and sand fleas. In addition to the Gulf of Maine gill net sampling of the dogfish fishery, 27 directed dogfish gill net trips were sampled off North Carolina in the winter of 1994. These trips resulted in an average catch of 7792 lbs, with 12% of the catch discarded.

Spiny dogfish catch data were also summarized for the gill net fishery directed at groundfish (*e.g.*, cod, haddock, redfish, silver hake, red hake, pollock, plaice, witch, yellowtail, winter flounder, summer flounder, halibut, flatfishes [NS], white hake, wolfish, cusk, groundfish [NS]). Spiny dogfish catch data from the directed groundfish gill net fishery are given in Table D9. In this fishery, about 90% of the catch (in weight) was discarded, primarily due to a lack of market for the dogfish catch, and also due to small size. Average dogfish catch rates per trip, set, and hour fished peaked in 1991 and declined slightly from 1992-1993.

Otter Trawl Trips

Catches of spiny dogfish in otter trawl trips are summarized in Tables D10-D12. Very few directed otter trawl trips for dogfish were sampled

Table D8. Disposition of spiny dogfish caught in sea sampling trips in the Gulf of Maine gill net fishery, 1989-1993

Disposition/ Reason	Year				
	1989	1990	1991	1992	1993
Kept lb	17,000	43,655	609,873	406,989	83,474
%	95.0	79.8	85.3	88.7	90.1
Discard lb	900	11,066	104,947	51,904	9,214
%	5.0	20.2	14,7	11.3	9.9
<u>reason</u>					
01- No market					
lb	0	750	905	600	0
%	-	1.4	0.1	0.1	0.1
02- Too small					
lb	800	8,720	83,268	44,194	8,580
%	4.5	15.9	11.7	9.6	9.3
03- Poor quality					
lb	100	1,461	16,869	6,312	381
%	0.5	2.7	2.4	1.4	0.4
08- Other					
lb	0	0	1,211	150	0
%	-	-	0.2	<0.1	-
31- Hagfish					
lb	0	0	275	0	15
%	-	-	<0.1	-	<0.1
32- Sandflea					
lb	0	135	2,419	648	238
%	-	0.2	0.3	0.1	0.3

Data are for trips in which dogfish was the primary species sought

Table D9. Summary of spiny dogfish catch (pounds) and effort from sea sampled gill net trips in the Gulf of Maine designating groundfish as the primary species sought

Year	Dogfish Catch			Number	Number	Hours	Catch Per		
	Landings	Discards	Total	Trips	Sets	Soaked	Trip	Set	Hour
1993	35,692	315,676	351,368	544	2,712	103,905	646	1303	
1992	76,987	478,637	555,624	829	4,091	164,826	670	1364	
1991	68,785	987,365	1,056,150	687	3,220	120,930	1,537	328	9
1990	10,235	43,827	54,062	114	530	24,142	474	102	2
1989	10,294	64,327	74,621	81	358	13,106	921	208	6

during 1989-1993, although most of the otter trawl catch came from directed trips. Therefore, otter trawl catches of spiny dogfish are primarily bycatches taken while directing for other species.

Spiny dogfish catches from the Georges Bank otter trawl fishery are given in Table D10. This fishery has generally been sampled on the basis of about 30 trips per year. In recent years, almost all of the sampling has been directed in and about the haddock closure areas on the bank and thus should not be considered necessarily representative of all otter trawl trips on the bank. For the period 1989-1993, 97% of the dogfish catch was discarded, primarily due to a lack of market and small fish size. Average dogfish catch rates have varied considerably over the time period and declined significantly from 1992 to 1993. However, this may reflect the change in emphasis of the sea sampling program rather than declines in dogfish abundance.

Table D10. Summary of spiny dogfish catch (pounds) and effort from sea sampled otter trawl trips on Georges Bank designating groundfish as the primary species sought

Year	Dogfish Catch			Number of	Number of	Hours	Catch Per		
	Landings	Discards	Total	Trips	Tows	Towed	Trip	Tow	Hour
1993	0	17,707	17,707	22	570	1,776	805	31	10
1992	7,225	62,722	69,997	29	792	2,253	2,414	8831	
1991	16	52,590	52,606	29	862	1,799	1,814	61	29
1990	40	61,611	61,651	26	814	2,061	2,371	76	30
1989	0	68,419	68,419	30	921	2,265	2,281	74	30

Table D11. Summary of spiny dogfish catch (pounds) and effort data from sea sampled otter trawl trips in Southern New England - Mid-Atlantic Bight designating groundfish as the main species sought (including summer flounder)

Year	Dogfish Catch			Number of	Number of	Hours	Catch Per		
	Landings	Discards	Total	Trips	Tows	Towed	Trip	Tow	Hour
1993	0	97,166	97,166	28	260	645	3,470	374	150
1992	3,225	280,304	283,529	60	768	2,055	4,725	369	138
1991	397	142,909	143,299	29	862	1,799	4,941	166	80
1990	75	135,192	135,267	26	814	2,061	5,203	166	66
1989	200	116,427	116,627	30	921	2,265	3,888	126	51

Table D12. Summary of spiny dogfish catch (pounds) and effort data from sea sampled otter trawl trips in the Gulf of Maine designating groundfish as the main species sought

Year	Dogfish Catch			Number of	Number of	Hours	Catch Per		
	Landings	Discards	Total	Trips	Tows	Towed	Trip	Tow	Hour
1993	0	32,161	32,161	17	258	1,052	1,892	125	31
1992	3,081	55,082	58,163	44	521	2,037	1,322	112	29
1991	443	30,578	31,021	54	506	1,924	574	61	16
1990	0	2,760	2,760	25	117	416	110	6	7
1989	591	19,333	19,924	46	333	1,226	433	60	16

Otter trawl sea sampling data from the Southern New England - Mid-Atlantic Bight region are given in Table D11. These data were collected from trips directed at "groundfish", primarily summer flounder. Average dogfish catch rates of 3500-5200 lbs. per trip were significantly higher than on Georges Bank or in the Gulf of Maine groundfish otter trawl fishery. More than 99% of the dogfish catch was discarded from this fishery, with the main reason again being the lack of a market. Average dogfish catch rates per trip have declined slightly since 1990, but catch per tow and catch per hour have increased.

Dogfish catches from groundfish otter trawl trips in the Gulf of Maine were summarized in Table D12. Average dogfish catch rates have increased steadily, however, sampling of this fishery has been reduced sharply in recent years. The overall discard rate for dogfish caught in this fishery was 97%.

Size and Sex Compositions

The size and sex composition of sea sampled catches is given in Table D13 and Figures D8-D11. Because of the low sampling priority given to dogfish, data are insufficient for monitoring time trends. Thus, size composition information was aggregated over the period 1989-1992. Length

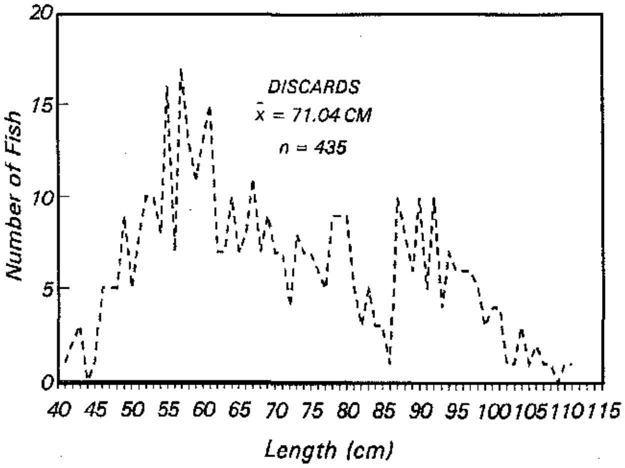

Figure D8. Length frequency distribution of spiny dogfish discards from otter trawl trips directed toward groundfish. Data are from sea sampled trips during 1989-1992.

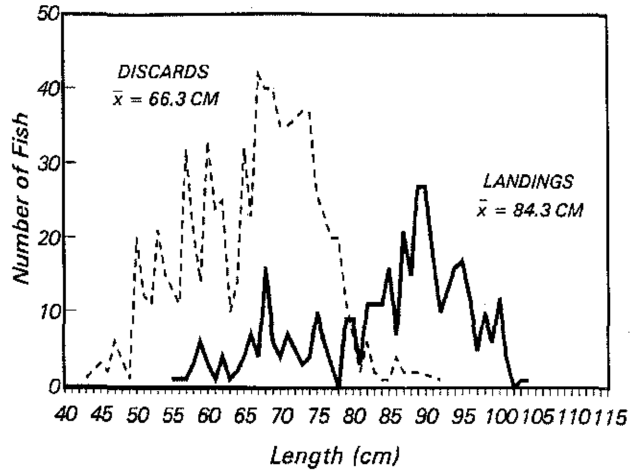

Figure D9. Length frequency distribution of spiny dogfish discards and landings from otter trawl trips directed toward dogfish. Data are from sea sampled trips during 1989-1992.

Table D13. Summary of size and sex composition of spiny dogfish from sea sampled trips during 1989-1992

Gear	**Primary Species Sought**	**Catch Disposition**	**Length (cm)** N'	Mean	CV	Range	**Percent** M	F	N[1]
Otter trawl	Cod	Discard	88	61.7	0.17	47-83	49	50	1
	Silver hake	Discard	39	60.7	0.43	19-100	0	0	100
	Silver hake	Kept	18	63.3	0.08	55-72	0	0	100
	Summer flounder	Discard	44	74.4	0.58	22-111	0	0	100
	Groundfish	Discard	49	81.6	0.24	54-104	39	61	0
	Spiny dogfish	Discard	310	66.3	0.21	43-92	26	24	50
	Spiny dogfish	Kept	155	84.3	0.21	55-104	10	27	63
Sink Gill Net	Cod	Discard	533	78.8	0.24	44-110	26	34	40
	Cod	Kept	73	78.6	0.19	57-106	1	59	40
	Pollock	Discard	49	67.4	0.18	50-91	0	0	100
	Flatfish	Kept	12	92.3	0.07	84-99	0	100	0
	Groundfish	Discard	3	91.0	0.06	87-97	0	0	100
	Groundfish	Kept	23	86.8	0.08	75-100	0	61	39
	Spiny dogfish	Discard	508	72.6	0.14	39-97	27	59	14
	Spiny dogfish	Kept	1,595	88.7	0.15	61-115	6	75	19

[1] Sex not recorded

samples from 1993 sea sampling were not available in computerized form.

In general, discard samples exhibited lower mean lengths and a higher proportion of male dogfish than corresponding samples of nondiscarded catch. Virtually all dogfish caught in designated groundfish otter trawl fisheries were discarded. The average size of otter trawl discarded dogfish was 71 cm, with a range of 40-111 cm. Pronounced modes occurred at 55-57 cm and at 85-92 cm, indicating a wide range of ages and sexes discarded by this segment of the fishery (Figure D8). Discards from the dogfish otter trawl fishery averaged 66 cm, versus 84 cm for the nondiscarded catch (Table D13; Figure D9). Modal sizes of discards from the dogfish otter trawl component were at about 70 cm, whereas the modal size of the non-discarded portion was about 90 cm (Figure D9). The sex ratio of the discards was about 1:1, whereas the sex ratio of the non-discarded catch was 1:2.7 (males:females).

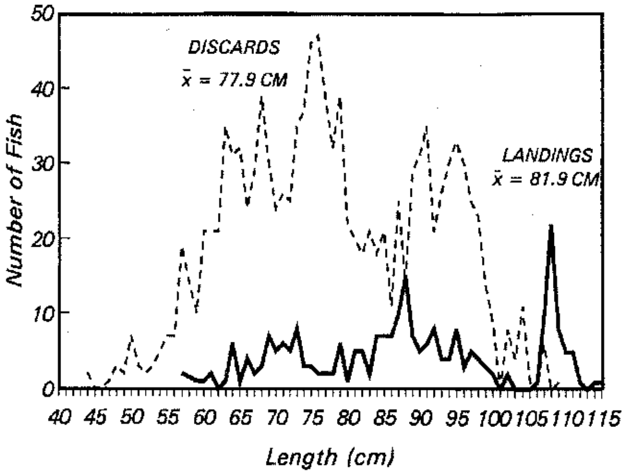

Figure D10. Length frequency distribution of spiny dogfish discards and landings from sink gill net trips directed toward groundfish. Data are from sea sampled trips during 1989-1992.

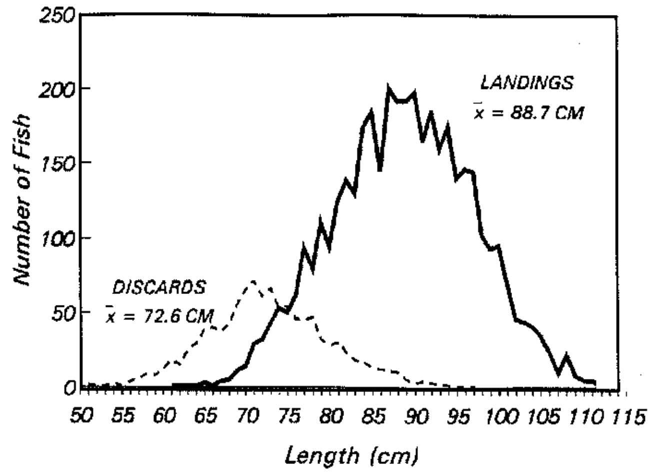

Figure D11. Length frequency distribution of spiny dogfish discards and landings from sink gill net trips directed toward dogfish. Data are from sea sampled trips during 1989-1992.

Table D14. Calculations of total discard mortalities of spiny dogfish from various fisheries for 1993.

Gear	Target Species	Area	Sea Sampled Discard/Ton[1]	Total 1993 Landings[2]	Est. 1993 Discard	Est. 1993 Discard Mortality[3]
Sink Gill Net	Dogfish	GOM-SNE	0.110	6,818	750	562
	Dogfish	MAB[4]	0.135	4,000	540	405
	Groundfish(cod)	GOM	1.038	2,130	2,211	1,659
OtterTrawl	Dogfish	GOM-SNE[5]	0.434	4,389	1,905	952
	Groundfish(cod)	GOM	0.924	6,391	5,906	2,953
	Groundfish(cod)	GBK[6]	0.377	11,700	4,411	2,205
	Groundfish(fluke)	SNE-MA	1.744	5,500	9,592	4,796
Total				25,315	13,532	

Note: Where indicated, 1993 sea sampling data are expanded to gear/area total catches

[1] Metric tons of dogfish per metric tons of target species (given in parentheses).
[2] Total 1993 landings of target species by designated gear type. Data are preliminary.
[3] Assumes 75% of discards dead by gill nets, and 50% of discards dead by otter trawls. Data given in metric tons.
[4] 1994 otter trawl sampling substituted for 1993.
[5] 1990 otter trawl sampling substituted for 1993.
[6] 1992 otter trawl sampling substituted for 1993.

Discards and landings from the groundfish sink gill net fishery were similar in size composition, with mean sizes of 78 cm (discards) and 82 cm (landings). The spiny dogfish gill net fishery landed fish with an average size of 89 cm (range = 61-115 cm), whereas discards averaged 73 cm (39-97 cm). The sex composition of the discards was 1:2.2 (males:females), and for the nondiscarded catch 1:12.5 (males:females).

Preliminary Discard Estimates

The summarized sea sampling data indicate a significant level of spiny dogfish discards from some gear/area/target species components of the Northeast fisheries. Unfortunately, because of the limited sampling of most fishery components, it was not possible to derive reliable annual estimates of dogfish discards by all major gear/area/target species cells. In most cases, the level of sea sampling has decreased in recent years, with the highest level of activity occurring in 1991. Nevertheless, the relative magnitude of spiny dogfish discards may be judged in a crude fashion, particularly to place these estimates in the context of recent landings.

Calculations given in Table D14 attempt to expand the dogfish discard sampling from some components of the fishery to overall discard estimates for 1993. These estimates are only provisional and are only useful to the extent that 1) sea sampled trips are representative of fleet activity in each gear/area/target species cell and 2) there are some components of the fishery in which dogfish discards occur, but are not accounted for in these calculations (*e.g.*, other gears, target species).

Spiny dogfish discards per ton of target species were calculated from the 1993 sea sampling data, supplemented to some extent by data from 1990, 1992, and 1994 (Table D14). These analyses assume a constant dogfish discard per ton of target species, but only for the year sampled. Total estimates of dogfish discards were expanded by multiplying the discard/ton ratio by the total tonnage of landings of the target species. There was very little information available on the mortality of discarded dogfish, although some observations suggest minimal mortality in the case of short otter trawl hauls or gill net sets and higher levels of mortality from longer hauls and sets and time to release. In this analysis, it was arbitrarily assumed that 75% of the gill net discards suffered mortality and 50% of the otter trawl discards suffered mortality.

Total dogfish discards for 1993 were estimated by this method to be 25,000 mt, with 13,500 mt of these suffering mortality. Trawl components, particularly in the Mid-Atlantic and Southern New England area, probably account for the largest fraction of the dogfish discard mortalities. It must be emphasized that these estimates are provisional and, since several fishery components were not included in the calculations, most likely are underestimates.

Total Catch

Total landings of spiny dogfish in NAFO Subareas 2-6 by all fisheries (U.S. and foreign commercial, U.S. recreational) climbed rapidly from the late 1960s to a peak of about 25,600 mt in 1974 (Table D1). During the period 1977-1989, total landings were fairly stable at an average of about 6200 mt per year. With the sharp intensification of the U.S. commercial fishery in 1990, total landings increased to over 18,000 mt in that year and increased further to 22,400 mt in 1993.

Additional quantities of spiny dogfish have been caught and discarded. Although information is lacking to make quantitative estimates of the amount of discards for years other than 1993, which might be an underestimate, it is likely that discards may have been of the same magnitude as reported landings. On the basis of the estimate of 13,500 mt of discards suffering mortality in 1993, the total catch in 1993 would have been about 36,000 mt. However, in view of the lack of quantitative discard estimates from earlier years and discard mortality, it is impossible to provide reliable estimates of total catch.

FISHERY-INDEPENDENT DATA

Research Vessel Abundance Indices

NEFSC Surveys

Indices of relative stock biomass and abundance were calculated from the NEFSC spring and autumn bottom trawl surveys. Indices were determined for seven different strata sets (subareas) and for the total offshore area. The seven subareas were defined as follows: Gulf of Maine offshore (offshore strata 26-30 and 33-40); Gulf of Maine inshore (inshore strata 56-90); Georges Bank offshore (offshore strata 13-25); Southern New England offshore (offshore strata 1-12); Southern New England inshore (inshore strata 1-17 and 45-55); Mid-Atlantic offshore (offshore strata 61-76); and Mid-Atlantic inshore (inshore strata 18-44). Overall indices were determined using only the offshore strata (1-30, 33-40, and 61-76) (Figure D12) in order to obtain longer time series (*i.e.*, 1967-1993 for the autumn survey and 1968-1994 for the spring survey). The autumn survey could not be extended back to 1963 because the Mid-Atlantic strata (61-76) were not sampled until 1967.

In both the spring and the autumn surveys, there is considerable variability in the indices (Table D15, Figures D13 and D14). Both sets of indices indicate an overall increase in abundance and biomass since the early 1970s.

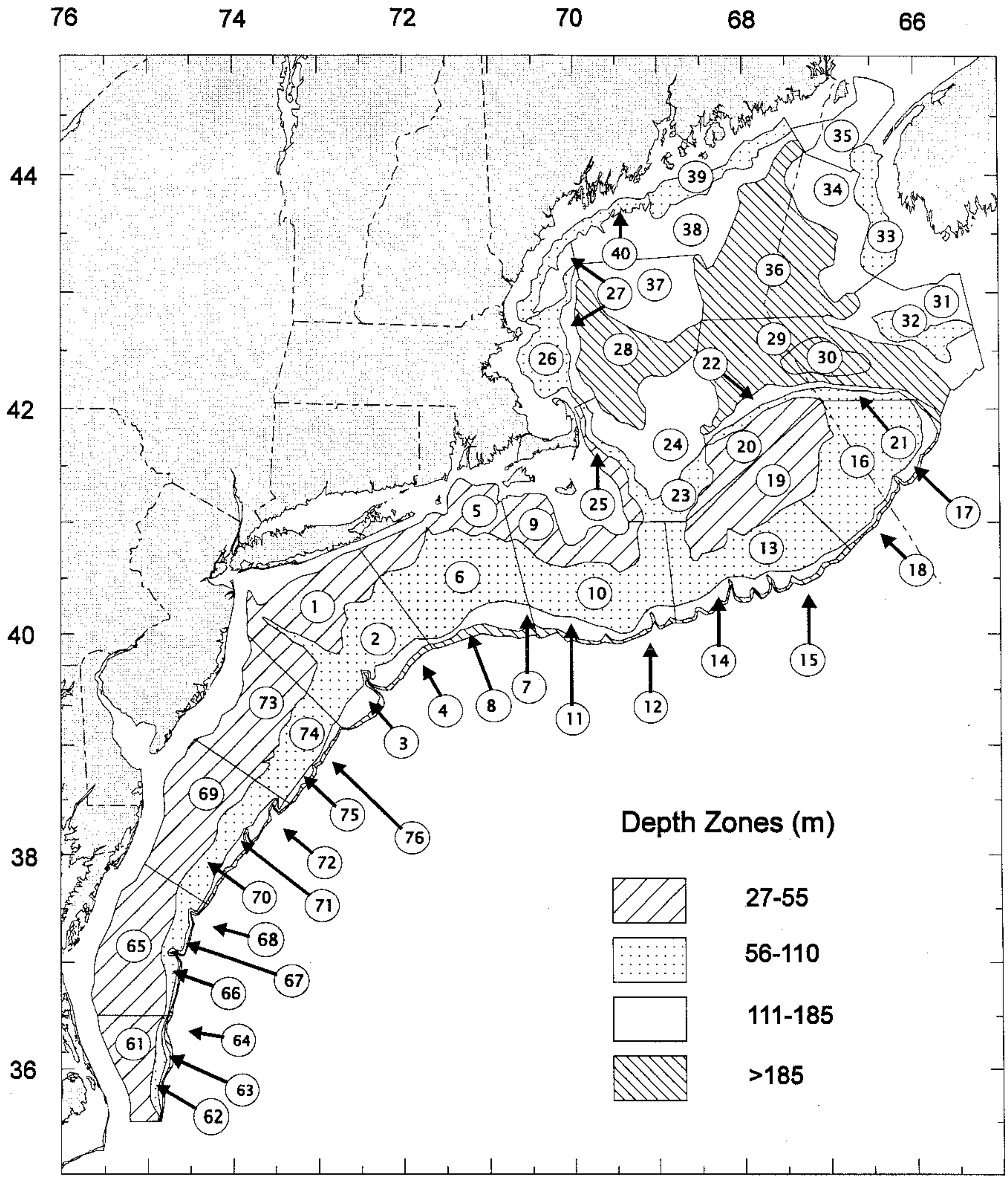

Figure D12. NEFSC bottom trawl survey sampling strata in the Northwest Atlantic.

Table D15. Weight per tow (kilograms) and number per tow indices for spiny dogfish from NEFSC spring and autumn bottom trawl surveys (vessel and gear conversion factors have been applied)

Year	Weight/Tow		Number/Tow	
	Autumn	Spring	Autumn	Spring
1967	34.9	-	-	34.0
1968	22.4	29.1	19.7	26.0
1969	55.3	16.1	27.7	13.3
1970	23.8	13.4	16.6	15.3
1971	15.5	24.0	12.9	15.9
1972	16.1	49.0	10.5	27.6
1973	21.7	57.2	15.0	35.2
1974	8.2	67.1	4.7	38.6
1975	20.9	45.6	17.8	35.0
1976	19.8	37.1	14.9	22.9
1977	16.1	24.2	6.8	12.9
1978	19.3	36.4	26.0	22.3
1979	26.6	13.3	22.1	9.9
1980	38.4	49.2	13.6	28.6
1981	48.5	69.2	76.3	41.2
1982	15.0	117.0	13.7	51.6
1983	35.8	38.9	32.4	41.7
1984	22.5	42.4	22.5	22.5
1985	39.6	167.1	38.7	117.3
1986	37.1	44.9	27.4	28.7
1987	21.8	102.3	32.8	65.1
1988	39.6	104.4	35.3	64.6
1989	11.5	77.8	12.8	56.7
1990	29.8	149.8	26.1	91.8
1991	51.3	89.5	38.4	62.3
1992	55.7	114.9	39.1	79.5
1993	7.2	87.9	6.9	60.9
1994	na	80.7	na	96.9

State Surveys

Data from the Massachusetts spring and autumn inshore bottom trawl surveys were used to obtain time series of stock biomass and abundance indices for 1980-1993 (Table D16). Indices were calculated for the entire strata set sampled, north and south of Cape Cod. In almost every year, indices from the autumn survey were much higher than from the spring survey, reflecting the greater availability of spiny dogfish inshore in the autumn than in the spring. As in the case of the NEFSC survey results, there is considerable year-to-year variability in these indices, but nevertheless there is some suggestion of a general increase in abundance and biomass during the period.

Canadian Surveys

Indices of relative abundance for 1970-1993 from the Canadian summer bottom trawl survey conducted in NAFO Divisions 4VWX (Dawe, pers. comm.) also indicate an increase in abundance in spiny dogfish since the early 1980s (Table D17).

Size and Sex Compositions

Size frequency distributions of spiny dogfish (sexes combined) from the spring and autumn NEFSC surveys are depicted in Figure D15. The spring survey length frequencies have three modes corresponding to new recruits (40 cm), mature males (70-80 cm), and mature females 95 cm. Large numbers of recruits have appeared periodically in the time series especially in the early 1970s. Whether these high levels of reproduction were responsible for subsequent increases in stock abundance in the late 1980s is open to question. The length frequency patterns in the autumn survey are much less consistent and there is no apparent tracking of modal lengths over time. Some compression of the maximum size categories is evident in the last five years (1990-1994).

When sex-specific length frequencies are considered (Figure D16), male distributions are strongly skewed and nearly truncated as predicted by the von Bertalanffy growth model. Females grow much larger than males. This truncation of male length frequencies is also evident when catches of the fishable population (80 cm) are mapped (Figures D17 and D18). Very few males 80 cm appear over a 15-year time span (Figure D18), whereas females appear in large numbers. The plots do not appear to differ very much between males and females except that females are found further inshore in the winter and spring. Dogfish 35 cm (new recruits) are found mainly in the slope area in all seasons (Figure D19). Very few are found in the inshore area of the Gulf of Maine where the larger dogfish are caught.

Spatial Distribution

The seasonal migration pattern of spiny dogfish can be seen from composite plots of survey catches at different times of year. In the winter

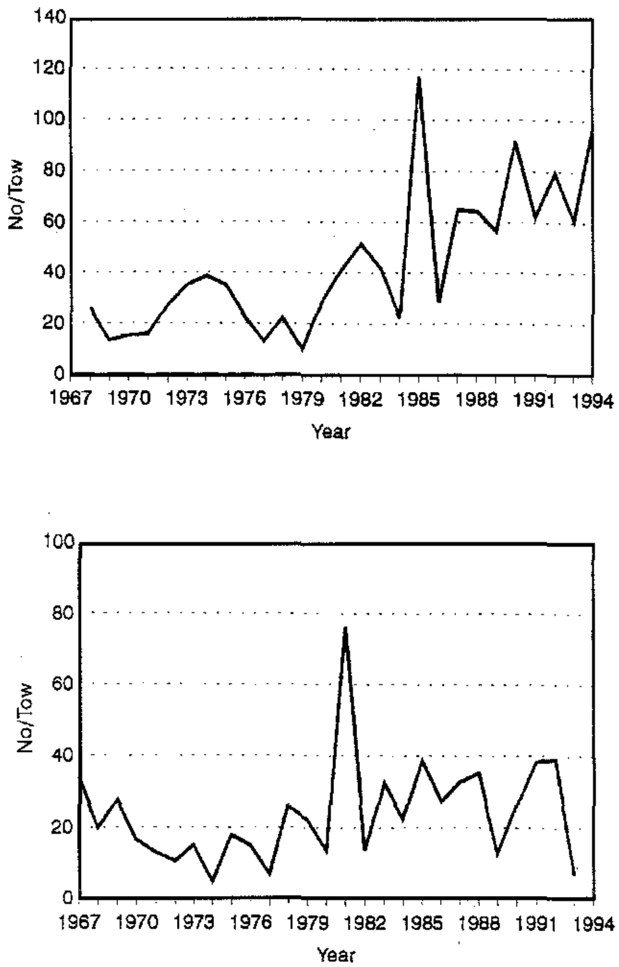

Figure D13. Abundance indices (mean catch per tow in numbers) of spiny dogfish from NEFSC spring and autumn surveys.

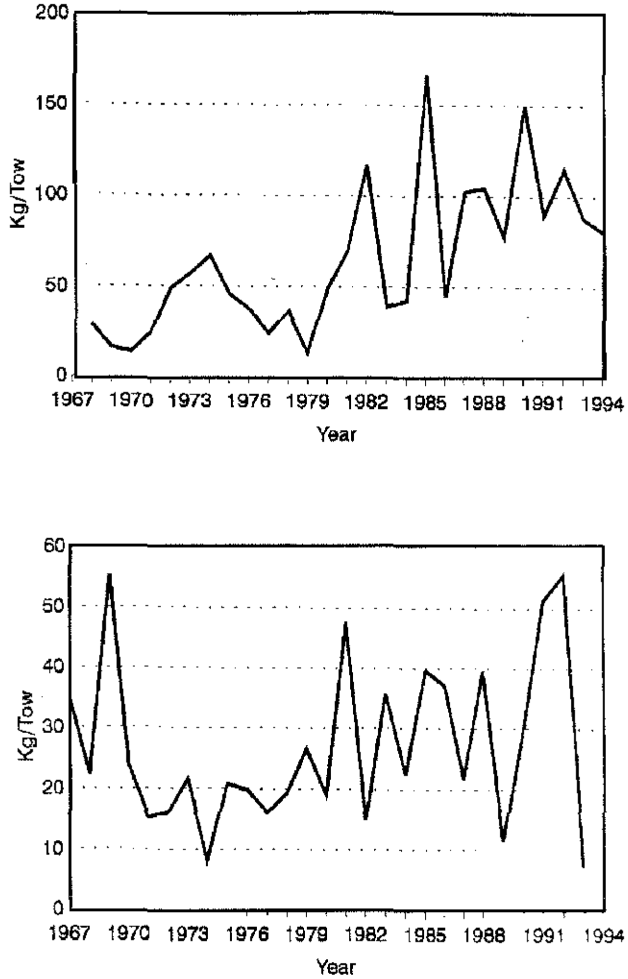

Figure D14. Biomass indices (mean catch per tow in kilograms) of spiny dogfish from NEFSC spring and autumn surveys.

Table D16. Massachusetts inshore survey indices

Year	Males				Females			
	Autumn		Sping		Autumn		Spring	
	Wt	No	Wt	No	Wt	No	Wt	No
1980	0.1	0.1	0.0	0.0	17.8	4.7	0.0	0.0
1981	0.2	0.1	0.0	0.0	1.3	0.3	4.3	1.0
1982	14.2	8.2	0.1	0.0	166.2	45.9	9.2	2.0
1983	4.1	2.6	0.0	0.0	18.6	7.6	3.2	0.8
1984	80.6	51.1	1.6	1.4	43.7	17.4	10.8	5.5
1985	7.4	4.0	0.1	0.1	92.6	29.1	3.4	0.8
1986	2.6	1.7	0.1	0.1	116.2	29.1	9.7	2.2
1987	11.6	8.3	0.0	0.0	103.1	35.3	0.9	0.2
1988	67.0	47.3	1.9	1.5	130.7	53.3	40.4	11.8
1989	1.6	1.3	4.8	9.2	23.6	8.4	14.0	16.4
1990	22.6	16.3	0.0	0.0	48.0	27.7	9.4	2.3
1991	0.1	0.1	0.0	0.0	60.7	19.9	4.5	0.9
1992	33.3	26.0	0.0	0.0	79.3	45.2	8.5	2.2
1993	23.3	15.8	10.4	9.4	211.7	93.9	19.5	10.5

Table D17. Canadian summer survey index, Division 4VWX

Year	No/Tow	Year	No/Tow
1970	6.5	1982	14.5
1971	19.2	1983	18.8
1972	3.0	1984	10.8
1973	4.4	1985	37.1
1974	6.6	1986	23.1
1975	0.8	1987	44.9
1976	1.0	1988	37.1
1977	19.8	1989	10.4
1978	0.2	1990	11.7
1979	3.2	1991	23.9
1980	10.7	1992	25.4
1981	3.2	1993	30.8

and spring, spiny dogfish are located primarily in Mid-Atlantic waters but also and extending onto southern Georges Bank on the shelf break (Figures D20a,b and D21a,b). In the summer, they are located further north in Canadian waters and move inshore into bays and estuaries (Figures D20c and D21c). They remain in northern waters throughout the autumn (Figures D20d and D21d) until water temperatures begin to cool and then return to the south.

Comparison of Research Vessel Surveys: Evidence for a Unit Stock

Spiny dogfish are highly migratory and are thought to comprise a single stock in the Northwest Atlantic (Scott and Scott 1988), although trans-Atlantic migrations have been recorded (Templeman 1976). The importance of transatlantic migrations is unknown, but the extent of such movements is considered negligible. Spatial and temporal abundance patterns were investigated for evidence of a single stock.

Plots of dogfish abundance in the NEFSC trawl surveys revealed high concentrations in the Mid-Atlantic and Southern New England regions in the spring and lower abundance on Georges Bank and in the Gulf of Maine. Past NEFSC assessments (*e.g.*, NEFSC 1990) have considered the spring survey to be a more accurate indicator of dogfish abundance, although both surveys are highly variable.

By autumn, dogfish have migrated north with high concentrations in Southern New England, on Georges Bank, and in the Gulf of Maine. Interannual abundance trends were less consistent than observed during the spring survey (Figure D22). Presumably, the northward migration continues into Canadian waters where surveys show a similar pattern of increased abundance over time, but indices exhibit high variability.

If dogfish populations comprise a single stock and most of the stock is present in U.S. waters in the winter, the NEFSC spring survey should provide a measure of total abundance. In contrast, the NEFSC autumn survey would sample only a portion of the population, the balance being present in Canadian waters. LOWESS (Cleveland 1979) smoothed plots of average weight (Figure D22) and number (Figure D23) per tow show upward trends in the spring survey, but not in the autumn. If the absence of trend in the autumn can be attributed to migrations to Canadian waters, then abundance indices from Canadian summer surveys should have increased since 1975. In particular, the increase in Canadian waters should be proportional to the difference between the NEFSC spring and autumn surveys. This hypothesis was tested graphically in Figure D24. The overall correlation is statistically significant and suggests that high survey indices in Canadian waters occur in response to annual variations in the fraction of the dogfish present.

To further test the concept of a unit stock, a general linear model of survey indices was examined. Let $I_{S,t}$, $I_{F,t}$, and $I_{C,t}$ represent the average number per tow in year t in the NEFSC spring and autumn and Canadian summer surveys, respectively. The statistical model can be expressed as

$$I_{S,t} = \beta_o + \beta_1 I_{F,t} = \beta_2 I_{C,t} \qquad (1)$$

If all the indices were absolute abundance measures, b_0 would equal zero and $\beta_1 = \beta_2 = 1$. Otherwise, the coefficients represent the differences in gear selectivity, mortality, and availability. The full model was highly significant and suggested that nearly 40% of the variation in the spring survey would be explained by the NEFSC autumn and Canadian summer surveys. Residual analyses (Figure D25) suggested that the model assumptions were satisfied. A general linear hypothesis was used to test the simultaneous hypothesis that $\beta_0 = 0$ and $\beta_1 = \beta_2 = 1$. The significance level for the null hypothesis was 0.334, suggesting negligible differences in the survey catchabilities ($\beta_1 = \beta_2 = 1$) and a zero intercept ($\beta_0 = 0$). The overall power of the simultaneous hypothesis test was not estimated, but was probably low owing to the small sample size (N = 22). These results collectively suggest that the sum of the NEFSC autumn and Cana-

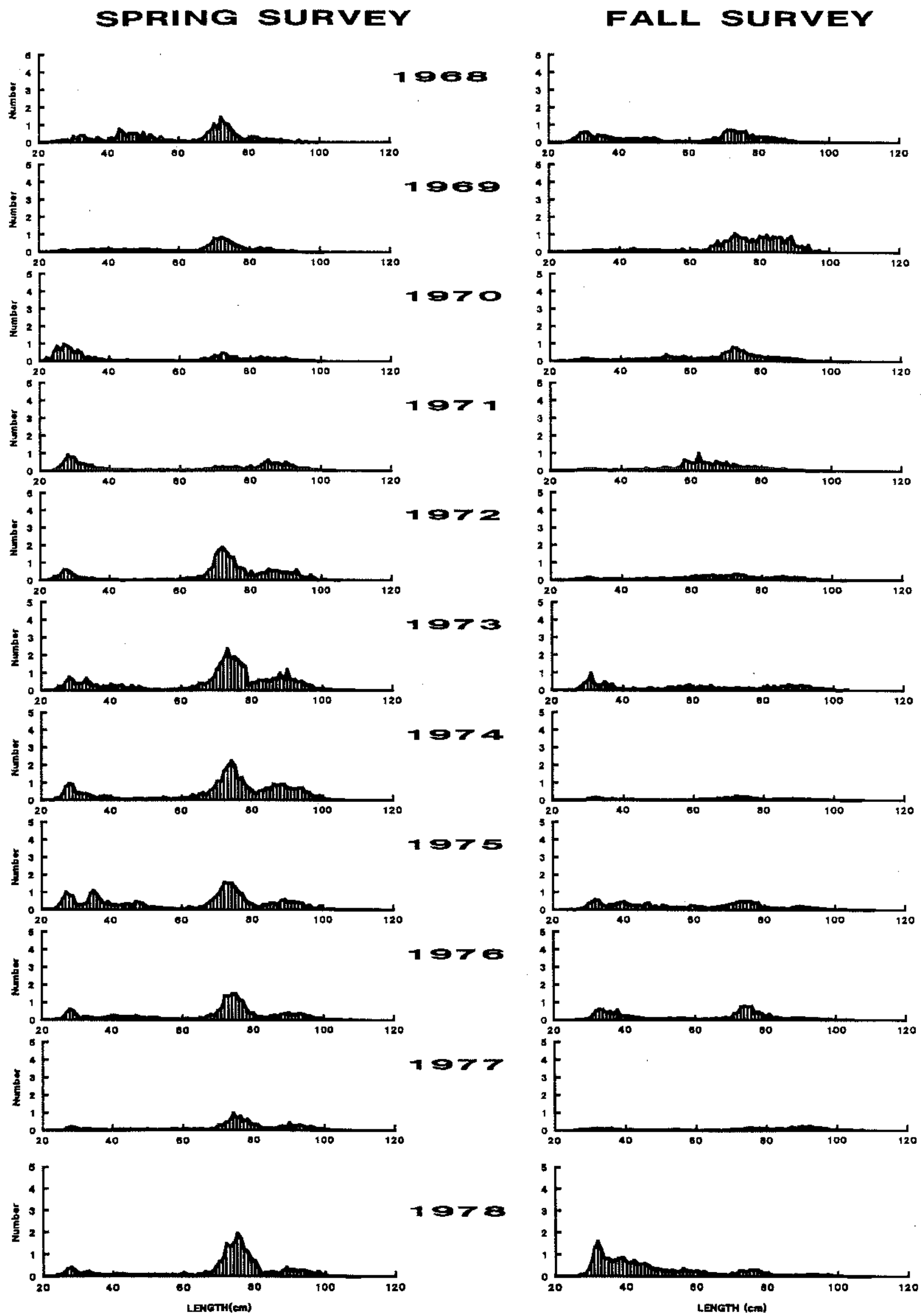

Figure D15. Length frequency distributions of spiny dogfish from NEFSC spring and autumn surveys.

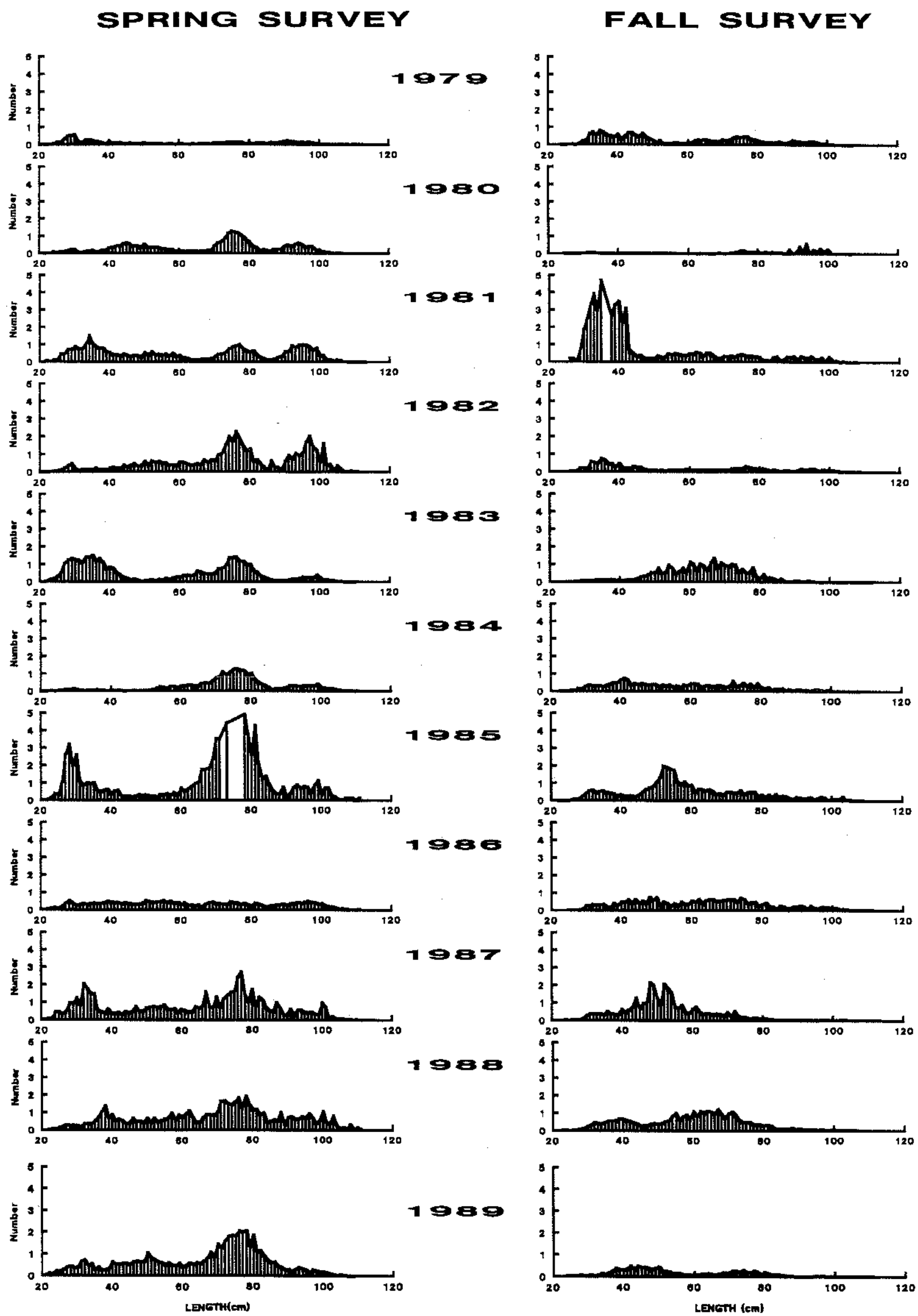

Figure D15.Continued.

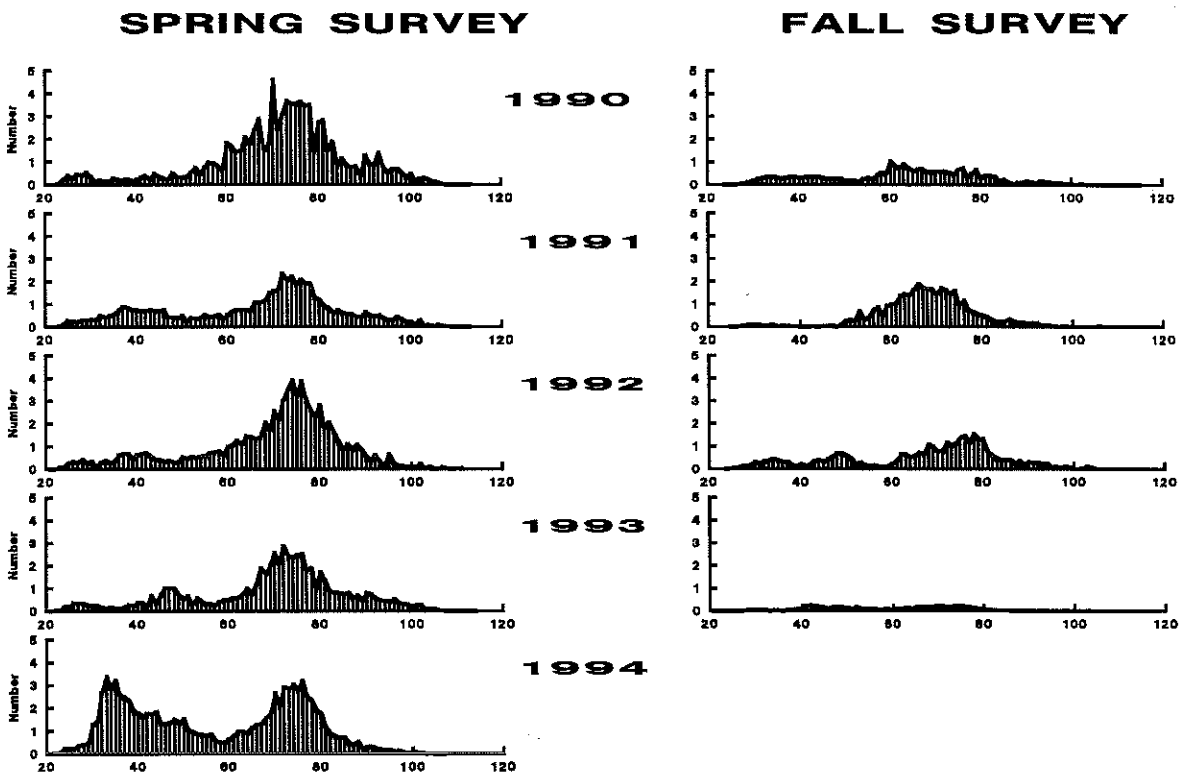

Figure D15.Continued.

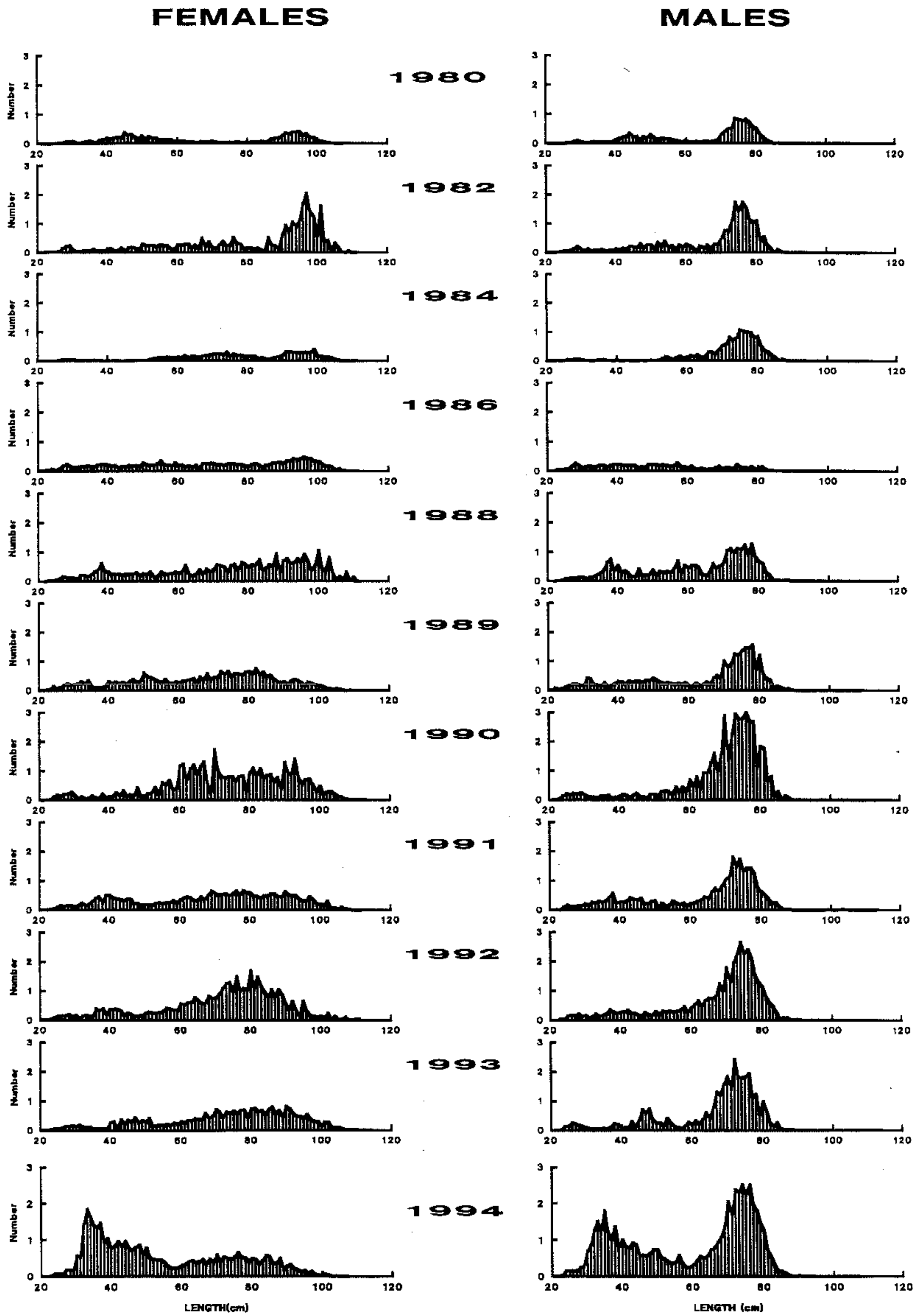

Figure D16. Length frequency distributions of male and female spiny dogfish from NEFSC spring surveys.

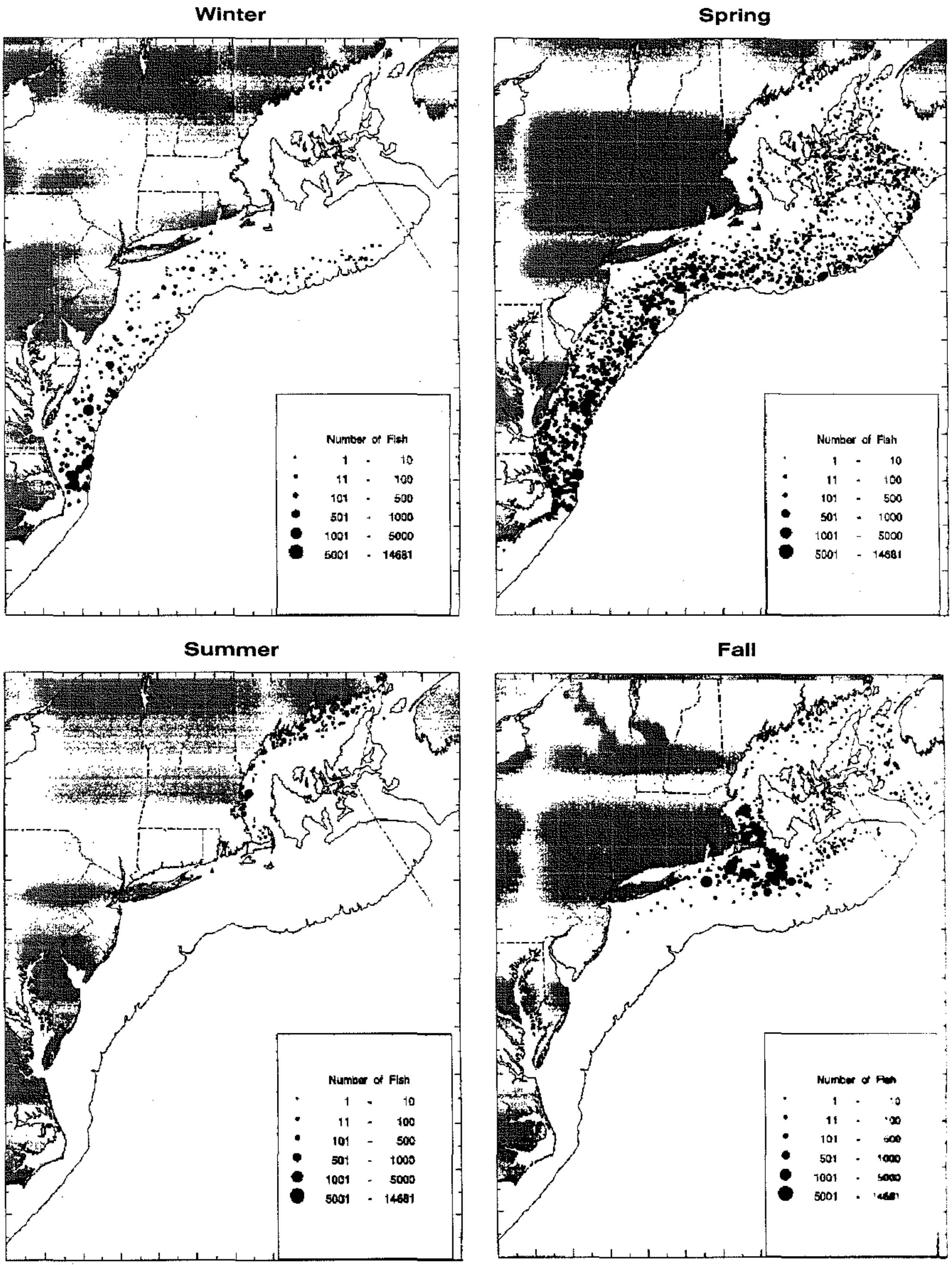

Figure D17. Distribution of catch of female spiny dogfish ≥80 cm in NEFSC surveys (winter: 1992-1994; spring: 1980-1994; summer: 1991-1993; autumn: 1980-1993).

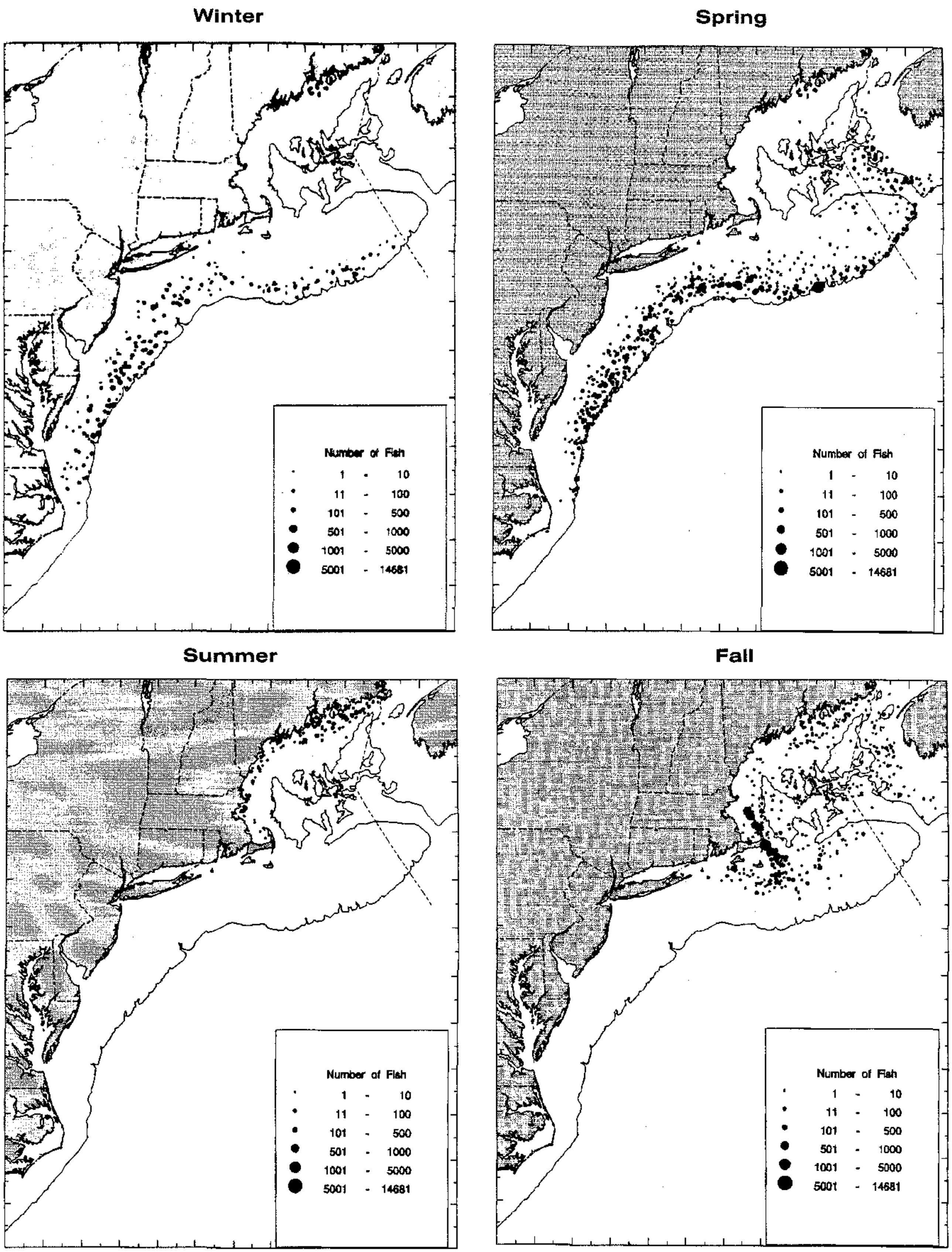

Figure D18. Distribution of catch of male spiny dogfish ≥80 cm in NEFSC surveys (winter: 1992-1994; spring: 1980-1994; summer: 1991-1993; autumn: 1980-1993).

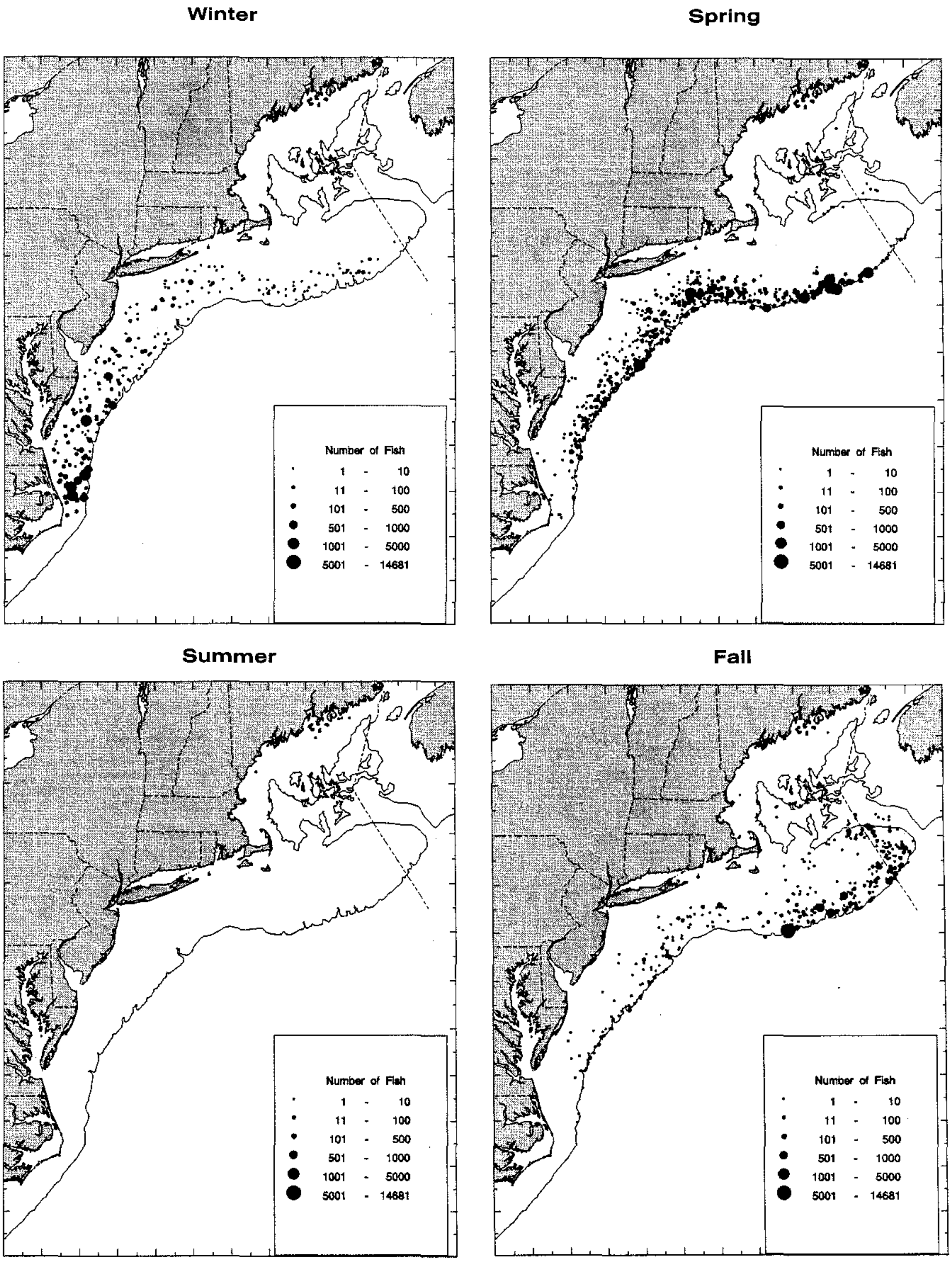

Figure D19. Distribution of catch of spiny dogfish ≥35 cm in NEFSC surveys (winter: 1992-1994; spring: 1980-1994; summer: 1991-1993; autumn: 1980-1993).

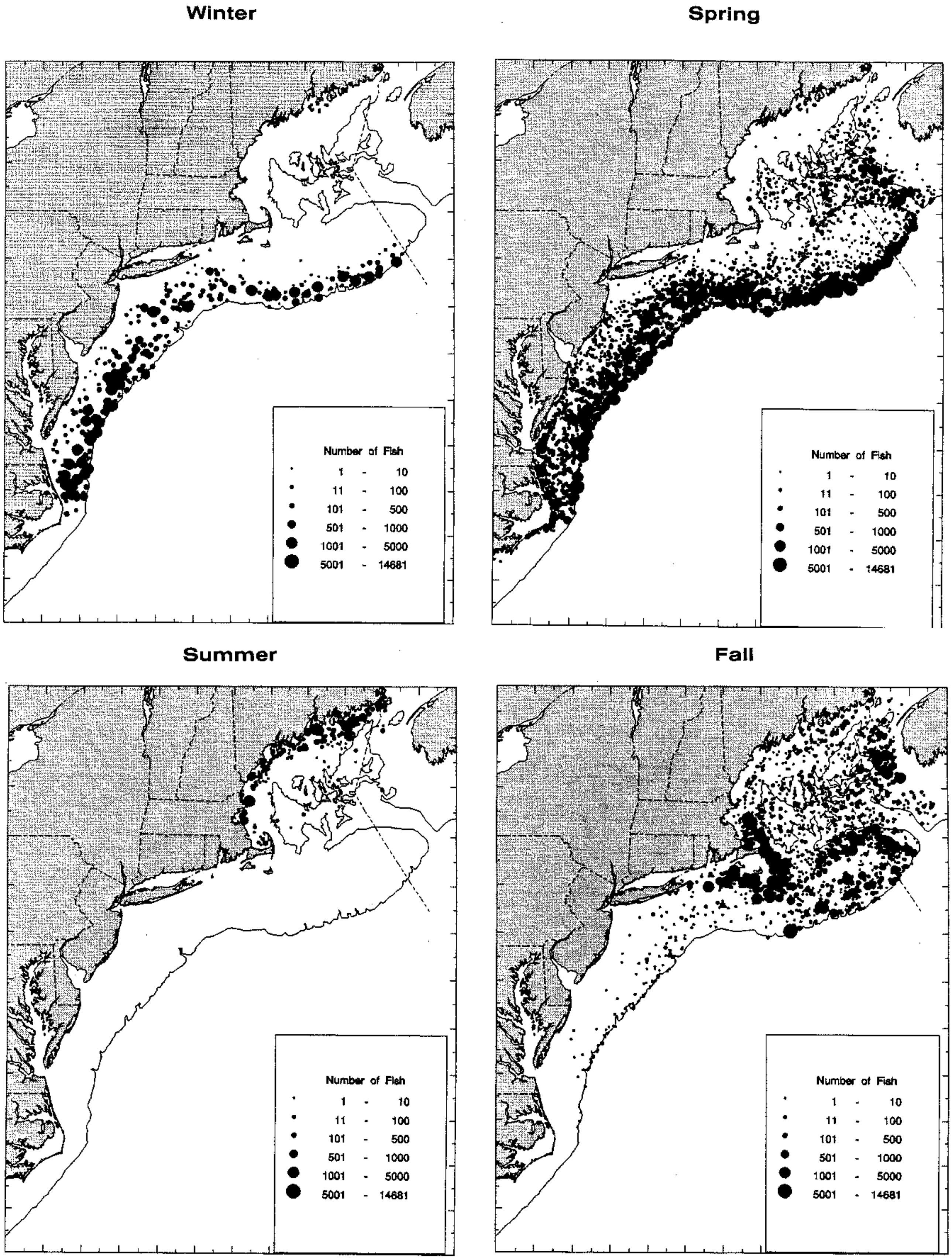

Figure D20. Distribution of catch of spiny dogfish in NEFSC surveys (winter: 1992-1994; spring: 1980-1994; summer: 1991-1993; autumn: 1980-1993).

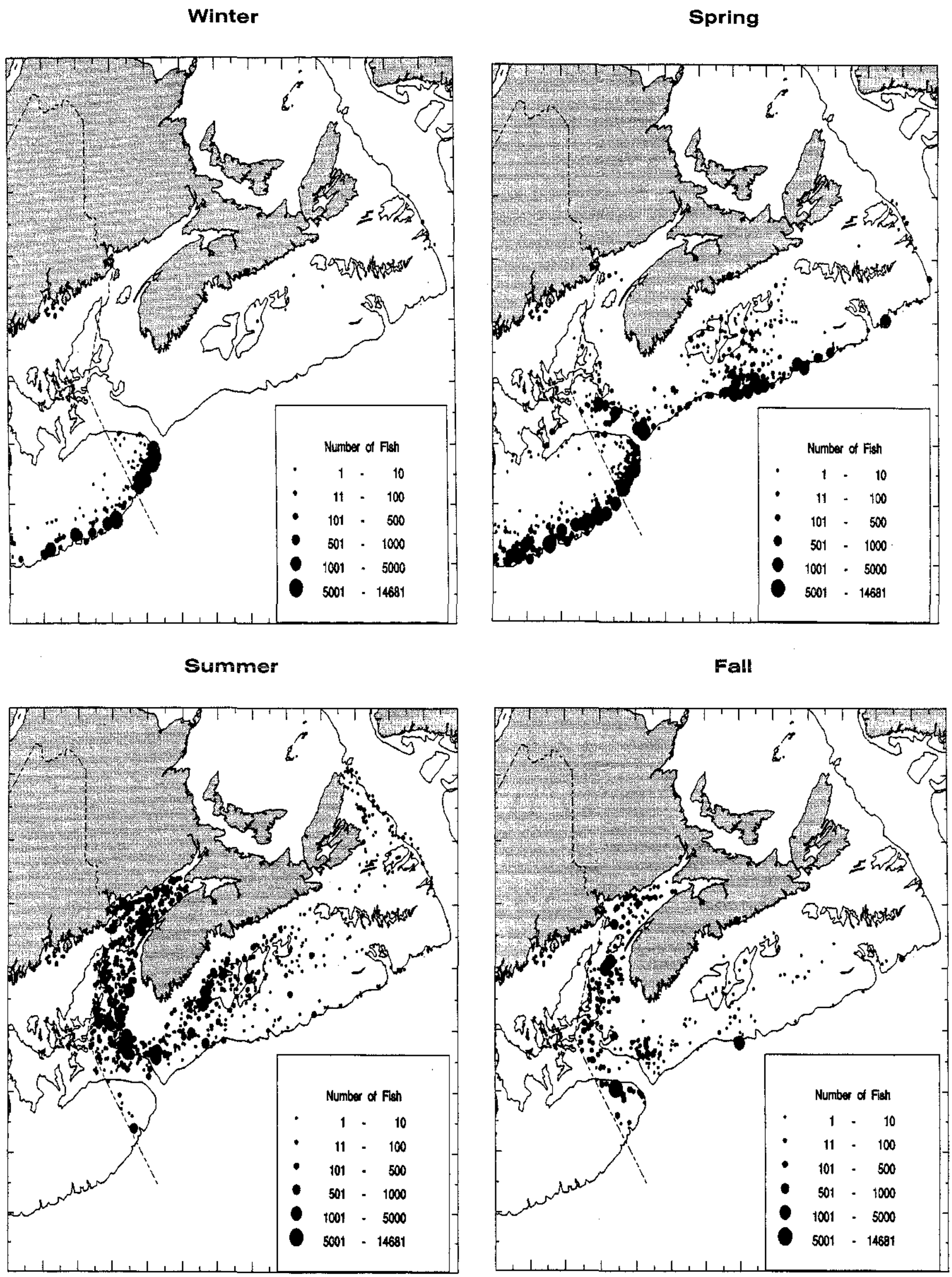

Figure D21. Distribution of catch of spiny dogfish in Canadian surveys by season from 1970-1994.

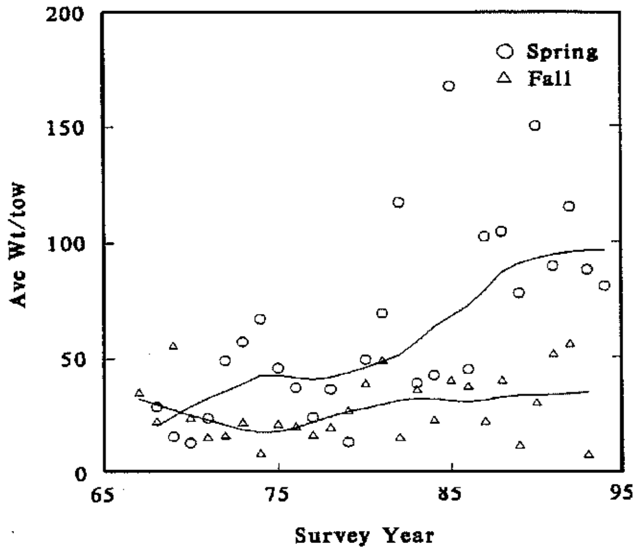

Figure D22. Catch per tow in weight (kilograms) of spiny dogfish in NEFSC spring (circles) and autumn (triangles) bottom trawl surveys (strata 1-30, 33-40, and 61-76). Lines are LOWESS smoothed plots of mean weight per tow from the two survey series (upper is spring, lower is autumn).

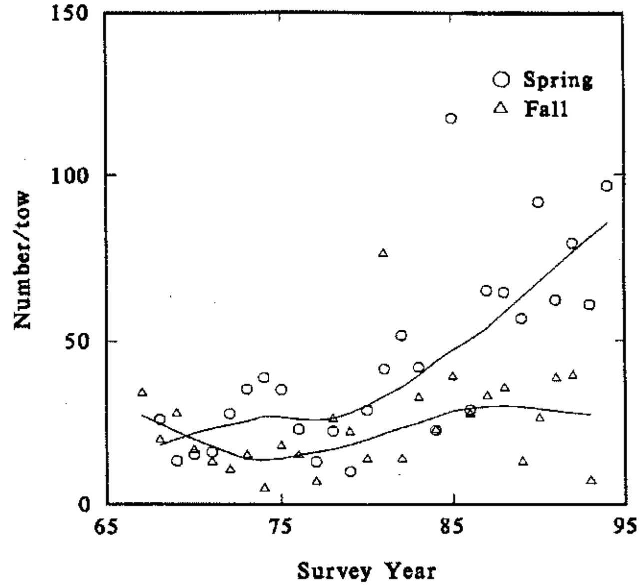

Figure D23. Catch per tow in numbers of spiny dogfish in NEFSC spring (circles) and autumn (triangles) bottom trawl surveys (strata 1-30, 33-40, and 61-76). Lines are LOWESS smoothed plots of mean number per tow from the two survey series (upper is spring, lower is autumn).

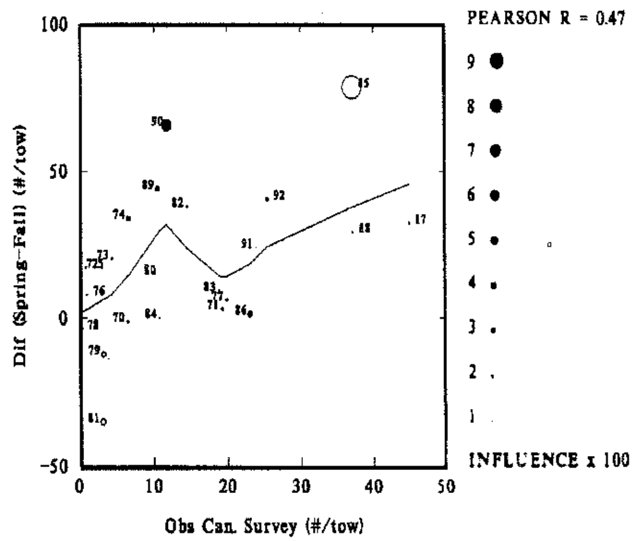

Figure D24. Predicted vs observed catch per tow (numbers) of spiny dogfish from Canadian surveys in NAFO Divisons 4VWX, 1970-1992.

dian summer survey indices provide an abundance estimate consistent with the NEFSC spring survey. The spring survey appears to provide a valid measure of the total Northwest Atlantic stock of spiny dogfish.

STOCK SIZE, MORTALITY, AND BIOLOGICAL REFERENCE POINTS

Introduction

Most attempts to assess stocks of elasmobranchs have suffered from insufficient data and the use of inappropriate models (Anderson 1990). One of the major data deficiencies for assessing the spiny dogfish stock in the Northwest Atlantic is age compositions of the catch. In the absence of such data to employ in preferred age-structured models (*e.g.*, virtual population analysis), a greater dependence has to be placed on the use of biomass models and other approaches which incorporate known information about the life history parameters of dogfish. Results from the application of several innovative approaches along these lines were used by the subcommittee to generate estimates of stock size, mortality rates, and potential biological reference points for use in managing the future harvest of spiny dogfish in the Northwest Atlantic.

Natural Mortality

As for most elasmobranchs, natural mortality (M) rates are poorly known for spiny dogfish. Most "estimates" have been derived by analogy among life history parameters. The most frequently used parameter is maximum longevity. For example, Hoenig (1983) developed an empiri-

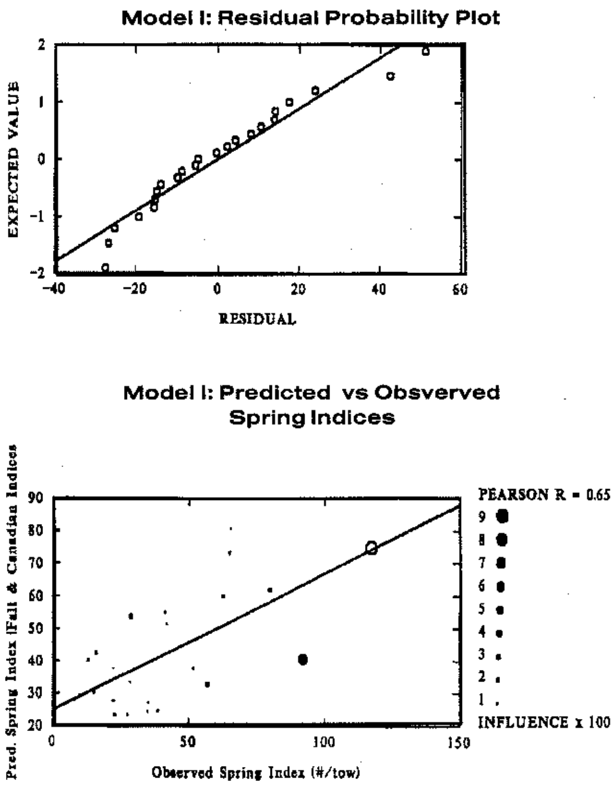

Figure D25. Results of residual analyses of NEFSC spring vs NEFSC autumn and Canadian summer surveys.

cal relationship between Z and T_{max} for 83 fish stocks:

$$\ln Z = 1.46 - 1.01 \ln T_{max} \qquad (2)$$

For a maximum longevity of 50 years, Hoenig's formula implies M = 0.083

Holden (1974) proposed that the solution of the equation $Z' = x\, e^{-Z' t_m}$ for Z' would provide an estimate of M for an unfished stock, where x is the expected number of pups produced per female per lifetime and t_m is the average age at 50% maturity. The maturation schedule in Silva (1993) implies 50% maturation at a size of 80 cm with a corresponding mean age of 10 yr. Substituting x = 2 and t_m = 10 implies Z' = 0.22.

Wood *et al.* (1979) estimated M = 0.094 for dogfish in the Northeast Pacific off British Columbia by solving for M required to obtain a net reproductive rate of 1.0 for an unfished population. Silva (1993) employed a similar technique by assuming a variety of density-dependent mechanisms and derived the natural mortality rate necessary to balance the population growth rate.

Finally, it is possible to derive M by considering the level of mortality necessary to reduce the recruited population to 1% of its initial value for different assumed estimates of longevity. Values

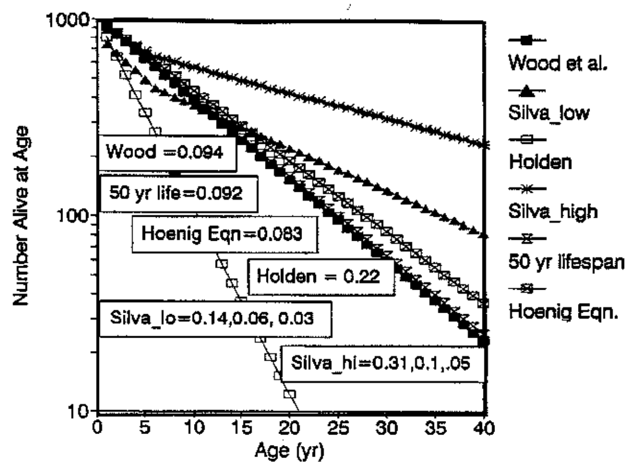

Figure D26. Comparison of natural mortality rates (M) for spiny dogfish.

for assumed longevities are presented here:

T_{max}	M
25	0.184
30	0.154
40	0.115
50	0.092
60	0.077
70	0.066

A summary of the implications of alternative M values for abundance at age is depicted in Figure D26. For the purposes of this assessment, a value of 0.092 was used for spiny dogfish greater than 30 cm. This agrees well with Wood *et al.* (1979) and the empirical value of 0.083 obtained in Hoenig's (1983) equation. Holden's (1974) equation yielded values that were inconsistent with other aspects of dogfish biology. For example, M = 0.22 implies an age at 1% of the initial size corresponding to 20 years. Moreover, the parameter x (i.e., net reproductive rate) in Holden's equation requires an estimate of M to be computed correctly.

Swept-Area Method

Estimates of minimum stock biomass were determined from the NEFSC spring survey catches. Mean numbers per tow by sex and 1-cm length class were converted to average weights using a length-weight regression (females: $W = \exp(-15.0251) * L^{3.606935}$; males: $W = \exp(-13.002) * L^{3.097787}$). These average weights were then multiplied by the total survey area (64,207 n mi^2) and divided by the average area swept by a 30-

Table D18. Minimum biomass estimates (thousands of metric tons) based on area swept by NEFSC trawl during spring surveys

Year	Lengths >= 80 cm			Lengths 36 to 79 cm			Lengths <= 35 cm			All Lengths
	Males	Females	Total	Males	Females	Total	Males	Females	Total	
1968	-	-	46.2	-	-	106.0	-	-	1.19	153.4
1969	-	-	31.6	-	-	76.4	-	-	0.54	108.6
1970	-	-	42.7	-	-	34.4	-	-	2.42	79.6
1971	-	-	110.9	-	-	27.3	-	-	2.21	140.4
1972	-	-	150.1	-	-	139.9	-	-	1.18	291.2
1973	-	-	223.0	-	-	192.4	-	-	2.12	417.5
1974	-	-	251.4	-	-	176.0	-	-	2.05	429.4
1975	-	-	132.5	-	-	139.7	-	-	3.07	275.3
1976	-	-	106.8	-	-	125.0	-	-	1.03	232.8
1977	-	-	83.6	-	-	67.9	-	-	0.45	151.9
1978	-	-	110.8	-	-	156.3	-	-	0.96	268.0
1979	-	-	58.9	-	-	18.5	-	-	1.45	78.9
1980	15.5	105.2	175.9	72.6	16.7	121.0	0.36	0.31	0.78	297.7
1981	26.1	279.0	308.8	76.7	25.4	102.2	2.69	2.04	4.86	415.8
1982	32.6	469.6	502.3	137.9	60.3	198.2	0.61	0.42	1.03	701.5
1983	31.5	89.1	120.6	102.7	40.0	142.7	3.80	2.97	6.77	270.1
1984	29.5	128.1	157.6	95.5	38.1	133.6	0.20	0.13	0.33	291.6
1985	114.1	370.1	484.2	453.8	110.6	564.4	4.43	3.49	7.92	1056.5
1986	3.5	187.5	191.1	29.3	51.8	81.0	1.07	0.81	1.88	274.0
1987	81.0	214.7	295.7	163.7	62.1	225.9	4.66	2.36	7.02	528.6
1988	23.0	390.0	413.1	140.2	91.8	232.0	0.97	0.78	1.75	646.9
1989	35.8	173.3	209.2	142.4	104.3	246.7	1.46	1.11	2.57	458.4
1990	69.0	396.6	465.5	296.3	165.3	461.7	0.96	0.65	1.61	928.8
1991	26.5	218.4	244.9	165.8	104.6	270.4	1.34	0.91	2.25	517.6
1992	42.5	291.3	333.8	239.2	177.3	416.4	0.99	0.71	1.69	751.9
1993	28.7	269.5	298.1	201.5	106.3	307.9	0.63	0.60	1.24	607.2
1994	40.6	118.1	158.7	269.8	114.6	384.4	5.91	4.55	10.47	553.6

NOTES: Total equals sum of males and females plus unsexed dogfish. Dogfish were not sexed prior to 1980.

minute trawl haul (0.01 n mi^2). Three size categories were defined (<35 cm, 36-79 cm, and >80 cm) that approximately correspond to new recruits, males and immature females, and mature females, respectively (Table D18). Swept-area estimates of stock biomass are considered to be minimum estimates because vulnerability of the stock to the trawl is not incorporated. Ability to avoid the net and dispersal of the stock above the bottom are two factors that may result in lower overall estimates.

The minimum estimates exhibit high annual variation generally in excess of what is realistic for such a long-lived species. Therefore, LOWESS smoothed estimates of biomass were considered to be better measures of population trends. For the fishable stock (*i.e.*, 80 cm), total biomass estimates have increased about three-fold since 1968, peaking in about 1988. Since then the population appears to have stabilized at about 300,000 mt. The 36-79 cm group continues to increase, perhaps reflecting higher levels of recruitment in the late 1970s and early 1980s (Figure D27). Spiny dogfish were sexed beginning in 1980. Since 1990, there is no evidence that the biomass of females in the fishable stock in continuing to increase; the male component of the 80 cm biomass has been relatively stable since 1980. Both female and male dogfish exhibit parallel patterns for recruits (35 cm) and the prefishery stock. Recent decreases in the minimum biomass of female dogfish are consistent with the removals by the commercial fishery. The implications of these sex-specific removals are considered further in the section on Mechanistic Models, page 127.

Biomass Dynamics Model

When catch-at-age data are unavailable or inadequate to perform an age-structured assessment, a biomass dynamics (or a surplus production) model is a natural alternative that can

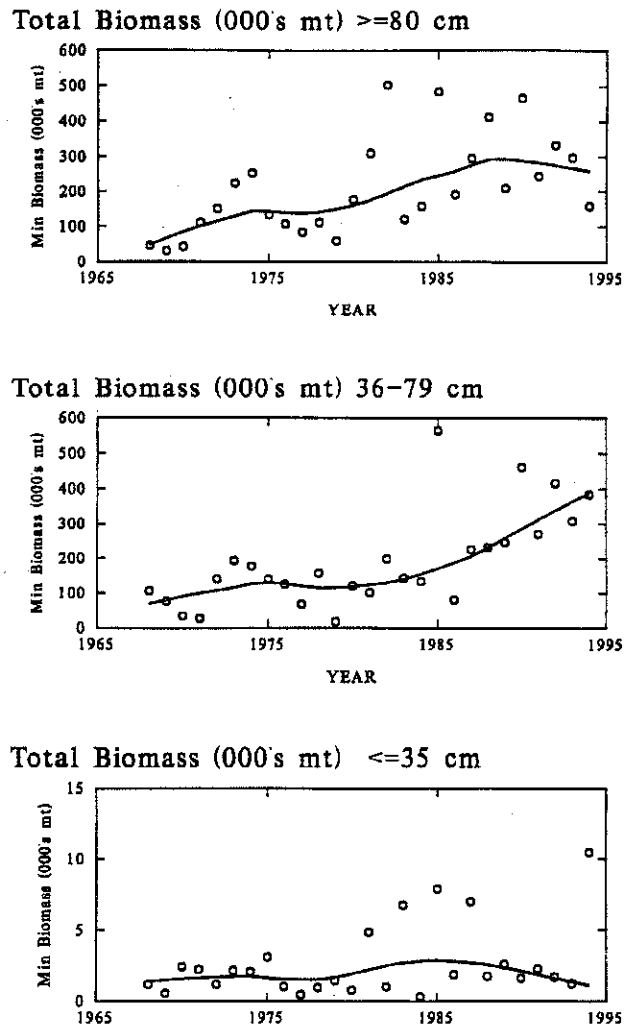

Figure D27. Minimum swept-area biomass estimate of spiny dogfish based on NEFSC spring survey catch-per-tow data for three size categories correponsding to recruits ($\leq$35 cm), males and immature females (39-79 cm). and mature females ($\geq$80 cm). Lines are LOWESS smoothed plots of the biomass estimates.

provide estimates of population biomass through time. Such a model developed by Shepherd (1987) and extended by Conser *et al.* (1991) was applied to obtain biomass estimates of the spiny dogfish stock. The model produced annual estimates of stock biomass based on total catches, natural mortality, and a biomass production function.

Description of Model

The model is based on a process equation and a measurement equation. The process equation relates biomass in year y+1 and biomass, catch, and biomass production during year y as

$$B_{y+1} = B_y + P(B_y) - C_y \qquad \textbf{(3)}$$

where B_y is the biomass on January 1 of year y, C_y is the catch in year y, and $P(\,)$ is the biomass production function that relates net biomass production to the current level of stock biomass.

The measurement equation is based on a relative biomass index, U_y, that provides a reliable measure of the relative abundance of stock biomass in year y. Given that U_y is proportional to the actual level of stock biomass, the measurement equation is

$$U_y = q \,.\, B_y \qquad \textbf{(4)}$$

where q is the catchability coefficient that scales stock biomass to the units of the relative abundance index.

Shepherd (1987) suggested that a useful biomass production function would have an asymptotic form analogous to a Beverton and Holt stock-recruitment relationship in the absence of natural mortality and that the process of natural mortality could be adequately represented as a constant proportion of stock biomass for this simplified model. These assumptions can be shown to give the biomass production function as

$$P(B_y) = \alpha M B_y \frac{B_{max} - B_y}{B_{max} + \alpha B_y} \qquad \textbf{(5)}$$

The parameter a is a measure of stock resilience, and higher values of a imply greater resilience. The parameter B_{max} is the level of stock biomass that produces no change in the level of biomass when there is no catch, *e.g.*, $P(B_{max}) = 0$. For this reason, the parameter B_{max} is termed the zero-production biomass.

Parameters of the biomass dynamics model can be estimated after error terms for the process and measurement equations have been specified. In this application, a multiplicative error term that was log-normally distributed with zero mean and constant variance was added to the process equation. Similarly, a multiplicative error term that was lognormally distributed with zero mean and constant variance was added to the measurement equation. Given that a series of Y consecutive years of catch and relative abundance data are available, the process and measurement errors can be combined into an estimation model that produces least squares estimates of U_1, U_2, ..., U_Y, and q (Brodziak *et al.* 1994). In this application, residuals of the relative abundance indices were bootstrapped (Efron 1982) to quantify the bias and precision of parameter estimates.

Application to Spiny Dogfish

Two applications of the biomass dynamics model to the spiny dogfish stock were considered. In the first, total stock biomass was estimated during 1968-1993. In the second, recruited biomass was estimated during 1980-1993, where recruited biomass consisted of all individuals greater than 80 cm in length. The estimation of recruited biomass was limited to 1980-1993 by the availability of representative size-frequency data. Relative abundance indices for both applications were estimated using LOWESS smoothing due to the high level of inter-annual variability in the observed abundance indices. The use of the observed abundance indices produced unrealistic annual variation in the biomass estimates.

For both applications, catch data consisted of total reported landings from U.S. and Canadian waters within NAFO Subareas 2-6. Estimates of discarded catch were not included in the catch. The natural mortality rate in this model was expressed as a fraction of the total biomass and was set equal to 0.088 (equivalent to M = 0.092) in both applications. This value was selected based on an assumed longevity of 50 years for spiny dogfish combined with the observation that adult spiny dogfish appear to have few natural predators. The stock resiliency parameter was set at 7 for both applications. This choice was based on the observation that spiny dogfish are relatively long-lived, but have low fecundity. The process error weight was set to unity for both applications so that process and measurement error contributions were equally weighted.

For both the stock biomass and recruited biomass applications, estimates of the catchability parameter and the true relative abundance indices were computed first. After estimating q, bootstrapping was applied to compute bias-corrected estimates of biomass and related quantities for both applications.

Results of the Stock Biomass Application

Bias-corrected estimates of total stock biomass (Table D19) increased steadily during 1968-1974 and varied without trend during 1975-1978. Estimates of stock biomass increased steadily during 1979-1990, but varied without trend since 1991. Overall, measurement error accounted for an average of 6% of the total sum of squares while process error accounted for 94%. The process errors during 1975-1979 accounted for 47% of the total sum of squares. Estimates of fishing mortality (F) were highest during the early 1970s ranging from 0.04 to 0.06. Since that time, F has been less than 0.02, with the exception of 1993. Estimated Fs during 1990-1993 were approximately twice as high as during 1984-1989. The bias-corrected estimate of maximum sustainable yield (MSY) was 56,000 mt and the bias-corrected estimate of the stock biomass that produced MSY was 346,000 mt. This gave a point estimate of the fishing mortality at MSY of approximately $F_{msy} = 0.18$. By comparison, the bias-corrected estimate of stock biomass in 1993 was 1.09 million mt with a standard deviation of 38,000 mt, while the bias-corrected

Table D19. Bias-corrected estimates of total stock biomass (thousand metric tons) and estimated instantaneous fishing mortality rates for the spiny dogfish stock in the Northwest Atlantic during 1968-1993

Year	Stock Biomass	F
1968	234.3	0.022
1969	278.4	0.036
1970	341.0	0.019
1971	376.0	0.033
1972	424.9	0.060
1973	441.2	0.046
1974	493.5	0.053
1975	470.5	0.051
1976	483.4	0.039
1977	472.5	0.019
1978	471.7	0.005
1979	505.1	0.013
1980	542.3	0.011
1981	555.7	0.019
1982	596.2	0.015
1983	638.7	0.010
1984	713.2	0.008
1985	796.0	0.008
1986	849.4	0.005
1987	935.6	0.005
1988	964.2	0.005
1989	1022.4	0.007
1990	1099.1	0.017
1991	1062.6	0.015
1992	1096.6	0.017
1993	1090.3	0.021

Table D20. Bias-corrected estimates of recruited biomass (thousand metric tons) and estimated instantaneous fishing mortality rates for the spiny dogfish stock in the Northwest Atlantic during 1980-1993

Year	Stock Biomass	F
1980	480.0	0.012
1981	469.0	0.022
1982	488.4	0.018
1983	481.0	0.013
1984	470.0	0.012
1985	467.8	0.014
1986	584.6	0.008
1987	587.0	0.007
1988	643.6	0.008
1989	682.2	0.010
1990	623.8	0.030
1991	607.7	0.026
1992	581.9	0.033
1993	523.7	0.044

estimate of F in 1993 was 0.021 with a standard deviation of 0.001.

Results of the Recruited Biomass Application

Bias-corrected estimates of recruited biomass (Table D20) varied without trend during 1980-1985, increased during 1986-1989, and decreased steadily during 1990-1993. Overall, measurement error accounted for an average of 4% of the total sum of squares, while process error accounted for 96%. The process error during 1986 accounted for 49% of the total sum of squares. Estimates of fishing mortality ranged from 0.01 to 0.02 during 1980-1989, but increased moderately to 0.03 to 0.04 in recent years. The bias-corrected estimate of MSY in terms of recruited biomass was 30,000 mt and the bias-corrected estimate of the biomass that produced MSY was 185,000 mt. This gave a point estimate of the fishing mortality at MSY of approximately $F_{msy} = 0.18$. By comparison, the bias-corrected estimate of recruited biomass in 1993 was 524,000 mt with a standard deviation of 19,000 mt, while the bias-corrected estimate of F in 1993 was 0.044 with a standard deviation of 0.002.

Sensitivity Analyses

A number of sensitivity analyses were performed for the stock biomass and recruited biomass applications. The sensitivity of the estimates of biomass, F, MSY, B_{msy}, and B_{max} to the underestimation of total catch and the misspecification of natural mortality, process error weight, stock resilience, and catchability were examined.

Underestimation of catch. The sensitivity of the model to an underestimation of catch, in particular the lack of discard estimates, was evaluated by doubling the input catches in each year of the time horizon for both applications while keeping all other parameters fixed. While the choice of doubling the catches was arbitrary, it represented a reasonable approach in light of the estimate of discards of 25,000 mt (including 13,500 mt suffering mortality) in 1993 (Table D14).

Biomass estimates with doubled catches were virtually unchanged from the baseline run in both applications. In contrast, doubling the catches increased the estimated Fs by a factor of 2, as expected. The effect of doubling the catch on MSY, B_{msy}, and B_{max} was to increase each, on average, by a constant factor. For the stock biomass application, doubling the catches increased estimates of MSY, B_{msy}, and B_{max} by 14%. For the recruited biomass application, doubling the catches increased estimates of MSY, B_{msy}, and B_{max} by 18%.

Misspecification of natural mortality. The sensitivity of the model to misspecification of the natural mortality rate was evaluated by examining model outputs for values of 0.05, 0.07, 0.11, and 0.13. These values were chosen to bracket the value of 0.088 based on the expected maximal lifespan.

Estimates of biomass and F were not affected by changes in the natural mortality rate for both the stock biomass and recruited biomass applications. An increase in the rate reduced the estimated biomass at MSY and zero-production biomass by a similar percentage, and increased MSY. Similarly, a decrease in the rate increased the estimated biomass at MSY and zero-production biomass by a similar percentage, and decreased MSY.

Misspecification of process error weight. The sensitivity of the model to the process error weight was evaluated by examining model outputs for a range of process error weights in both applications. The process error weights used were 10, 2, 1/2, and 1/10.

Overall, the changes in process error weight examined had no effect on estimated biomasses or Fs. Similarly, the effect of varying the process error weight was negligible for MSY, B_{msy}, and B_{max}.

Table D21. Sensitivity of estimates of maximum sustained yield (MSY), stock biomass that produces MSY (B_{msy}), and stock biomass that gives zero biomass production (B_{max}) to catchability (q) for total stock biomass and recruited stock biomass (80 cm) of spiny dogfish (*Squalus acanthias*) in the Northwest Atlantic

Stock Biomass[1]

q ($x10^{-5}$)	MSY (mt)	B_{msy} (mt)	B_{max} (mt)
0.7330	577,000	3,589,000	13,745,000
4.7164	96,000	597,000	2,286,000
8.6998	56,000	346,000	1,322,000
12.6832	41,000	252,000	966,000
16.6667	33,000	204,000	782,000

Recruited Biomass[2]

q ($x10^{-5}$)	MSY (mt)	B_{msy} (mt)	B_{max} (mt)
4.4927	46,000	286,000	1,096,000
5.9903	36,000	223,000	853,000
7.4879	30,000	185,000	707,000
8.9854	26,000	159,000	610,000
10.4830	23,000	141,000	541,000

[1] For the stock biomass application, q was estimated to be $8.69984x10^{-5}$ and sensitivities at $q\pm\sigma_q$ and $q\pm2\sigma_q$ are given.

[2] For the recruited biomass application, q was estimated to be $7.48787x10^{-5}$ and sensitivities at $q \pm 0.2q$ and $q \pm 0.4q$ are given.

Misspecification of stock resilience. The sensitivity of the model to the stock resilience parameter was evaluated by examining model outputs for a range of stock resiliences in both applications. The stock resilience parameters used were 4, 5, 6, 8, and 9.

Changing the value of stock resilience had no effect on the estimated biomasses or Fs. In general, increasing stock resilience increased MSY and decreased B_{msy} and B_{max}. Similarly, decreasing stock resilience decreased MSY and increased B_{msy} and B_{max}.

Misspecification of catchability. The sensitivity of the model to the estimated catchability parameter was evaluated by examining model outputs for a range of catchabilities in both applications. For the stock biomass application, values of -2 SD, -1 SD, +1 SD, and +2 SD of the estimated catchability were examined. The standard deviation of q was estimated using a standard asymptotic approximation for the covariance matrix of the estimated parameters. For the recruited biomass application, the estimated standard deviation of q was large, and values of q that were -40%, -20%, +20%, and +40% of the estimated q were used.

Changing the value of catchability had a substantial effect on the estimated biomasses for both applications. Similarly, effects on estimated Fs were also substantial. In general, increasing catchability decreased estimated biomasses and increased estimated Fs. In terms of estimates of management parameters, increasing catchability decreased MSY, B_{msy}, and B_{max} (Table 4.4.5).

Summary of sensitivity analyses. Underestimation of catch appeared to have no substantial effect on estimated biomasses, for the changes examined. However, underestimating catches would lead to underestimates of F and also to underestimation of MSY, B_{msy}, and B_{max}. The model is relatively insensitive to the value of the process weight parameter in this application. Changes in natural mortality or stock resilience have virtually no effect on estimated biomasses or Fs. However, changes in natural mortality and stock resilience have similar effects on MSY, B_{msy}, and B_{max}. In particular, increasing natural mortality or stock resilience would increase MSY and decrease B_{msy} and B_{max}. Overall, key outputs of the biomass dynamics model appear to be highly sensitive to changes in the catchability parameter.

Empirical Estimates of Survival, Growth, and Recruitment

Fishing Mortality

Presently, spiny dogfish collected or examined during routine research vessel surveys or port sampling of commercial landings are not aged. Silva (1993) used the software package MULTIFAN (Fournier *et al.* 1990) to decompose the length frequencies from research cruises into age groups, but was unable to obtain accurate separation above 8 years old. This limitation restricts the utility of such methods for providing management advice on the fishable stock. Other methods based on length frequencies (*e.g.*,

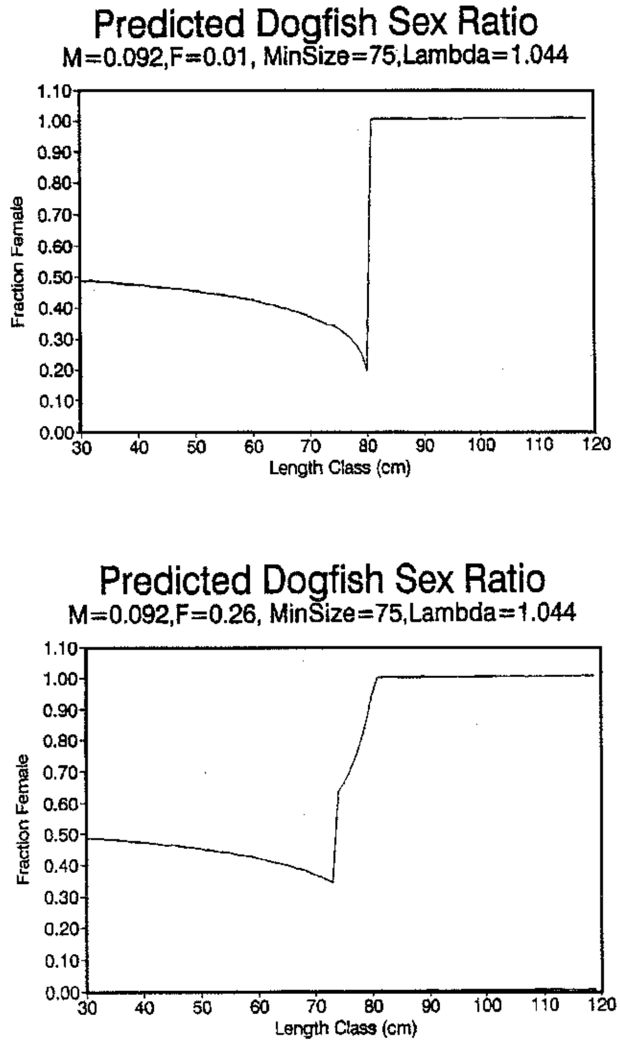

Figure D28. Predicted equilibrium proportion of spiny dogfish in population by 1 cm length interval based on mechanistic model. Top panel shows expected pattern when F is minimal; bottom panel shows pattern when F = 0.26, the change-in-ratio estimate of F for 1993 from Table D22.

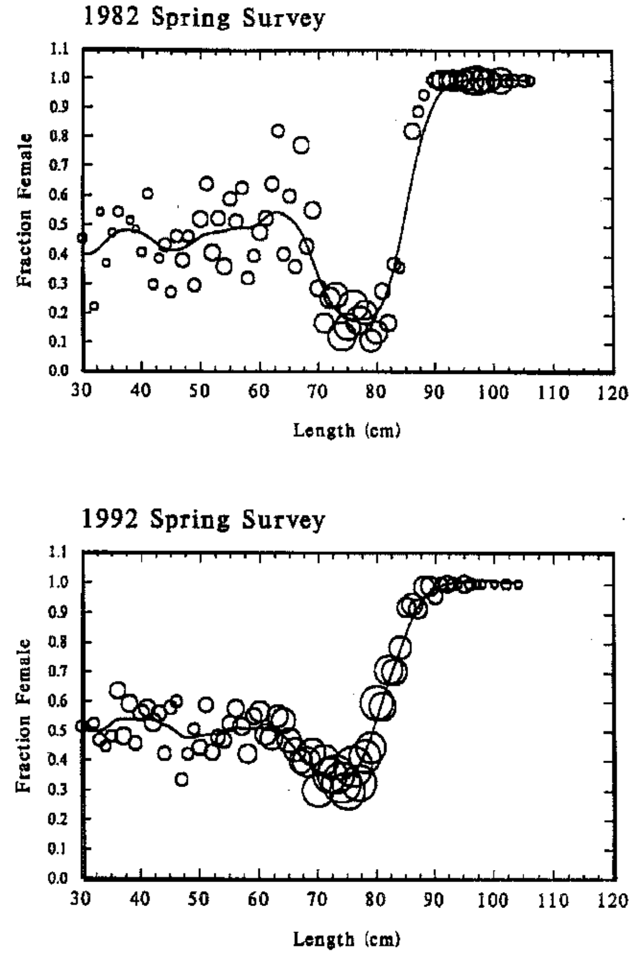

Figure D29. Observed proportion of spiny dogfish in population by 1 cm length interval caught during NEFSC spring surveys in 1982 and 1992. Symbol size is proportional to the total number sampled; lines represent distance-weighted least squares estimates of average proportion female by 1 cm length interval.

Wetherall *et al.* 1987) were not attempted for this assessment, but will be considered in the future. In theory, tagging studies could be used to estimate total mortality rates, but no contemporary tagging programs have been conducted.

Theoretical analyses of length-specific sex ratios (see section on Mechanistic Models, page 127) suggested the potential utility of change in ratio methods (Seber 1982). Based on the large disparity between maximum lengths of males (L_∞ = 81 cm) and females (L_∞ = 105), model results predicted marked changes in sex ratios for fish 70 cm in response to changes in fishing mortality. An example of predicted and observed sex ratios is illustrated in Figures D28 and D29, respectively. It should be possible to develop a maximum likelihood estimator of fishing mortality based on the length-specific sex ratio; however that could not be accomplished for this assessment.

The method of Chapman and Murphy (1965) was applied to LOWESS smoothed estimates of male and female numbers per tow for spiny dogfish 70cm in length from the NEFSC spring survey for the period 1982-1994. Length frequency samples from U.S. commercial landings were used to characterize the sex ratio of removals. Let x_1 and x_2 represent the number of animals of type x in the population at times 1 and 2, respectively. Similarly, let y_1 and y_2 represent the comparable numbers of animals of type y. The removals of types x and y that occur between times 1 and 2 are denoted as R_x and R_y, respec-

Table D22. Change in ratio estimators of fishing mortality on males and females from commercial fisheries for 1982 to 1993

Year	Spring Survey (yr i)		Removals via Fishery		Spring Survey (yr i + 1)		Intermediate Vars Survey M-F		Instantaneous Rates		Ratio of Mortality Rates
	Males X_t	Females Y_{t_0}	Males R_x	Females R_y	Males X_2	Females Y_2			Males r_1	Females r_2	F/M
1982	13.976	13.900	1360	11114	11.706	12.479	0.1217	0.9330	-0.0100	-0.0794	7.9316
1983	11.706	12.479	NA	NA	9.166	11.232	-	-	-	-	-
1984	9.166	11.232	62	10248	9.937	11.372	0.0074	1.0708	0.0005	0.0689	139.4986
1985	9.937	11.372	80	9433	10.654	13.259	0.0097	0.9196	-0.0009	-0.0847	98.7137
1986	10.654	13.259	933	6091	11.661	14.068	0.1906	1.0316	0.0072	0.0383	5.3273
1987	11.661	14.068	111	6618	14.342	15.517	0.0202	1.1151	0.0021	0.1110	52.1117
1988	14.342	15.517	65	6641	16.168	17.975	0.0106	0.9732	-0.0003	-0.0275	93.1482
1989	16.168	17.975	329	10881	17.229	18.865	0.0336	1.0154	0.0005	0.0158	29.9748
1990	17.229	18.865	1024	35820	18.826	20.077	0.0313	1.0267	0.0008	0.0272	32.3683
1991	18.826	20.077	2420	27383	18.714	19.065	0.0942	1.0468	0.0046	0.0504	10.8530
1992	18.714	19.065	340	28206	19.633	16.308	0.0123	1.2265	0.0023	0.2064	89.7431
1993	19.633	16.308	1123	42446	20702	13.269	0.0220	1.2959	0.0051	0.2644	54.4015
1994	20.702	13.269	-	-	-	-	-	-	-	-	-

Notes: Estimates are based on numberf of fish≥ 70 cm in both the spring survey and commercial landings. Estimates are based on LOWESS smoothed survey values

tively. Chapman and Murphy (1965) demonstrated that the approximate instantaneous fishing mortality rates for types x and y animals can be estimated as:

$$F_x = \frac{r_1 \log_e(r_2)}{1 + 0.5 \log_e(r_2) - r_1} \quad (6)$$

and

$$F_y = F_x + \log_e(r_2) \quad (7)$$

where

$$r_1 = \frac{R_x Y_1}{R_y X_1} \quad (8)$$

and

$$r_2 = \frac{X_2 Y_1}{X_1 Y_2} \quad (9)$$

Chapman and Murphy (1965) also illustrated that F_x and F_y are insensitive to the rate of natural mortality over the range M = 0 to 0.4. It is also important to note that F_x and F_y depend only on the estimated ratios and not the absolute numbers. Thus removal ratios from the fishery are sufficient for estimation, even though the numbers removed are orders of magnitude greater than the numbers observed in the research vessel surveys.

Application of the change-in-ratio method to smoothed survey indices (Table D22) revealed a marked increase in fishing mortality rates (F) on females since 1989. Estimates of F on females increased 17-fold from 0.016 in 1989 to 0.264 in 1993. In contrast, estimates of F on males were negligible. This increase in F agrees well with the observed increase in landings. It should be noted that these estimates of F are independent of the magnitude of the catches in this period. The Chapman-Murphy model applies to open populations. Slightly negative estimates of F in some years in Table D22 suggest changes due to either sampling error or recruitment into the 70 cm length category.

The estimates of F obtained from this application of the change-in-ratio method must be viewed with some uncertainty. The sex ratios used may not be representative of the actual catches. The length frequency samples used to characterize the sex ratio of the catches were only from U.S. commercial landings and are not fully applicable to the discards that contain a higher proportion of males than the landed catch (Table D13). In addition, the available samples of landings may not necessarily be representative of landings from all areas. Furthermore, the spring survey proportion of female dogfish per tow, which exhibits considerable year-to-year variability, dropped sharply from 1993 to 1994. The LOWESS smoothed survey number-per- tow values for those years decreased as well and sharply increased the estimates of F for 1992 and 1993. Nevertheless, in spite of these sources of error, it is evident that fishing mortality on mature females appears to have increased markedly in recent years. Fishing mortality estimates from the biomass dynamics model (Table D20) differ in magnitude but exhibit the same trend since 1990. This concentration of mortality on the spawning stock has important long-term consequences for population growth rates (see section on Mechanistic Models, page 127).

Decomposition of Population Growth Rate

The observed increases in total biomass (B_t) of spiny dogfish are the result of changes in both numbers of fish (N_t) and average weight per individual (w_t) in the population. To determine the relative importance of these processes, an empirical approach for decomposing the rate of change in B_t into rates of change N_t and w_t over time was examined (Rago *et al.*, 1994). Minimum swept-area estimates (see section on Swept-Area Method, page 118) were analyzed. Since the minimum swept-area estimates simply represent a scaler multiplier of the average total weight per tow, this variable, average number per tow, and average mean weight per fish per tow were used as surrogates for B_t, N_t, and w_t, respectively.

Estimates of average weight per tow, average number per tow, and average weight per fish per tow were examined for the NEFSC spring survey data for the 36-79 cm and 80 cm size classes. LOWESS smoothing was used to identify appropriate time periods over which the variables appeared to be linear. Both size groups were arbitrarily divided into two time periods: 1968-1979 and 1980-1994. Regression estimates of percentage changes for B_t, N_t, and w_t versus year are summarized here (note that the percentage change in B_t does not necessarily equal the sum of the percentage changes in N_t and w_t):

Size class (cm)	Period (yr)	Variable Name	Percentage Change	P
36-79	1968-79	B_t	0	0.980
		N_t	-1	0.862
		w_t	-1	0.570
	1980-94	B_t	+9	0.007
		N_t	+9	0.002
		w_t	0	0.842
80	1968-79	B_t	+7	0.261
		N_t	+5	0.402
		w_t	+1	0.000
	1980-94	B_t	+1	0.784
		N_t	+3	0.339
		w_t	-2	0.003

Results suggest that increases in the 36-79 cm range since 1980 have been driven primarily by significant increases in numbers of recruits rather than changes in mean weights. The continuing increase in the 36-79 cm range may reflect higher levels of recruitment during the late 1970s and early 1980s. The 80 cm size group represents ages ranging from 10 to 50 years. Therefore, changes associated with recruitment to the size range are expected to be small and occur slowly. Variation in individual year classes would be damped by the large number of year classes present. Under these conditions, changes in average weight per fish potentially have much greater influence. Regression analyses of the unsmoothed data suggest that the biomass in the 80 cm group increased at about 7% per year prior to 1980 and was driven by both increases in numbers and a statistically significant increase in average weight per fish of about 1% per year. Since 1980, the biomass growth rate has declined to less than 1% per year. The rate of numerical increase has been halved and more importantly, the average size has been declining at a rate of about 2% per year. The decreasing average size is consistent with increased removals from the fishery and could also be related to density-dependent growth responses. These alternative hypotheses should be investigated further.

Estimates of Spawning Stock and Recruits

Spawning stock and recruitment were examined *via* analysis of the NEFSC spring research vessel survey data. The number of spawners was approximated as the number of dogfish 80 cm, corresponding to the predicted length at 50% maturity for females (Silva 1993). In most years since 1980, this size range consisted of more than 75% females; prior to 1980, survey catches of dogfish were not sexed. The 80 cm size group permitted an investigation of the entire spring time series since 1968. Using the von Bertalanffy growth model (Rago *et al.* 1994), 80 cm corresponds to 10.5 yr and older for females. Recruits were defined as all dogfish 35 cm. For male dogfish, this corresponds to a predicted age of 1.11 yr; for females, the predicted age is 1.04 yr.

Total numbers of spawners show an overall upward trend since 1968 (Figure D30) with an apparent threefold increase during the period. About 10-15 mature fish per tow have been taken since 1987. The number of recruits per tow exhibits no consistent trend, although estimates appear to have become more variable since 1981.

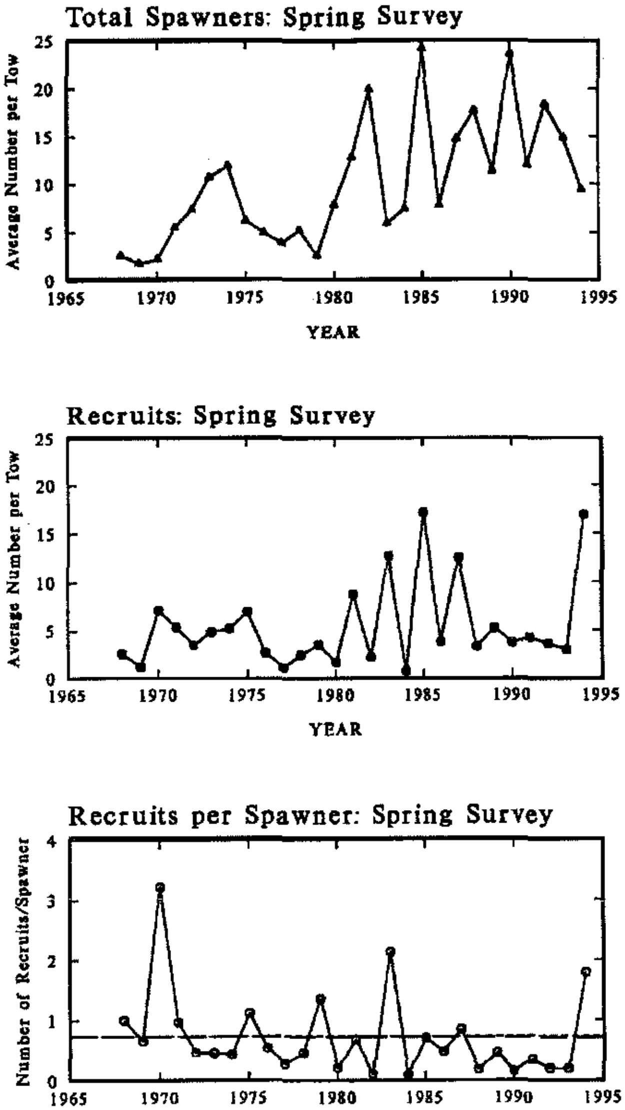

Figure D30. Number of potential spawners (*i.e.* spiny dogfish ≥ 80 cm, top), recruits (≤35 cm, middle), and recruits per spwaner (bottom) from NEFSC spring surveys. Dashed line in the bottom panel represents the predicted ratio of recruits to spawners (=0.73) from the mechanistic model.

Numbers of recruits per tow are in the same range as the number of spawners, and recruits per spawner vary from 0.1 to 3. LOWESS smoothing of the recruits per spawner (not shown) suggested a gradual decline since 1968, but a linear regression of the ratio versus time was not statistically significant ($P = 0.18$).

It is particularly interesting to note that the expected number of recruits per spawner (0.73, dashed line in bottom panel of Figure D30) predicted by the mechanistic model (Rago *et al.* 1994) used later in the report, is close to the observed ratio since 1968. The length model computes the equilibrium length frequency of the population, given estimates of population growth rate and fishing mortality.

Low fecundity and longevity of dogfish suggest that interannual variations in recruitment should be small relative to most teleosts. Moreover, annual pup production should be proportional to the number of spawners. Temporal variations should be related primarily to incomplete vulnerability to the survey gear and sampling variability. These deductions from life history theory are supported by the observed patterns in the spring survey. The observed range of recruits per spawners is relatively small (0.1 to 3) and agrees well with the independent predictions of the mechanistic life history model (Rago et al. 1994). The implications for future fisheries management are clear: "strong" year classes are infrequent in dogfish and would be unlikely to permit rapid recovery of the stock if overfishing occurred.

Mechanistic Models

Difficulties in aging, sexual dimorphism, and mammalian-like reproduction are some of the important aspects of spiny dogfish biology relevant to the derivation of biological reference points. The size- and sex-specific nature of the contemporary U.S. fishery present further difficulties. In spite of these apparent constraints on population growth, the spiny dogfish stock has increased greatly in the last 20 years. A model allowing insights into potential mechanisms and derivation of testable hypotheses is highly desirable as the scientific basis of future fishery management decisions.

A general model of dogfish life history was developed by Rago *et al.* (1994). The model incorporates literature-based life history parameters into a size- and sex-structured equilibrium model. The model was calibrated using empirically derived values of sex-specific fishing mortality and the finite rate of population increase (see section on Empirical Estimates of Survival, Growth, and Recruitment, page 123).

Model Description

The von Bertalanffy growth equation was used to estimate the length at age for dogfish. Parameters used were those estimated by Nammack et al. (1985) and revised by Silva (1993) for male and female spiny dogfish (Table D23, Figure D31). By inverting this equation, it

Table D23. Summary of population parameters related to growth, survival, and reproduction of spiny dogfish

Symbol	Parameter Name	Sex	Value	Reference
L	Maximum length	F	105	Approx 95th percentile of catch and survey data
		M	81.32	Nammack *et al.*, 1985
K_∞	von Bertalanffy equation	F M	0.1128 0.1578	" "
t_o	Age at length = 0, von Bertalanffy eqn.	F M	-2.552 -2.4523	" "
M	Instantaneous natural mortality rate	B	0.092	1% population at 50 yrs
F	Instantaneous fishing mortality rate	B	0.04	Change in ratio estimator
L_{crit}	Minimum size length in fishery	B	84 cm	Commercial landings
a	Maturation parameter, intercept	F M	-46.9 -59.8	Silva, 1993 "
b	Maturation parameter, slope	F M	0.582 0.999	" "
$t_{gestation}$	Gestation time (yr)	F	2	Templeman, 1944
λ	Estimated finite rate of population increase	B	1.044	Survey data
litter $size_{Lj}$	Number of large embyos per female of length class j	F	80-85 cm 3.86 86-90 cm 5.03 91-95cm 6.07 96-100cm 7.00 101-105cm 8.33 106+ cm 9.50	Silva, 1993
	Sex ratio at birth	B	50:50	Templeman, 1944
a,b	Length-weight regression $W = aL^b$	F M	$W = e^{15.025}L^{3.606935}$ $W = e^{-13.002}L^{3.097787}$	Reparameterization of Nammack *et al.*, 1985 "

was possible to express age as a function of length. Expected length frequency distributions by sex were obtained by solving for age as a function of length and integrating the number over the age interval corresponding to a given length interval. Fishing mortality was implemented using knife-edge recruitment. The minimum length at entry to the fishery was set at 84 cm, which corresponded approximately to the 5th percentile of the observed length frequencies in the commercial landings. A simple illustration of the predicted length frequency distributions by sex for a minimum size limit of 75 cm, F = 0.04, and M = 0.092 is shown in Figure D32. The predicted sex ratio (*i.e.*, proportion females) for two alternative fishing mortality rates is depicted in Figure D28. The observed proportion of female spiny dogfish from NEFSC spring surveys in 1982 and 1992 are presented in Figure D29. Reproduction rates for a fixed length class were estimated using a similar approach. The average rate of reproduction, defined as the annual number of pups surviving to a 30 cm minimum size, was expressed as a function of the fraction pregnant within a given length interval, the gestation time, the fraction of females in the length class,

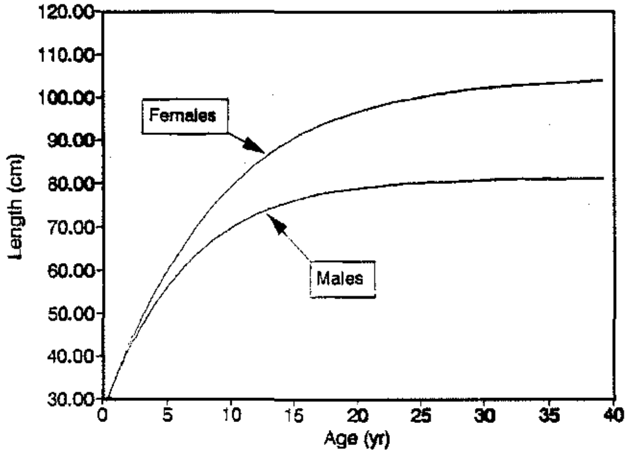

Figure D31. The von Bertalanffy growth equations for male and female spiny dogfish.

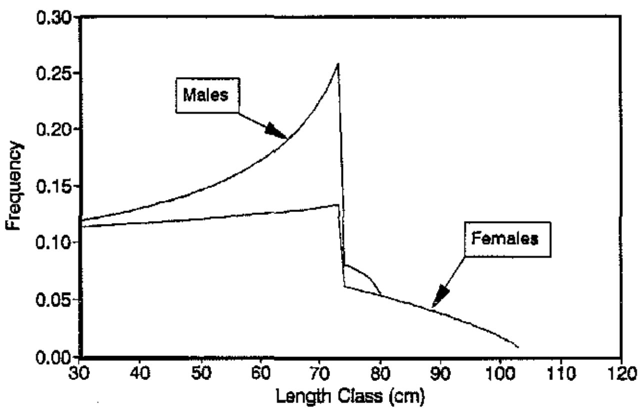

Figure D32. Predicted length frequency distributions of male and female spiny dogfish based on equilibrium model with M=0.092, F=0.09; and L_{crit} =75 cm.

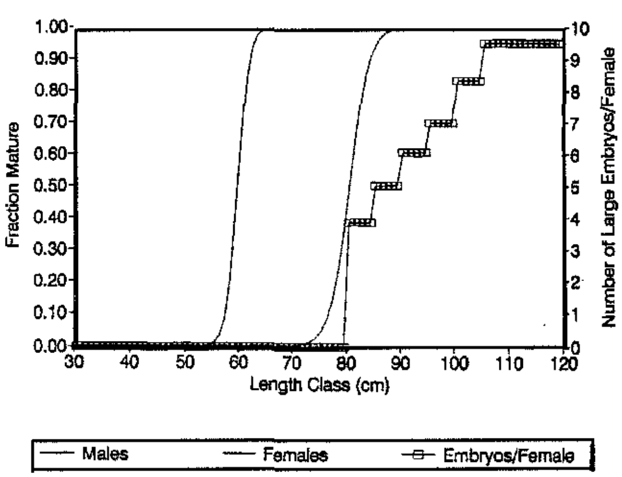

Figure D33. Predicted fraction mature for male and female spiny dogfish and number of large embryos per females vs length.

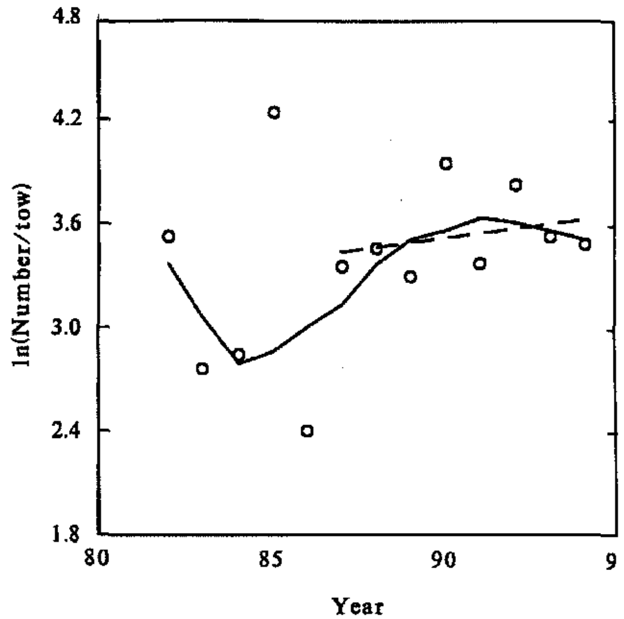

Figure D34. Estimated finite rate of increase for spiny dogfish ≥70 cm. The solid line represents the LOWESS smoothed (tension = 0.5) estimates of $\log_e$ average total number per tow of dogfish ≥70 cm from the NEFSC spring survey, 1982-1994. The dashed line represents the linear regression of $\log_e$ N/tow vs year for 1987-1994; Y = 0.46 + 0.044 X, r^2 = 0.44, P = 0.075.

the average number of embryo pups present, and the probability surviving from the large embryo stage to 30 cm. Parameters for this purpose were taken from Silva (1993). The average litter size for females in a given size interval was approximated as a step function and ranged from 4 to 9 pups per female (Figure D33). The average survival rate from pup to recruit was estimated indirectly using a modification of the method of Vaughan and Saila (1976).

Model Calibration

In order to apply the life history model, it was necessary to calibrate it to contemporary stock status. Two measures of stock status were required: total population rate of change and fishing mortality (F). Linear regression of LOWESS smoothed values of spring survey abundance for dogfish 70 cm (Figure D34) versus year suggests a slight rate of increase in the population since 1987. This overall rate of increase appears to be fueled by a steady increase in the number of males. Females, in contrast, appear to have peaked in 1991 with an average of 20 dogfish per

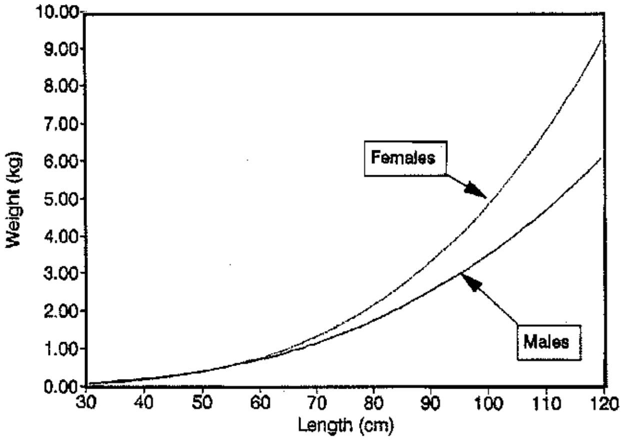

Figure D35. Weight *vs.* length regression for spiny dogfish.

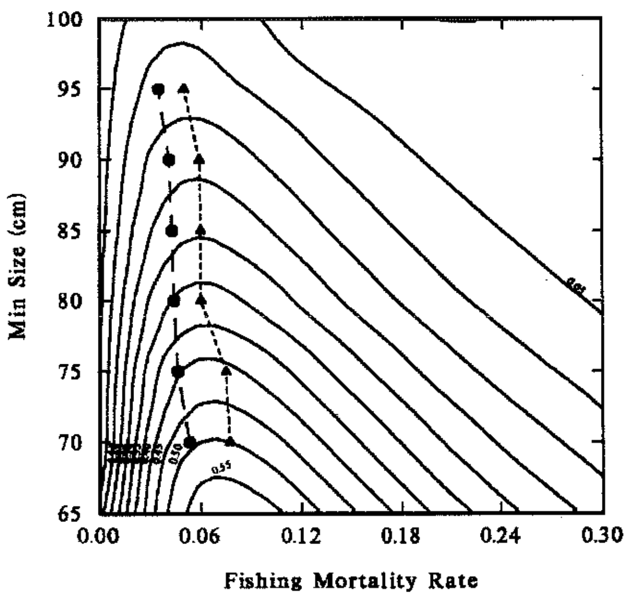

Figure D36. Yield per recruit isopleths (kilograms) for spiny dogfish as a function of fishing mortality and minimum size at entry to the fishery. The triangles represent F_{max}; the circles represent $F_{0.1}$.

tow. Estimates for 1994 of 13.3 females per tow are comparable to values observed in the early 1980s.

The average F on females since 1986, based on the estimates in Table D22, was 0.09. Given the rate of population increase shown in Figure D34 and an average F of 0.09, the probability of a female pup surviving from the large embryo stage to 30 cm would be 0.34.

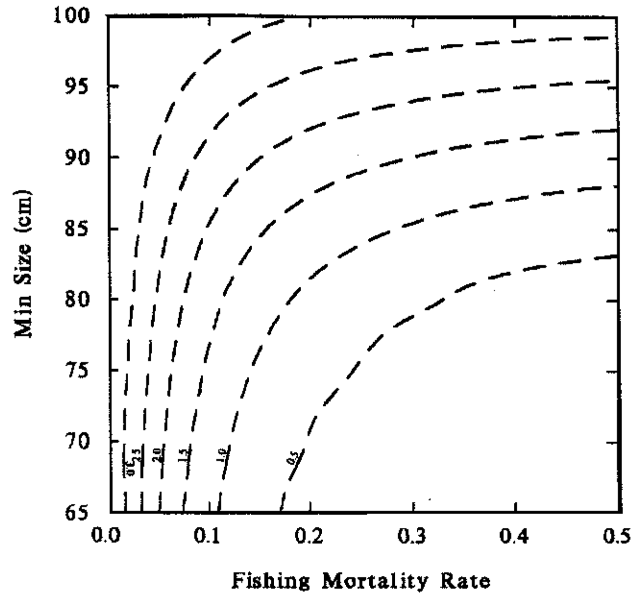

Figure D37. Number of female pups per recruit (PPR) for spiny dogfish as a function of fishing mortality and minimum size at entry to the fishery.

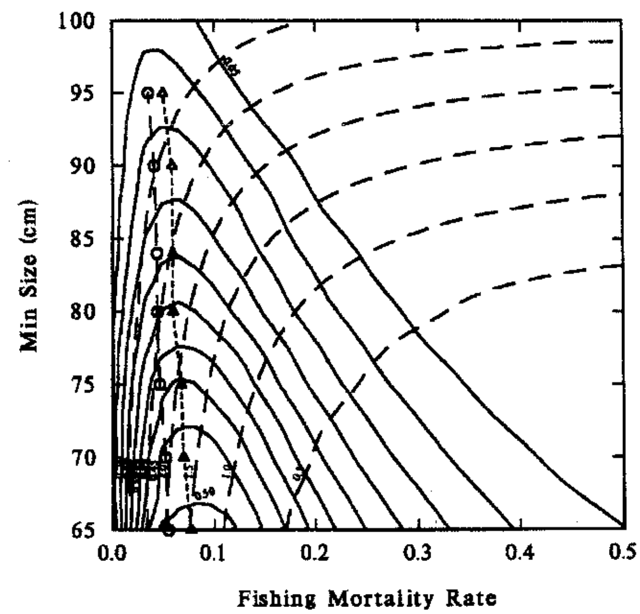

Figure D38. Superposition of yield per recruit (solid lines) and female pups per recruit (dashed line) as function of fishing mortality and minimum size at entry to the fishery. Triangles represent F_{max}; the circles represent $F_{0.1}$.

Yield Per Recruit

Yield per recruit (YPR) was estimated for the sex- and size-structured model as the sum of separate yield equations for males and females. The standard yield equation was modified to account for the duration of the age interval corresponding to a unit length increment. Parameters for the length-weight regression used in the YPR analysis were obtained by reformulation of the equations reported by Nammack (1982) (Table D23, Figure D35). Yield isopleths (kilograms/recruit) for combined sexes of spiny dogfish are depicted in Figure D36. The greatest YPR, up to 0.55 kg/recruit, occurs at 67 cm and an F of 0.07. The more conservative $F_{0.1}$ criterion changes little with respect to minimum length in the fishery and is below 0.05 for all minimum lengths examined. It is important to note the increment in F_{max} that occurs at minimum lengths <80 cm. This increment results from the inclusion of males (L = 80.3 cm) into the expected yield.

Pups Per Recruit

The expected number of female pups per recruited female dogfish over its lifespan (PPR) is equivalent to the net reproductive rate when the rate of population change equals 1. As in the case of YPR, pups per recruit were computed for various combinations of F and minimum sizes. The resulting isopleths (Figure D37) can be used to define a domain of feasible parameter combinations that will ensure population stability. For example, points interior (*i.e.*, below and to the right) to the PPR = 1.0 isopleth would result in a gradual decline in population abundance. Results suggest that recruitment overfishing could occur at Fs as low as 0.08 when the minimum size is 65 cm. These computations of course do not incorporate potential density-dependent responses to exploitation. Exploration of the potential effects of compensatory responses would have to be investigated.

The yield and pup-per-recruit analyses can be combined to define rates of harvest that ensure maximum yield while simultaneously ensuring sustainability of the resource. Superposition of the YPR and PPR isopleths (Figure D38) suggests that minimum sizes lower than 75 cm would probably result in population decline. Uncertainty in the estimation of such low levels of F would make it difficult to determine whether recruitment overfishing was occurring. Given the long life span of dogfish, the implications of recruitment overfishing would take many years to be recognized. The point estimate of F in 1993 of 0.26 for females and minimum size landed of 84 cm suggests a PPR of about 1 and a YPR of less than 0.05 kg. At an 84 cm minimum size, the maximum F that would ensure replacement recruitment is about 0.25. Sea sampling data indicate a large quantity of discarded catch significantly below 84 cm. This implies that at the current level of F on females, the stock is at or possibly below a biological reference point that would allow recruitment replacement.

DISCUSSION

Since the late 1960s, the Northwest Atlantic stock of spiny dogfish has increased in abundance more than threefold. Following passage of the Magnuson Act and extension of the U.S. exclusive economic zone in 1977, landings dropped dramatically due to the exclusion of foreign vessels from U.S. waters. As more valuable groundfish stocks have declined, directed fishing for dogfish has resulted in a nearly fourfold increase in landings in the last six years. Landings now approach levels reported prior to 1976 (*e.g.*, 25,000 mt). In addition, the discarded catch, depending on what percentage of the discards actually suffer mortality, are at least two-thirds the level of and possibly equivalent to or higher than the current reported landings. Therefore, the total catch in 1993 was probably at least 36,000 mt and possibly as high or higher than 50,000 mt.

Data and analyses presented in this report indicate that the spiny dogfish stock in the Northwest Atlantic is stable at best and has possibly begun to decline as a consequence of the recent increase in exploitation. United States commercial fishery LPUE indices (otter trawl and sink gill net) all exhibit declines since 1990. Research vessel survey data document a steady increase in both abundance and biomass since the early 1970s, but total biomass indices in the last several years and abundance indices of large fish (*i.e.*, females 80 cm, which constitute the bulk of the fishery landings) show no evidence of increase. Length-frequency data from both the U.S. commercial landings and research vessel survey catches indicate a decrease in average length of females in recent years.

Swept-area estimates of the fishable biomass (defined as 80 cm fish) increased threefold from 1968 to 1988 and have since declined by over 10% to an estimated 258,000 mt in 1994, but the estimated biomass of 80 cm females has declined since 1990 even more sharply as a result of their being targeted by the fishery.

Results from a biomass dynamics model assuming catches equivalent to total reported landings indicated a total biomass of 1.1 million mt and an F of 0.021 in 1993, and a recruited or fishable biomass of 524,000 mt and an F of 0.044. The MSY was estimated to be 56,000 mt with F_{msy} = 0.18 for the total stock, and 30,000 mt with F_{msy} = 0.18 for the recruited stock. This F_{msy} value is considerably higher than F_{max}, and should thus be viewed with caution, particularly given the longevity and slower growth rate of the species. These results are most sensitive to changes in the catchability parameter used in the model. In contrast, estimates of F from a change-in-sex-ratio method indicated an increase in F on females from 0.016 in 1989 to 0.264 in 1993.

The swept-area method applied to NEFSC spring trawl survey catch per tow indices produced estimates of fishable biomass about half as large as those from the surplus production (biomass dynamics) approach. The estimates produced by both methods are likely to be biased, with the swept-area method underestimating stock biomass (to an unknown degree) and the biomass dynamics model being sensitive to a variety of input data, including estimates of the catches and of catchability. These estimates are not independent, as both are derived from trends in spring survey indices.

Estimates of fishing mortality on fully-recruited females in 1993 range from 0.044 (biomass dynamics model - BD) to 0.264 (change-in-ratio method - CIR). The CIR estimate was based on the numerical change in NEFSC survey sex ratios following removals by the fishery and mortality was partitioned into male and female components for fish 70 cm. The BD estimate was based on pooled males and females 80 cm and biomass estimates from the survey and fishery. Fishing mortality scales directly with total catch (*i.e.*, landings plus discards) for the BD estimate, but not for the CIR estimate. Uncertainty in the biomass estimate is denoted in Figure D39 by the vertical lines indicating the minimum swept-area biomass estimate and the upper bound of the biomass dynamics estimate of B [= U/(0.6 q)]. The horizontal line corresponds to the total catch (landings plus discard) estimate for 1993 (36,000 mt). Figure D39 suggests that the range of feasible estimates for F from the biomass dynamics model is from about 0.044 to 0.15. For the CIR estimate of F (0.26) to be feasible, the total catch would have to be about triple the reported landings in 1993 or about 67,000 mt (*i.e.*, discards twice the level of reported landings) and with a biomass estimate corresponding to the minimum swept-area value. If the actual biomass were higher than that estimated by the swept-area method, an F of 0.26 would imply discard levels even greater than double the reported landings.

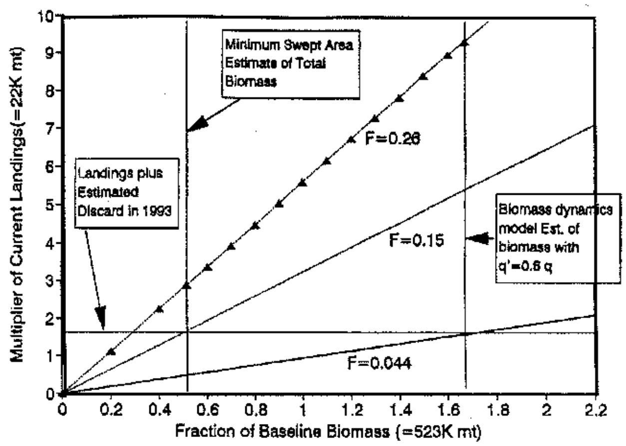

Figure D39. Effect of changes in landings and baseline biomass estimates on the derived rate of fishing mortality.

With an F of 0.26 and assuming a minimum length at entry to the fishery of 84 cm, the estimated number of pups per recruit is about 1, with a yield per recruit of less than 0.05 kg. Maximum yield per recruit (0.55 kg) occurs at an F of about 0.07 and a minimum size of 67 cm. Yield per recruit decreases with increasing minimum sizes, owing to the very slow growth rate at these ages. However, since reproduction in females occurs primarily in animals 80 cm, fishing mortality rates in excess of 0.1 on animals >80 cm results in negative female pup replacement. At an 84-cm minimum size, the maximum F that would ensure replacement recruitment is about 0.25. However, based on sea sampling, it is apparent that a substantial amount of fishing mortality also occurs on dogfish as small as 50 cm. Consequently, the minimum size at entry to the fishery is less than 84 cm, as assumed in the analyses presented in this report. Thus, it is even more likely that current fishing mortality is at a level which will result in negative replacement. Under these conditions, the stock will eventually decline.

Considerable uncertainty still exists in a number of critical data and parameters important for assessing and managing the spiny dogfish stock. Current estimates of fishing mortality are based on two very different approaches, giving similar trends of increase in recent years, but differing in level. Point estimates for the two methods probably bracket the actual fishing mortality rate on the stock. Estimates of total catch, accounting for all sources of potential catch and discard, and a more comprehensive characterization of the length and sex composition of the total catch are also uncertain. In spite of these uncertainties, the information presented in this report suggests that the stock may be fully utilized with respect to the level of fishing mortality and that the mature female component of the stock has not increased in recent years. A protracted period of harvesting at current levels would still be required to reduce the total biomass to levels observed in the 1970s. However, since the fishery is concentrated on mature females, such a strategy may well result in reduced long-term recruitment.

Spiny dogfish are important predators of commercially important fish species. Bowman *et al.* (1984) reported that the dominant component of the diet of spiny dogfish greater than 60 cm TL comprised several species of herring, Atlantic mackeral, redfish, Atlantic cod, haddock, silver hake, red hake, spotted hake, and sandlance. Squid were also a major component of the diet. It was concluded that predation mortality by spiny dogfish is a significant source of mortality on commercially valuable species. Preliminary calculations indicated that the biomass of commercially important species consumed by spiny dogfish was comparable to the amount harvested by man. Accordingly, the impact of spiny dogfish consumption on other species should be considered in establishing harvesting policies for this species.

A management program should be instituted expeditiously for this species and appropriate management targets for stock biomass and fishing mortality rates should be established. The present prominence of this species in the Northwest Atlantic multispecies ecosystem, several lines of evidence demonstrating fishing mortality effects, and little understanding of its impact on other important fish species, constitute strong justification for prompt management action. Furthermore, given the evidence for a single unit stock of spiny dogfish in the Northwest Atlantic, joint assessment and management of this stock by the U.S. and Canada should be considered.

RESEARCH RECOMMENDATIONS

1. Aging data are necessary to determine maximum age, revision of length at age, and possibly for development of an age-structured model with transition probabilities.

2. Determine maturation and fecundity rates by length class.

3. Update length-weight equation.

4. Examine migration patterns by sex from survey data.

5. Improve sea sampling coverage to estimate discards.

6. Obtain estimates of discard mortality in both the commercial (by gear and area) and recreational fisheries.

7. Audit historical survey data and make results available to determine sex compositions of spiny dogfish catches and to make any corrections that may arise in indices.

8. Explore the use of LPUE as an indicator of spiny dogfish abundance.

9. Explore the use of jack-knifing of survey indices.

10. Develop measures of risk associated with alternative fishery management procedures.

11. Investigate alternative methods for estimating mortality, including length-based methods and the incorporation of additional survey data into the change-in-ratio method.

12. Update information on distribution and dispersal patterns.

13. Investigate the impact of using longer time delays in the biomass dynamics model applied to spiny dogfish.

14. Conduct retrospective studies to evaluate population mechanisms that led to the rapid growth of the spiny dogfish stock in the late 1970s and 1980s.

15. Investigate the role of temperature as an explanatory variable for survey abundance estimates.

16. Evaluate available food and feeding information for spiny dogfish to aid in determining the ecological impact of high dogfish stock sizes.

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E. GEORGES BANK YELLOWTAIL FLOUNDER

Terms of Reference

The Steering Committee set the following terms of reference to be addressed at SARC/SAW 18:

a. Assess the status of Georges Bank yellowtail flounder through 1993 and characterize the variability of stock abundance and fishing mortality rates.

b. Provide 1994 projected estimates of catch and 1995 SSB options at various levels of F.

The Southern Demersal Subcommittee met in Woods Hole, MA, 9-13 May 1994 to address these terms of reference.

INTRODUCTION

A unit stock of Georges Bank yellowtail flounder extending eastward of the Great South Channel along the bank has been defined based on results of tagging experiments and studies (Royce *et al.* 1959; Lux 1963). Some intermixing occurs with stocks off Southern New England and off Cape Cod (*ibid.*). The stock distribution is represented by U.S. Statistical Reporting Areas 522, 525, and 561-562 and Northeast Fisheries Science Center (NEFSC) offshore bottom trawl survey strata 13-21.

Given the wide variations in yellowtail flounder catch and its importance as a food fish, fishery managers have struggled over the past two decades to develop adequate fishery regulations. Yellowtail flounder were managed under the International Commission for Northwest Atlantic Fisheries (ICNAF) with nationally-allocated catch quotas from 1971 to 1976. With the implementation of the Magnuson Fishery Conservation and Management Act in 1976, yellowtail flounder were managed under the New England Fishery Management Council's Fishery Management Plan for Atlantic Groundfish from 1977-1982. This complex plan regulated minimum cod end meshes on trawls, defined spawning area closures, and imposed trip limits and mandatory reporting. These measures were difficult to enforce and in aggregate, ineffective.

From September 1982 to September 1986, the species was managed under the Interim Plan, which included a minimum possession size of 28 cm (11 in.). The Interim Plan made reporting voluntary and defined "large mesh (5-1/8 inch stretch mesh)" fishing areas. Under the plan, small mesh fisheries were permitted within the large mesh areas. These measures also failed to arrest the decline of yellowtail flounder.

The New England Multispecies Fisheries Management Plan (FMP) of September 1986 imposed minimum sizes of 30 cm (12 in.), increased the minimum mesh size to 5-1/2 inches, and required seasonal area closures west of 69° 40" longitude. Amendment 5 of this plan later revised the minimum size to 33 cm (13 in.) in September 1989.

LANDINGS DATA

Landings of yellowtail flounder from Georges Bank increased from negligible levels in the mid-1930s to average 6500 mt in 1948-1949 (Table 2 in Sissenwine *et al.*, 1978). By 1955, landings declined to 1600 mt. Some recovery was observed by the 1960s, and estimated landings from the stock peaked at 18,300 mt in 1969 (Table E1, Table 1 in Clark *et al.*, 1985), including a foreign fishery that also harvested the stock between 1965-1976. Landings averaged 15,600 mt between 1968-74 but declined to 4500 mt by 1978. A brief increase to an average of 11,000 mt in 1982-83 was short-lived, with landings declining to 1100 mt in 1989, the lowest level since 1946.

In 1992, total commercial landings were 2,800 mt, 1000 mt above the 1991 level, due to recruitment of the 1990 year class. In 1993, total commercial landings declined to 2100 mt, obtained from the remains of the 1989-1990 year classes. There is no recreational fishery for this stock.

A landings-at-age matrix (Table E2) was developed from quarterly length samples and age-length keys from the commercial fishery as de-

Table E1. Commercial landings of yellowtail flounder (thousands of metric tons) from Southern New England (U.S. Statistical Reporting Areas 526, 537-539) and Georges Bank (Areas 522-525, 561-562), 1960 - 1993, as reported by NEFSC weighout, state bulletin and canvas data (U.S.) and by ICNAF/NAFO or estimated by Brown and Hennemuth 1971 (foreign [For.]).

	Southern New England			Georges Bank		
Year	U.S.	For.	Total	U.S.	For.	Total
1960	8.3	-	8.3	4.4	-	4.4
1961	12.3	-	12.3	4.2	-	4.2
1962	13.3	-	13.3	7.7	-	7.7
1963	22.3	0.2	22.5	11.0	0.1	11.1
1964	19.5	-	19.5	14.9	-	14.9
1965	19.4	1.4	20.8	14.2	0.8	15.0
1966	17.6	0.7	18.3	11.3	0.3	11.6
1967	15.3	2.8	18.1	8.4	1.4	9.8
1968	18.2	3.5	21.7	12.8	1.8	14.6
1969	15.6	17.6	33.2	15.9	2.4	18.3
1970	15.2	2.5	17.7	15.5	0.3	15.8
1971	8.6	0.3	8.9	11.9	0.5	12.4
1972	8.5	3.0	11.5	14.2	2.2	16.4
1973	7.2	0.2	7.4	15.9	0.3	16.2
1974	6.4	0.1	6.5	14.6	1.0	15.6
1975	3.2	-	3.2	13.2	0.1	13.3
1976	1.6	<0.1	1.6	11.3	<0.1	11.3
1977	2.8	<0.1	2.8	9.4	-	9.4
1978	2.3	-	2.3	4.5	<0.1	4.5
1979	5.3	-	5.3	5.5	<0.1	5.5
1980	6.0	-	6.0	6.5	<0.1	6.5
1981	4.7	-	4.7	6.2	<0.1	6.2
1982	10.3	-	10.3	10.6	<0.1	10.6
1983	17.0	-	17.0	11.3	<0.1	11.3
1984	7.9	-	7.9	5.8	<0.1	5.8
1985	2.7	-	2.7	2.5	<0.1	2.5
1986	3.3	-	3.3	3.0	<0.1	3.0
1987	1.6	-	1.6	2.7	-	2.7
1988	0.9	-	0.9	1.9	-	1.9
1989	2.5	-	2.5	1.1	-	1.1
1990	8.0	-	8.0	2.7	-	2.7
1991	3.9	-	3.9	1.8	-	1.8
1992	1.4	-	1.4	2.8	-	2.8
1993	0.5	-	0.5	2.1	-	2.1

scribed in Conser *et al.* (1991). Average weights at age in the landings (Table E3) were estimated from the age-specific length frequencies and a length-weight regression.

DISCARD DATA

Discarding of undersized fish has long been recognized as a problem in the yellowtail flounder fishery (*e.g.*, Royce *et al.* 1959). Information on discarding is available from a number of sources but the quality and quantity of information varies widely. For the period 1973 to 1992, age-specific discard rates were estimated from three sources: interviewed trips, research surveys, and sea sampling. The advantages, limitations, and computational details of each of these sources are described in Rago *et al.* 1994. In principle, actual observations of discard rates from observers on commercial vessels provide the best empirical data. But in recent years, spatial, temporal, and vessel size coverage of the Georges Bank otter trawl fishery has been limited. For example, in 1991, only two sea sampling trips were made (in a single quarter), which measured 49 fish discarded. In 1992, only two quarters were sampled and discard was characterized by 108 measured fish from a single trip.

Models for Age-Specific Retention

A wide variety of methodologies were employed to estimate numbers of yellowtail flounder discarded by age group. In many instances the estimates fluctuated widely by year and quarter within year. Such fluctuations include sampling variability and process error (or alternatively, model misspecification). To reduce these effects of this variation, Conser *et al.* (1991) used nonlinear least squares to fit a cumulative logistic function to estimated discard fractions by age class for a given year class. The cumulative logistic function has several attractive properties for smoothing discard data. First, it is bounded by zero and one, as are the observed input data. Second, the function is monotonically increasing, thereby modeling the general tendency of fisheries to become increasingly efficient at capturing older and larger fish. Finally, the parameters correspond to easily interpreted concepts of 50% retention and the rate of increase in retention with age.

The general logistic model for retention can be written as:

$$R = 1 - \frac{1}{1 + exp\left(-\frac{K_{50} - Age}{a}\right)} \qquad (1)$$

where R is fraction of catch retained, K_{50} is the age at 50% retention, a is the slope of the regression and Age is the age group.

Table E2. Commercial landings at age of yellowtail flounder (thousands), Georges Bank (U.S. Statistical Reporting Areas 522-525, 561-562), 1973-1993

Year	**Age**								**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
1973	0	3837	13076	9274	3743	1259	278	81	31548
1974	180	6297	7818	7397	3544	852	452	173	26713
1975	427	16851	6943	3391	2084	671	313	164	30844
1976	43	19320	5085	1347	532	434	287	147	27195
1977	31	6616	9805	1721	394	221	129	124	19041
1978	0	2140	3970	1660	459	102	37	35	8403
1979	17	6804	3396	1242	550	141	79	52	12281
1980	0	2371	8696	1419	321	85	4	10	12906
1981	6	479	5267	4555	796	122	4	0	11229
1982	217	13132	7061	3245	1031	62	19	3	24770
1983	239	7667	16016	2316	625	109	10	8	26990
1984	244	1913	4266	4734	1592	257	47	17	13070
1985	371	3335	816	652	410	60	5	0	5649
1986	90	5733	978	347	161	52	16	8	7385
1987	15	1819	2730	761	132	39	32	41	5569
1988	0	1650	1181	624	165	15	20	3	3658
1989	0	1337	664	262	68	11	8	0	2350
1990	0	735	4582	738	105	17	3	0	6180
1991	0	27	867	2256	289	56	4	0	3498
1992	0	3183	1891	1176	502	20	7	0	6779
1993	0	375	1538	1392	287	65	4	1	3662

Table E3. Mean weight (kilograms) at age of yellowtail flounder in landings, Georges Bank, 1973-1993

Year	**Age**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1973	0.198	0.375	0.464	0.527	0.603	0.689	1.067	1.136
1974	0.200	0.378	0.500	0.609	0.680	0.725	0.906	1.249
1975	0.211	0.340	0.492	0.554	0.618	0.687	0.688	0.649
1976	0.185	0.339	0.545	0.636	0.741	0.814	0.852	0.866
1977	0.197	0.364	0.527	0.634	0.782	0.865	1.036	1.013
1978	0.182	0.337	0.513	0.684	0.793	0.899	0.930	0.948
1979	0.139	0.356	0.462	0.649	0.728	0.835	1.003	0.882
1980	0.138	0.354	0.495	0.656	0.813	1.054	1.256	1.214
1981	0.091	0.389	0.493	0.603	0.707	0.798	0.832	1.044
1982	0.213	0.313	0.487	0.650	0.748	1.052	1.024	1.311
1983	0.215	0.296	0.440	0.604	0.736	0.952	1.018	0.987
1984	0.208	0.240	0.378	0.500	0.642	0.738	0.944	1.047
1985	0.236	0.363	0.497	0.647	0.733	0.819	0.732	1.044
1986	0.234	0.343	0.540	0.664	0.823	0.864	0.956	1.140
1987	0.212	0.338	0.523	0.666	0.680	0.938	0.793	0.788
1988		0.351	0.557	0.688	0.855	1.054	0.873	1.385
1989		0.355	0.543	0.725	0.883	1.026	1.254	1.044
1990		0.337	0.419	0.588	0.699	0.807	1.230	1.044
1991		0.270	0.383	0.484	0.728	0.820	1.306	1.044
1992		0.341	0.381	0.528	0.648	1.203	1.125	1.044
1993		0.316	0.390	0.510	0.562	0.858	1.263	1.044

As in the assessment of Southern New England yellowtail flounder (Rago *et al.* 1994), Eq. 1 was applied to fishery years. Five major management periods may have affected discard:

1. 1973-1977: Limited regulation, including foreign fishing under ICNAF (1973-1976).
2. 1978-1982: Groundfish FMP (1977-1982), including mesh, area, trip limit and mandatory reporting requirements; data may be poor.
3. 1983-1986: Interim Plan, including 11" size limit, 5 1/8" mesh and a mixture of small and large mesh fisheries
4. 1989: Northeast Multispecies FMP, including 12" size limit, 5 1/2" mesh
5. 1990-1993: Amendment 4, including 13" size limit (September 1989).

To compare effects of management periods on estimates of K_{50} and a, the model was generalized as:

$$R = 1 - \frac{1}{1 + \exp\left(- \dfrac{K_{50} + \sum_{j=1}^{J} \beta_j X_j - Age}{a + \sum_{j=1}^{J} \gamma_j X_j} \right)} \qquad (2)$$

where C_j is a dummy variable (0,1) corresponding to period of interest; β and γ are parameters related to the period effect on K_{50} and a, respectively.

Models from nonlinear least square fitting procedures were judged on the basis of a) asymptotic confidence intervals of parameter estimates; b) modified C_p Mallow statistic; and c) residual patterns. The C_p Mallow statistic (Neter, *et al.* 1990) for the nonlinear model was approximated as:

$$C_p = \frac{SSB \text{ (reduced model with p parameters)}}{MSE \text{ (full model with } \mathbf{P} \text{ parameters)}} - (n - 2p) \qquad (3)$$

where $E(C_p) = P$, the number of parameters in the full model. If the estimate of $C_p < p$ (where p = number of parameters in the reduced model), then the model has greater precision and less bias than full model. The term (n-2p) is a "penalty" function for adding variables.

No difference was observed between models fitted for 1973-1977 and 1978-1982 periods (*i.e.*, the same parameters were estimated for both periods), so the two periods were pooled. Performance of other models in terms of the C_p Mallow and related statistics is summarized as follows:

Model	p	SSE_p	MSE_p	R^2	C_p	Variables: $+K_{50}$, a
1	8	5.401	.027	.817	9.00	$\beta_2\beta_3\beta_4\gamma_2\gamma_3\gamma_4$
2	7	5.410	.027	.817	7.370	$\beta_2\beta_3\beta_4\gamma_2\gamma_4$
3	6	5.566	.028	.811	11.148	$\beta_2\beta_4\gamma_2\gamma_4$
4	5	5.750	.028	.805	15.960	$\beta_2\beta_4\gamma_4$
5	6	5.596	.028	.810	12.259	$\beta_2\beta_3\beta_4\gamma_4$
6	7	5.564	.028	.811	13.074	$\beta_2\beta_4\gamma_2\gamma_3$
7	4	7.288	.036	.753	70.920	$\beta_4\gamma_4$

Model 2 was adopted as the best model on the basis of the C_p Mallow statistic, indicating period-specific effects of management periods 3, 4, and 5 (above) on age at 50% retention and effects of management periods 3 and 5 on slope of the logistic function (Figures E1-E4).

The retention pattern appears to have changed systematically through the three periods from 1983-1992. Age at 50% retention trended upward, while the slope of the logistic function declined over the same timespan. Potential interaction between fishing mortality and growth rates should be investigated.

Commercial landings (Table E2) and discard at age (Table E4) were summed to provide a total catch-at-age matrix (Table E5). From 1989-1991, landings were dominated by the 1987 year class (Table E2). In 1992-1993, almost half the landings (47% and 42%, respectively) were contributed by the 1990 year class. Age 1 fish have been absent from landings since 1988, a circumstance that may have been reinforced by minimum size regulations implemented in 1989. It was felt that without landings, age 1 discards were poorly estimated in recent years, so subsequent analysis of catch at age data was restricted to ages 2 and older.

The age structure of the landings became more truncated during the 1970s. In 1973-1974, landings of fish age 6 and older averaged 1500 thousand annually (5.33% of total landings, average). Since 1980, fish aged 6 and older contributed an average of 0.98% of the landings, declining overall from an average of 150,000 between 1980-1984 to 39,000 between 1988-1992.

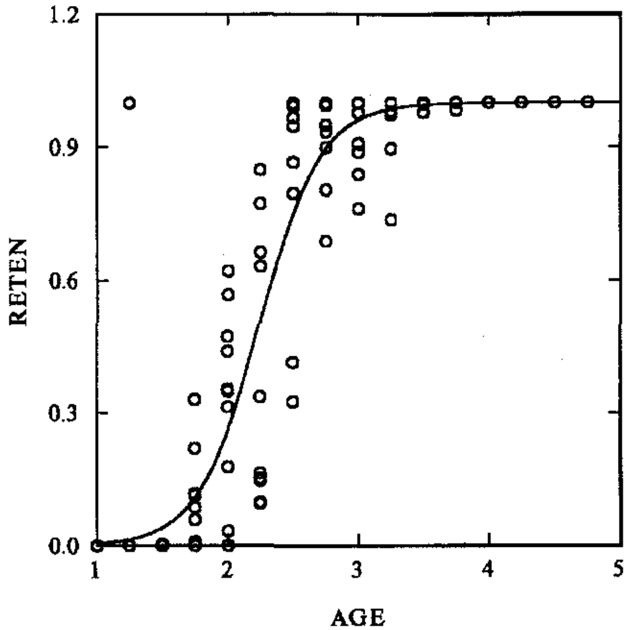

Figure E1. Observed age-specific retention rates and smoothed values for 1973-1982 for Georges Bank stock of yellowtail flounder. The solid line is the smoothed prediction from the nonlinear fit of the cumulative logistic distribution function.

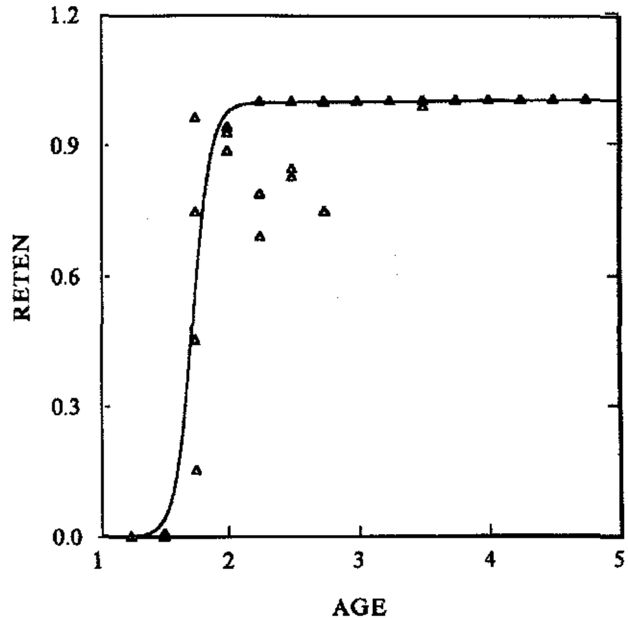

Figure E2. Observed age-specific retention rates and smoothed values for 1983-1986 for Georges Bank stock of yellowtail flounder. The solid line is the smoothed prediction from the nonlinear fit of the cumulative logistic distribution function.

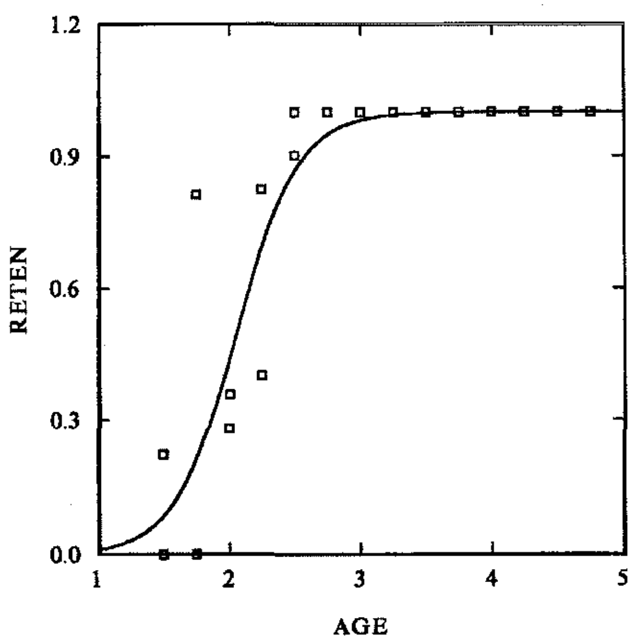

Figure E3. Observed age-specific retention rates and smoothed values for 1987-1989 for Georges Bank stock of yellowtail flounder. The solid line is the smoothed prediction from the nonlinear fit of the cumulative logistic distribution function.

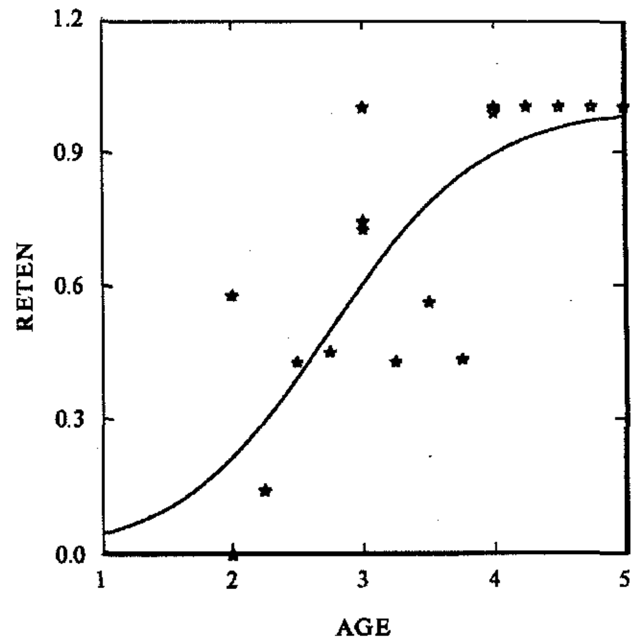

Figure E4. Observed age-specific retention rates and smoothed values for 1990-1992 for Georges Bank stock of yellowtail flounder. The solid line is the smoothed prediction from the nonlinear fit of the cumulative logistic distribution function.

Table E4. Estimated discard at age of yellowtail flounder (thousands), Georges Bank, 1973-1993

Year	Age								Total
	1	2	3	4	5	6	7	8	
1973	347	1053	167	2	0	0	0	0	1569
1974	1963	2674	86	1	0	0	0	0	4724
1975	3945	8433	114	1	0	0	0	0	12492
1976	572	11692	61	0	0	0	0	0	12325
1977	299	1964	112	0	0	0	0	0	2376
1978	9659	965	64	0	0	0	0	0	10689
1979	216	2701	49	0	0	0	0	0	2966
1980	309	1201	125	0	0	0	0	0	1636
1981	49	250	84	1	0	0	0	0	383
1982	1846	4359	61	1	0	0	0	0	6266
1983	457	22	0	0	0	0	0	0	479
1984	184	4	0	0	0	0	0	0	188
1985	279	10	0	0	0	0	0	0	290
1986	68	38	0	0	0	0	0	0	106
1987	125	834	21	0	0	0	0	0	980
1988	483	717	10	0	0	0	0	0	1211
1989	185	179	4	0	0	0	0	0	368
1990	219	1196	1541	62	2	0	0	0	3020
1991	412	27	355	174	4	0	0	0	972
1992	2389	5176	636	93	8	0	0	0	8302
1993	5189	549	512	99	4	0	0	0	6353

Table E5. Total catch at age of yellowtail flounder (thousands), Georges Bank, 1973-1993

Year	Age								Total
	1	2	3	4	5	6	7	8	
1973	347	4890	13243	9276	3743	1259	278	81	33117
1974	2143	8971	7904	7398	3544	852	452	173	31437
1975	4372	25284	7057	3392	2084	671	313	164	43336
1976	615	31012	5146	1347	532	434	287	147	39520
1977	330	8580	9917	1721	394	221	129	124	21417
1978	9659	3105	4034	1660	459	102	37	35	19092
1979	233	9505	3445	1242	550	141	79	52	15247
1980	309	3572	8821	1419	321	85	4	10	14542
1981	55	729	5351	4556	796	122	4	0	11612
1982	2063	17491	7122	3246	1031	62	19	3	31036
1983	696	7689	16016	2316	625	109	10	8	27469
1984	428	1917	4266	4734	1592	257	47	17	13258
1985	650	3345	816	652	410	60	5	0	5939
1986	158	5771	978	347	161	52	16	8	7491
1987	140	2653	2751	761	132	39	32	41	6549
1988	483	2367	1191	624	165	15	20	3	4869
1989	185	1516	668	262	68	11	8	0	2718
1990	219	1931	6123	800	107	17	3	0	9200
1991	412	54	1222	2429	294	56	4	0	4470
1992	2389	8359	2527	1269	509	20	7	0	15081
1993	5189	923	2050	1492	292	65	4	1	10015

STOCK ABUNDANCE INDICES

Survey abundance indices from NEFSC spring and autumn bottom trawl surveys were adjusted for the effects of different door, net, and vessel types over the survey time series, with multipliers of 1.22, 0.57 and 0.85, respectively:

Survey	Effect				Survey	Effect		
Spring	Door	Net	Vessel	None	Autumn	Door	Vessel	None
1968-72	X				1963-76[1]	X		
1973-80[1]	X	X			1977-81	X	X	
1981	X	X	X		1982-84	X		
1982	X		X		1985-86[2]		X	
1983-84	X				1987			X
1985-88[1]				X	1988[2]		X	
1989-91			X		1989-91		X	
1992-93				X	1992			X
					1993		X	

[1] Vessel change took place during cruise but didn't affect Georges Bank in 1973, 1976, 1977, 1979, 1980, 1987 (Spring); 1970, 1975 (Autumn).
[2] Vessel changes affected individual stations on Georges Bank.

Table E6. NEFSC spring trawl survey mean number per of Georges Bank yellowtail flounder per tow at age (NEFSC offshore strata 16, 19-21)

Year	Age								Total
	1	2	3	4	5	6	7	8	
1968	0.149	3.364	3.579	0.316	0.084	0.160	0.127	0.000	7.779
1969	1.015	9.406	11.119	3.096	1.423	0.454	0.188	0.057	26.758
1970	0.093	4.485	6.030	2.422	0.570	0.121	0.190	0.000	13.911
1971	0.791	3.335	4.620	3.754	0.759	0.227	0.050	0.029	13.565
1972	0.138	7.136	7.198	3.514	1.094	0.046	0.122	0.000	19.248
1973	1.931	3.266	2.368	1.063	0.410	0.173	0.023	0.020	9.254
1974	0.316	2.224	1.842	1.256	0.346	0.187	0.085	0.009	6.265
1975	0.420	2.939	0.860	0.298	0.208	0.068	0.000	0.013	4.806
1976	1.034	4.368	1.247	0.311	0.196	0.026	0.048	0.037	7.267
1977	0.000	0.671	1.125	0.384	0.074	0.013	0.000	0.000	2.267
1978	0.936	0.798	0.507	0.219	0.026	0.000	0.008	0.000	2.494
1979	0.279	1.933	0.385	0.328	0.059	0.046	0.041	0.000	3.071
1980	0.057	4.644	5.761	0.473	0.057	0.037	0.000	0.000	11.029
1981	0.012	1.027	1.779	0.721	0.205	0.061	0.000	0.026	3.831
1982	0.045	3.742	1.122	1.016	0.455	0.065	0.000	0.026	6.471
1983	0.000	1.865	2.728	0.531	0.123	0.092	0.061	0.092	5.492
1984	0.000	0.093	0.809	0.885	0.834	0.244	0.000	0.000	2.865
1985	0.110	2.199	0.262	0.282	0.148	0.000	0.000	0.000	3.001
1986	0.027	1.806	0.291	0.056	0.137	0.055	0.000	0.000	2.372
1987	0.000	0.128	0.112	0.133	0.053	0.055	0.000	0.000	0.481
1988	0.078	0.275	0.366	0.242	0.199	0.027	0.000	0.000	1.187
1989	0.047	0.424	0.740	0.290	0.061	0.022	0.022	0.000	1.606
1990	0.000	0.065	1.108	0.393	0.139	0.012	0.045	0.000	1.762
1991	0.435	0.000	0.254	0.675	0.274	0.020	0.000	0.000	1.658
1992	0.000	2.010	1.945	0.598	0.189	0.000	0.000	0.000	4.742
1993	0.046	0.290	0.500	0.317	0.027	0.000	0.000	0.000	1.180

Table E7. NEFSC autumn trawl survey mean number per of Georges Bank yellowtail flounder per tow at age (NEFSC offshore strata 16, 19-21)

Year	Age								Total
	1	2	3	4	5	6	7	8	
1963	14.722	7.896	11.226	1.858	0.495	0.281	0.034	0.233	36.745
1964	1.721	9.723	7.370	5.998	2.690	0.383	0.095	0.028	28.008
1965	1.138	5.579	5.466	3.860	1.803	0.162	0.284	0.038	18.330
1966	8.772	4.776	2.070	0.837	0.092	0.051	0.000	0.000	16.598
1967	9.137	9.313	2.699	1.007	0.309	0.076	0.061	0.000	22.602
1968	11.782	11.946	5.758	0.766	0.944	0.059	0.000	0.000	31.255
1969	8.106	10.381	5.855	1.662	0.553	0.149	0.182	0.000	26.888
1970	4.610	5.133	3.144	1.952	0.451	0.063	0.017	0.000	15.370
1971	3.627	6.949	4.904	2.248	0.551	0.234	0.024	0.024	18.561
1972	2.424	6.525	4.824	2.095	0.672	0.279	0.000	0.000	16.819
1973	2.494	5.497	5.104	2.944	1.216	0.416	0.171	0.031	17.873
1974	4.623	2.854	1.524	1.060	0.460	0.249	0.131	0.000	10.901
1975	4.625	2.511	0.877	0.572	0.334	0.033	0.000	0.031	8.983
1976	0.336	1.929	0.475	0.117	0.122	0.033	0.000	0.067	3.079
1977	0.928	2.161	1.649	0.618	0.113	0.056	0.036	0.016	5.577
1978	4.729	1.272	0.773	0.406	0.139	0.011	0.000	0.024	7.354
1979	1.312	1.999	0.316	0.122	0.138	0.038	0.064	0.007	3.996
1980	0.761	5.086	6.050	0.678	0.217	0.162	0.006	0.033	12.993
1981	1.584	2.333	1.630	0.500	0.121	0.083	0.013	0.000	6.264
1982	2.424	2.185	1.590	0.423	0.089	0.000	0.000	0.000	6.711
1983	0.109	2.284	1.914	0.473	0.068	0.012	0.000	0.038	4.898
1984	0.661	0.400	0.306	2.428	0.090	0.029	0.000	0.018	3.932
1985	1.363	0.529	0.170	0.060	0.071	0.000	0.000	0.000	2.193
1986	0.281	1.107	0.341	0.081	0.000	0.000	0.000	0.000	1.810
1987	0.113	0.390	0.396	0.053	0.079	0.000	0.000	0.000	1.031
1988	0.019	0.213	0.102	0.031	0.000	0.000	0.000	0.000	0.365
1989	0.248	1.992	0.774	0.069	0.066	0.000	0.000	0.000	3.149
1990	0.000	0.326	1.517	0.280	0.014	0.000	0.000	0.000	2.137
1991	2.100	0.275	0.439	0.358	0.000	0.000	0.000	0.000	3.172
1992	0.151	0.396	0.712	0.162	0.144	0.027	0.000	0.000	1.592
1993	0.842	0.136	0.587	0.536	0.000	0.000	0.000	0.000	2.101

Table E8. NEFSC scallop survey mean number per of Georges Bank yellowtail flounder per tow at age

Year	Age								Total
	1	2	3	4	5	6	7	8	
1982	0.4855	0.4991	0.1947	0.0750	0.0158	0.0000	0.0000	0.0000	1.2701
1983	0.1831	0.5316	0.4038	0.0823	0.0346	0.0000	0.0000	0.0177	1.2531
1984	0.2945	0.1177	0.0501	0.0822	0.0194	0.0006	0.0000	0.0000	0.5645
1985	0.4559	0.0601	0.0030	0.0089	0.0000	0.0000	0.0000	0.0000	0.5279
1986	0.1451	0.1005	0.0056	0.0037	0.0000	0.0000	0.0000	0.0000	0.2549
1987	0.0230	0.1469	0.0697	0.0115	0.0060	0.0000	0.0000	0.0000	0.2571
1988	0.0995	0.0460	0.0352	0.0387	0.0157	0.0000	0.0000	0.0000	0.2351
1989	0.0831	0.4775	0.1997	0.0573	0.0000	0.0000	0.0000	0.0000	0.8176
1990	0.0125	0.1125	0.3198	0.0705	0.0000	0.0000	0.0000	0.0000	0.5153
1991	2.2570	0.0340	0.0990	0.1100	0.0000	0.0000	0.0000	0.0000	2.5000
1992	0.1300	0.0960	0.0600	0.0050	0.0020	0.0000	0.0000	0.0000	0.2930
1993	1.1370	0.1000	0.3010	0.2990	0.0240	0.0000	0.0000	0.0000	1.8610

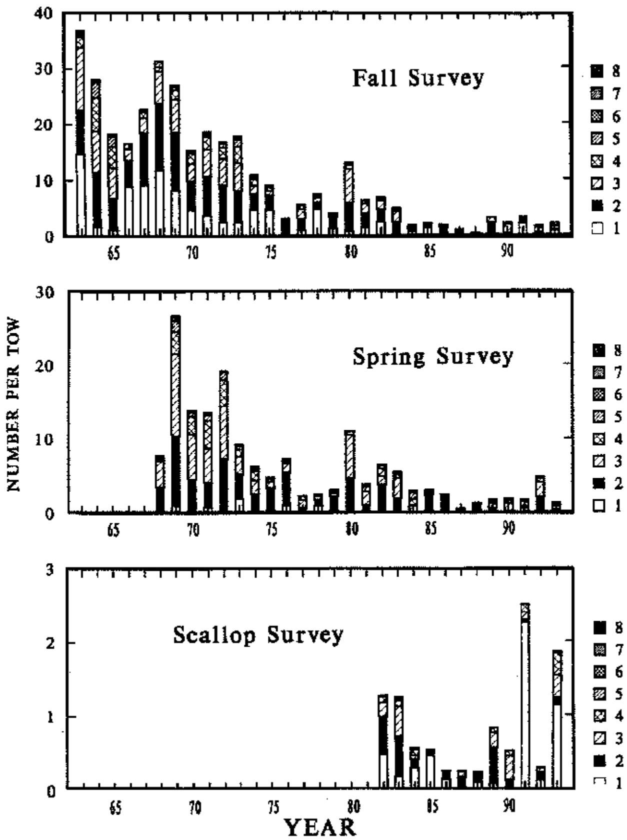

Figure E5. Number by age group of yellowtail flounder caught per tow during NEFSC fall (1963-1993), spring (1968-1993), and scallop (1982-1993) research surveys on Georges Bank (adjusted for effects of vessel, door and net).

Indices of age-specific stratified mean catch per tow were available from NEFSC spring and autumn bottom trawl surveys (Table E6, 1968-1993; Table E7, 1963-1993; respectively) and from NEFSC scallop surveys (Table E8, 1982-1993)(Figure E5). Indices declined precipitously between the 1960s and 1970s, to low levels in 1976-1977. The 1977-1978 year classes led to a brief increase in indices in the late 1970s and early 1980s. Survey indices reached record lows in 1987-1988, between the 1978-1979 year classes and the relatively strong 1987 year class.

The 1993 spring trawl survey index was the second lowest in the 26-year time series. The 1993 autumn trawl survey index was the fifth lowest in the 31-year time series. Those indices are supported primarily by the 1989 and 1990 year classes. The latter year class appeared strong based on scallop and autumn age 1 indices in 1991 and spring age 2 indices in 1992, but did not remain especially large in subsequent surveys. Although indices for the 1991 year class appear unremarkable, the 1992 year class may be of interest based on the 1993 autumn survey age 1 index.

Utility of Indices for Tuning VPA Models

Research survey indices were used to calibrate the catch equation projections in ADAPT. To investigate the utility of survey estimates as tuning indices, it was hypothesized that survey indices should have internal consistency, or coherency. Cohorts measured at time t by survey j should be positively correlated with subsequent observations at time t+Δt by the same survey or another survey k (Rago, *et al.* 1994).

Define $I_k(a,t)$ as an index of abundance for fish of age a at time t from the kth survey and assume that the survey index is related to abundance by some constant, say $q_{k,a}$. If the relationship between true abundance and the index varies with density then the relation between an index and true abundance can be generalized as

(4) $$I_k(a,t) = q_{k,a} N_{a,t}^{1/\theta_{k,a}}$$

where $\theta_{k,a}$ is an estimable parameter. It can then be shown that the log indices are related the linear equation:

(5) $$\log_e(I_k(a + \Delta a, t + \Delta t)) = a + \left(\frac{\theta_{j,a}}{\theta_{k,a+\Delta a}}\right)\log_e(I_j(a,t))$$

where a is a function of q and θ. Equation 5 should have a slope of one if the age- and survey-specific exponents are approximately equal. The variability about the regression line is a measure of the sampling variation in the index, interannual variation in catchabilities (q) and θ.

Equation 5 was applied to the fall, spring, and scallop survey indices for within-year, between survey comparisons and comparisons between years for different surveys. Coefficients of determination for the regressions among survey indices are summarized in Table E9; zero observations were not included in any of the regressions. Of the 23 regressions examined, 13 were statistically significant at the 5% level. The hypothesis that $\theta_{k,a+\Delta a} = \theta_{k,a}$ was tested by testing the equivalent hypothesis that slope of Eq. 5 equaled 1. Results (Table E9) suggested equal θ's for 10 of the 23 comparisons across surveys and age groups. In five of the instances where the null

Table E9. Coefficients of determination for linear regressions among log transformed NEFSC research survey indices (number/tow) for Georges Bank yellowtail flounder

Comparison Type	Dependent Variable		Independent Variable				Regression Statistics				
	S	Age	S	Age	Lag	N	R^2	P	$S_{y.x}$	β_1	H_o: β_1=1 Eq.5
Within year and age class, between surveys	Fal	1	Spr	1		20	.148	.094	1.410	.405	0.018
		2		2		25	.603	.000	0.797	.704	0.021
		3		3		26	.756	.000	0.591	.862	0.179
		4		4		26	.583	.000	0.836	.957	0.797
		5		5		22	.188	.044	0.994	.421	0.008
	Fal	1	Sca	1		11	.561	.008	1.036	.865	0.610
		2		2		12	.664	.001	0.580	.848	0.445
		3		3		12	.554	.006	0.627	.430	0.001
		4		4		12	.404	.026	0.801	.462	0.013
		5		5		5	.686	.083	0.181	-.206	
0.001											
	Sca	1	Spr	1		7	.369	.148	1.092	.837	0.752
		2		2		11	.075	.417	0.865	.161	0.002
		3		3		12	.275	.080	1.382	.868	0.773
		4		4		12	.305	.062	1.189	.915	0.849
		5		5		7	.0	.980	1.066	.010	0.044
Across years and age groups, between surveys	Spr	2	Fal	1	L25	.660	.000	0.815	.707	0.011	
		3		2	L	26	.515	.000	0.841	.753	0.112
		4		3	L	26	.560	.000	0.685	.678	0.015
		5		4	L	26	.312	.003	0.923	.506	0.004
	Spr	2	Sca	1	L	10	.446	.035	1.083	.742	0.404
		3		2	L	11	.084	.386	0.965	.290	.053
		4		3	L	11	.904	.000	0.256	.482	.000
		5		4	L	11	0.392	.039	0.744	.456	0.018

Note: Zero observations were not included in the computations.

hypothesis that β_1 = 1 was rejected, the overall regression was not significant.

Age 1 indices are imprecisely estimated in all surveys, but research survey indices for ages 2, 3, and 4 showed highly significant correlations between the spring and fall surveys (Table E9). both within years and between years (for appropriately lagged variables). The spring and fall surveys for age 5 abundance were strongly correlated with each other and with fall age 4 abundance. Age 5 yellowtail flounder are infrequently captured in the NEFSC scallop survey; this index is poorly related to either the fall or spring surveys or with the previous year's scallop survey estimate of age 4 abundance.

Correlation analyses of the research survey indices suggest that the most appropriate set of indices are the fall and spring surveys for ages 2 to 5. Scallop survey indices for age 2 to 4 appear to be somewhat less consistent internally and with spring surveys. The VPA model was tuned with the following survey indices Spring: ages 2, 3, 4, 5+; Scallop: age 4+; and Fall: ages 2, 3, 4, 5+. In addition, age 2 abundance on January 1 was tuned with respect to the age 1 fall survey index from the preceding year.

VIRTUAL POPULATION ANALYSIS

Estimates of Stock Size and Fishing Mortality Rates

Virtual population analysis (VPA) results indicated a marked 75% decline in abundance since 1973, although population size of age 2+ fish has been relatively stable since 1984, averaging 15 million fish (Table E10). Stock numbers in 1993, however (11.5 million fish ages 2-6+) were the fourth lowest in the 1973-1993 time series. The abundance of age 4+ fish declined substantially between 1973-1975, and then de-

Table E10. Results of ADAPT tuning, virtual population analysis, Georges Bank yellowtail flounder, this reweighted version is used for bootstrap and projections

Catch at Age (millions)

■	1973	1974	1975	1976	1977	1978	1979	1980	1981
2 ■	4.890	8.971	25.284	31.012	8.580	3.105	9.505	3.572	0.729
3 ■	13.243	7.904	7.057	5.146	9.917	4.034	3.445	8.821	5.351
4 ■	9.276	7.398	3.392	1.347	1.721	1.660	1.242	1.419	4.556
5 ■	3.743	3.544	2.084	0.532	0.394	0.459	0.550	0.321	0.796
6 ■	1.618	1.477	1.148	0.868	0.474	0.174	0.272	0.099	0.126
2+ ■	32.770	29.294	38.965	38.905	21.086	9.432	15.014	14.232	11.558

■	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2 ■	17.491	7.689	1.917	3.345	5.771	2.653	2.367	1.516	1.931	0.054	8.359	0.923
3 ■	7.122	16.016	4.266	0.816	0.978	2.751	1.191	0.668	6.123	1.222	2.527	2.050
4 ■	3.246	2.316	4.734	0.652	0.347	0.761	0.624	0.262	0.800	2.429	1.269	1.492
5 ■	1.031	0.625	1.592	0.410	0.161	0.132	0.165	0.068	0.107	0.294	0.509	0.292
6 ■	0.084	0.127	0.321	0.065	0.076	0.112	0.038	0.019	0.020	0.060	0.027	0.070
2+ ■	28.974	26.773	12.830	5.288	7.333	6.409	4.385	2.533	8.981	4.059	12.691	4.827

Stock Numbers (Jan 1) in millions

■	1973	1974	1975	1976	1977	1978	1979	1980	1981
2 ■	23.279	22.848	39.214	52.140	18.208	12.605	32.871	18.927	17.814
3 ■	28.937	14.635	10.589	9.228	14.628	7.144	7.510	18.312	12.264
4 ■	16.960	11.709	4.830	2.284	2.899	3.003	2.199	3.032	7.011
5 ■	6.729	5.492	2.893	0.885	0.651	0.816	0.957	0.677	1.198
6 ■	2.859	2.240	1.551	1.417	0.768	0.304	0.465	0.206	0.185
2+ ■	78.765	56.924	59.077	65.954	37.155	23.872	44.001	41.153	38.472

■	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2 ■	49.947	15.840	4.134	6.670	11.360	5.309	5.618	15.352	6.719	6.997	14.734	4.099	11.917
3 ■	13.925	25.067	6.011	1.650	2.434	4.079	1.946	2.458	11.198	3.754	5.680	4.499	2.521
4 ■	5.199	4.957	6.031	1.062	0.613	1.108	0.851	0.516	1.408	3.628	1.967	2.364	1.829
5 ■	1.618	1.319	1.962	0.654	0.279	0.188	0.219	0.132	0.185	0.429	0.772	0.463	0.585
6 ■	0.129	0.264	0.382	0.102	0.129	0.155	0.049	0.036	0.034	0.085	0.040	0.109	0.141
2+ ■	70.818	47.447	18.520	10.138	14.816	10.839	8.682	18.494	19.543	14.893	23.193	11.534	16.994

Summaries for ages 2-6, 3-,6 4-6, 5-6

■	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
2-6 ■	78.765	56.924	59.077	65.954	37.155	23.872	44.001	41.153	38.472	70.818	47.447	18.520	10.138
3-6 ■	55.486	34.076	19.863	13.814	18.946	11.268	11.130	22.226	20.658	20.871	31.607	14.386	3.468
4-6 ■	26.549	19.441	9.274	4.586	4.318	4.124	3.620	3.914	8.394	6.946	6.540	8.375	1.818
5-6 ■	9.589	7.732	4.444	2.302	1.419	1.120	1.421	0.882	1.384	1.747	1.584	2.344	0.756

	1986	1987	1988	1989	1990	1991	1992	1993	1994
2-6 ■	14.816	10.839	8.682	18.494	19.543	14.893	23.193	11.534	16.994
3-6 ■	3.456	5.530	3.064	3.142	12.825	7.896	8.460	7.434	5.077
4-6 ■	1.021	1.451	1.118	0.684	1.627	4.142	2.780	2.935	2.555
5-6 ■	0.409	0.343	0.268	0.168	0.219	0.514	0.812	0.571	0.727

Table E10. Continued

Fishing Mortality

	■	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
2	■	0.2642	0.5690	1.2468	1.0710	0.7356	0.3178	0.3850	0.2339	0.0463	0.4894	0.7689	0.7184
3	■	0.7048	0.9085	1.3339	0.9579	1.3833	0.9783	0.7072	0.7601	0.6582	0.8330	1.2246	1.5338
4	■	0.9275	1.1982	1.4967	1.0549	1.0673	0.9439	0.9788	0.7283	1.2665	1.1712	0.7265	2.0211
5	■	0.9538	1.2487	1.5907	1.0911	1.1047	0.9713	1.0088	0.7432	1.3251	1.2187	0.7413	2.2687
6	■	0.9538	1.2487	1.5907	1.0911	1.1047	0.9713	1.0088	0.7432	1.3251	1.2187	0.7413	2.2687

	■	1985	1986	1987	1988	1989	1990	1991	1992	1993
2	■	0.8080	0.8242	0.8036	0.6266	0.1156	0.3822	0.0086	0.9862	0.2861
3	■	0.7908	0.5870	1.3677	1.1283	0.3572	0.9271	0.4460	0.6767	0.7003
4	■	1.1355	0.9835	1.4227	1.6648	0.8248	0.9886	1.3471	1.2476	1.1959
5	■	1.1793	1.0139	1.5038	1.7944	0.8446	1.0194	1.4166	1.3039	1.1959
6	■	1.1793	1.0139	1.5038	1.7944	0.8446	1.0194	1.4166	1.3039	1.1959

Avg F for ages 2-6, 3-6, 4-6, 5-6

	■	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
2-6	■	0.7608	1.0346	1.4518	1.0532	1.0791	0.8365	0.8177	0.6417	0.9243	0.9862	0.8405	1.7621
3-6	■	0.8849	1.1510	1.5030	1.0488	1.1650	0.9662	0.9259	0.7437	1.1438	1.1104	0.8584	2.0231
4-6	■	0.9450	1.2319	1.5594	1.0790	1.0922	0.9622	0.9988	0.7382	1.3056	1.2029	0.7363	2.1861
5-6	■	0.9538	1.2487	1.5907	1.0911	1.1047	0.9713	1.0088	0.7432	1.3251	1.2187	0.7413	2.2687

	■	1985	1986	1987	1988	1989	1990	1991	1992	1993
2-6	■	1.0186	0.8845	1.3204	1.4017	0.5973	0.8673	0.9270	1.1037	0.9148
3-6	■	1.0712	0.8996	1.4495	1.5955	0.7178	0.9886	1.1566	1.1330	1.0720
4-6	■	1.1647	1.0038	1.4768	1.7512	0.8380	1.0091	1.3935	1.2851	1.1959
5-6	■	1.1793	1.0139	1.5038	1.7944	0.8446	1.0194	1.4166	1.3039	1.1959

Mean Biomass (thousands of metric tons)

	■	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
2	■	6.984	6.025	7.047	10.005	4.305	3.316	8.859	5.436	6.142	11.296	3.003	0.649
3	■	8.835	4.422	2.664	2.979	3.869	2.153	2.281	5.827	4.059	4.228	5.879	1.079
4	■	5.360	3.840	1.288	0.828	1.042	1.224	0.838	1.296	2.218	1.839	1.952	1.210
5	■	2.408	1.973	0.832	0.368	0.284	0.381	0.404	0.356	0.435	0.646	0.629	0.467
6	■	1.317	0.996	0.492	0.665	0.408	0.164	0.241	0.144	0.076	0.073	0.164	0.111
2+	■	24.904	17.256	12.323	14.845	9.908	7.238	12.623	13.058	12.929	18.082	11.627	3.517

	■	1985	1986	1987	1988	1989	1990	1991	1992	1993
2	■	1.525	2.438	1.133	1.342	4.674	1.716	1.705	2.942	1.026
3	■	0.520	0.910	1.077	0.600	1.023	2.814	1.059	1.441	1.157
4	■	0.379	0.238	0.365	0.265	0.234	0.484	0.893	0.549	0.650
5	■	0.260	0.133	0.061	0.081	0.072	0.075	0.155	0.259	0.140
6	■	0.045	0.068	0.063	0.021	0.025	0.017	0.036	0.024	0.052
2+	■	2.730	3.788	2.699	2.309	6.029	5.107	3.848	5.215	3.024

Table E10. Continued

SSB at the Start of the Spawning Season - Males & Females (thousands of metric tons)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
2 ■	6.331	5.516	6.421	9.159	3.949	3.013	8.070	4.921	5.503	10.322	2.755
3 ■	9.210	4.610	2.749	3.104	3.985	2.243	2.378	6.076	4.228	4.409	6.092
4 ■	5.587	3.982	1.319	0.861	1.084	1.275	0.873	1.351	2.295	1.098	2.035
5 ■	2.509	2.042	0.848	0.383	0.296	0.397	0.421	0.371	0.499	0.670	0.656
6 ■	1.372	1.031	0.501	0.691	0.424	0.171	0.251	0.150	0.078	0.075	0.171
2+ ■	25.009	17.182	11.839	14.198	9.738	7.099	11.992	12.868	12.553	17.385	11.709

■	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2 ■	0.595	1.400	2.238	1.039	1.230	4.205	1.563	1.524	2.697	0.931
3 ■	1.103	0.543	0.947	1.110	0.623	1.058	2.933	1.098	1.502	1.206
4 ■	1.195	0.394	0.248	0.375	0.269	0.244	0.505	0.921	0.568	0.674
5 ■	0.450	0.270	0.139	0.063	0.081	0.075	0.078	0.159	0.267	0.145
6 ■	0.107	0.046	0.071	0.064	0.021	0.026	0.018	0.037	0.025	0.054
2+ ■	3.451	2.653	3.643	2.652	2.224	5.609	5.097	3.740	5.060	3.010

The SSBs by age (a) and year (y) are calculated following the algorithm used in the NEFSC projection program:

SSB(a,y) = W(a,y) x P(a,y) x N(a,y) x exp[-Z(a,y)]

where Z(a,y) = 0.4167 x M(a,y) + 0.4167 x F(a,y)
N(a,y) - Jan 1 stock size estimates (males & females)
P(a,y) - proportion mature (generally females)
W(a,y) - weight at age at the beginning of the spawning season

The W(a,y) are assumed to be the same as the mid-year weight at age estimates (see "WT AT AGE" table in input section).

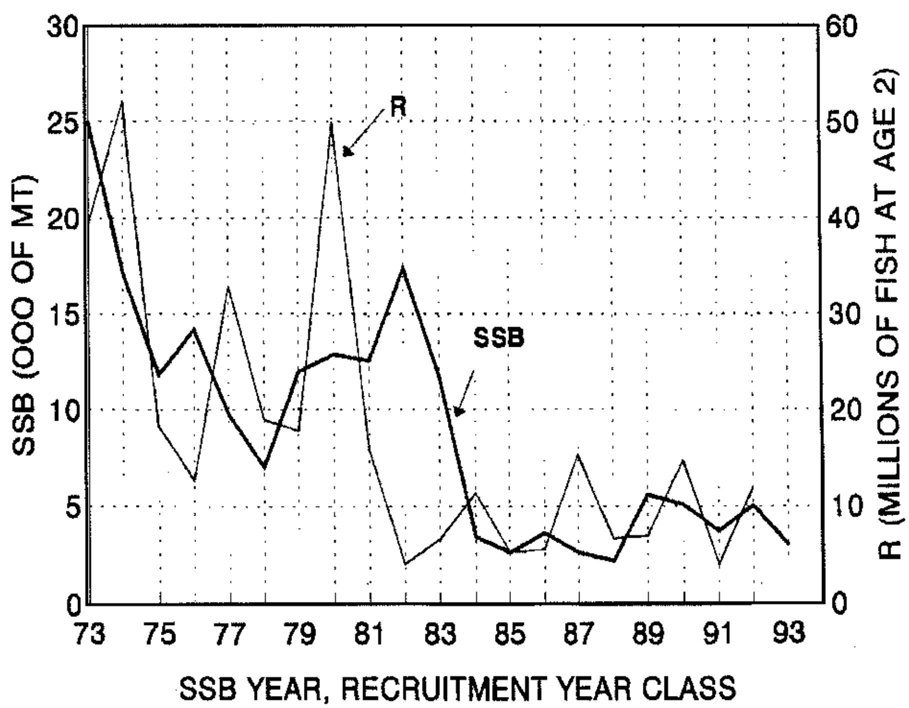

Figure E6. Trends in spawning stock biomass and recruitment, 1972-1993, Georges Bank yellowtail flounder.

clined further in the late 1980s to record low levels, one-sixth the level observed in 1973. The slight upturn in the early 1990s reflects the contribution of the remnants of the 1987 year class. Spawning stock biomass fluctuated between 2200 and 3600 mt in 1984-1988, compared to the series peak of 25,000 mt in 1973 (Figure E6). The 1987 year class supported spawning stock biomasses in 1989-1990 of 5600 mt and 5100 mt, respectively. Spawning stock biomass of 5100 mt in 1992 was supported by the 1990 year class (53%) and the 1989 year class (30%). In 1993, spawning stock biomass of 3000 mt was divided between the 1989-1991 year classes (22%, 40% and 30%), and was the fourth lowest value in the 21 year time series.

The 1991 year class (at age 2) was the lowest in the 21 year time series (4.1 million), about equal to the 1982 year class (Figure E6). Since 1982, the 1987 and 1990 year classes have been the largest (at age 2), averaging 15 million. On average, year class strength from 1982-1992 year classes (8.4 million) has been about one-third of the average levels observed from 1971-1981 year classes (27.6 million). Although the estimate of 1992 year class strength is uncertain, it may be somewhat greater than the 1982-1992 average level.

Fishing mortality levels obtained from VPA has fluctuated widely in recent years, but average F (4+, unweighted) equaled or exceeded 1.0 in 16 of the 20 years of the analysis, including 1991-1993 (F=1.4, 1.3 and 1.2, respectively)(Table E10, Figure E7).

Spawning stock biomass at the start of the 1993 spawning season (3010 mt) was estimated with little bias (<4%), and a coefficient of variation of 22%. The entire distribution of spawning stock biomass estimates was below 5000 mt., *i.e,* the probability that spawning stock biomass exceeded 5000 mt in 1994 is nil (Figure E8).

A coefficient of variation of 45% was associated with the estimate of fully-recruited F in the terminal year, based on bootstrap analysis. The lowest bootstrap realization of fully-recruited F was 1.20, *i.e.*, the probability of F being less than 0.5 was less than 1% (Figure E9). Coefficients of variation for F at ages 2-5 were 46%, 31%, 45% and 45%, respectively.

The distribution of bootstrapped estimates of numbers at age is displayed in Figure E10, reflecting considerable uncertainly in age 2, 5 and 6+ estimates. Cumulative frequency distributions of 1993 spawning stock biomass and fishing mortality rates are displayed in Figures E8 and E9, respectively.

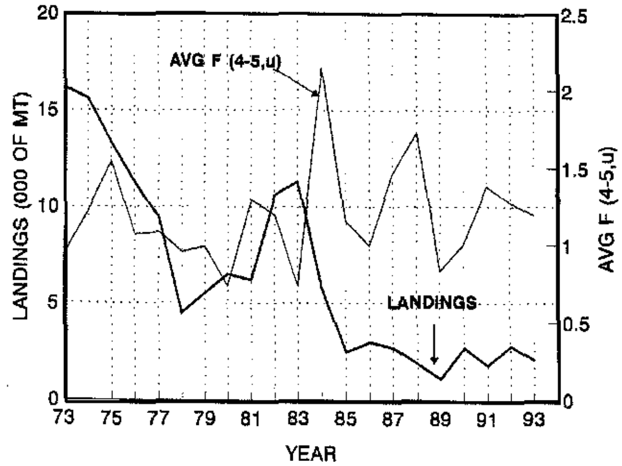

Figure E7. Trends in commercial landings and fishing mortality, 1973-1993, Georges Bank yellowtail flounder.

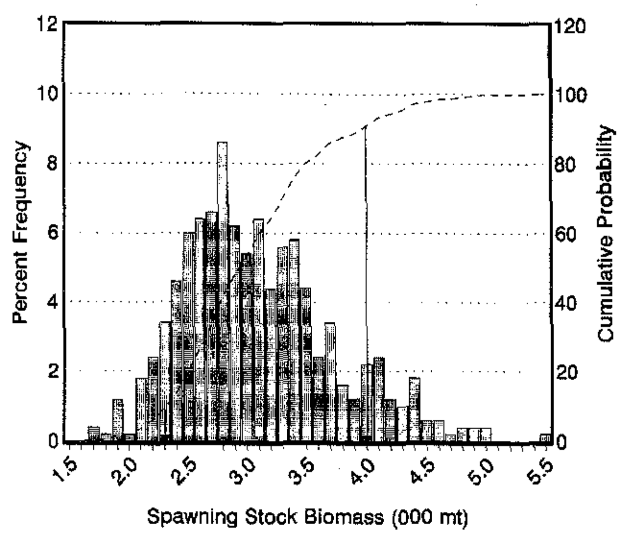

Figure E8. Precision of the estimates of spawning stock biomass in 1993 for Georges Bank yellowtail flounder. Vertical bars display the range of the bootstrap estimates and the probability of individual values in the range. The dashed line gives the probability that spawning stock biomass is less than the value on the X axis. The 10% and 90% probability levels are marked by arrows.

Yield per Recruit and Spawning Stock Biomass per Recruit Analyses

Biological reference points were calculated in 1990 based on a Thompson-Bell model (Conser, et al. ,1991). Analyses were not revised in this

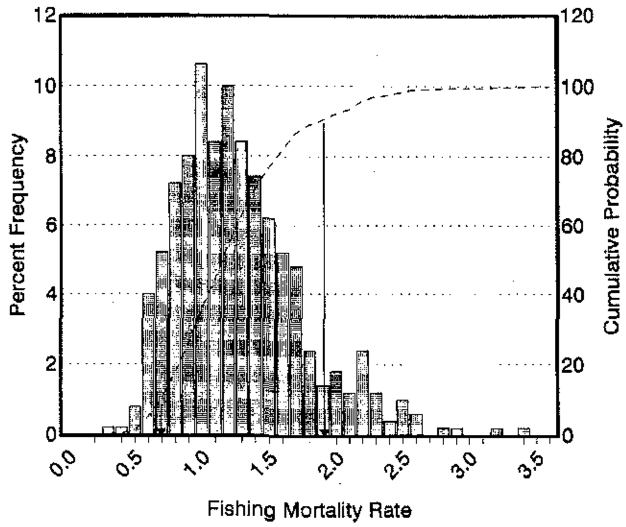

Figure E9. Precision of the estimates of spawning stock biomass in 1993 for Georges Bank yellowtail flounder. Vertical bars display the range of the bootstrap estimates and the probability of individual values in the range. The dashed line gives the probability that the fishing mortality rate is greater than the value on the X axis. The 10% and 90% probability levels are marked by arrows.

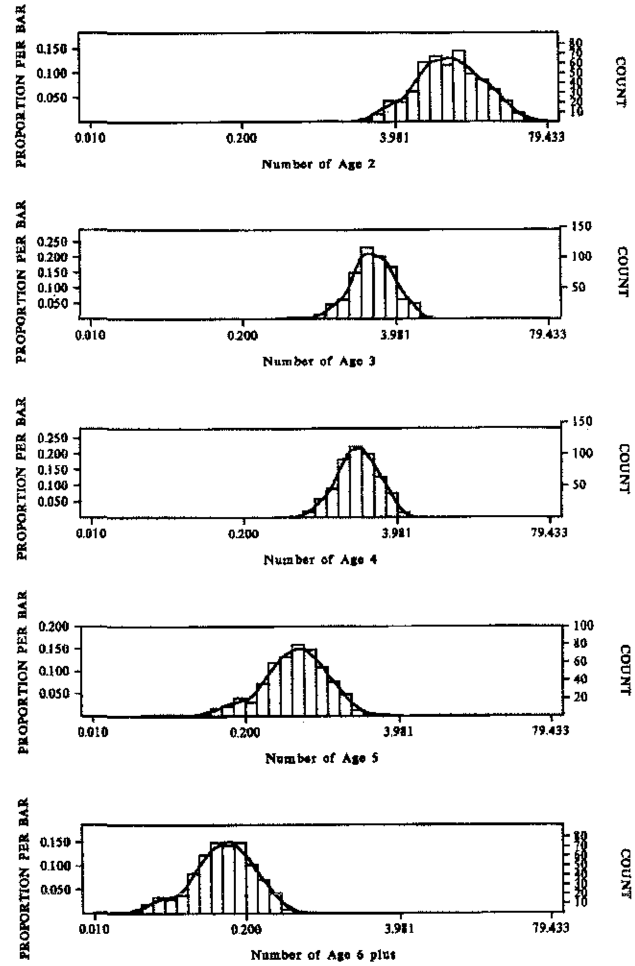

Figure E10. Precision of estimates of numbers at age in 1993, Georges Bank yellowtail flounder. Vertical bars display the range of the bootstrap estimates and the probability of individual values in the range.

assessment because the partial recruitment vector may vary over the short term as a function of stock any year class abundance; and although mean weights at age have been fairly variable over time, no trend in weight at age was observable. Based on the 1990 analysis, $F_{0.1 = 0.29}$, F_{max} = 0.63 and $F_{20\%}$ = 0.58 (Figure E11).

Short-Term Projections

The methodology for projecting future landings, discard, and spawning stock biomasses was modified to more fully incorporate the uncertainty in estimated population abundances for the terminal year +1, and the historical distribution of age 2 recruitment indices (Brodziak and Rago, ms.). The sampling distribution of future abundance and SSB levels was approximated by considering the set of bootstrap-generated random abundance vectors (Figure E10). Each of the 500 realized population vectors at age in 1994 from ADAPT bootstrap runs was projected froward through 1995 under an F option of interest.

Recruitment in 1995 was drawn from a cumulative distribution of recruitment from 1984-1993, the period after the substantial decline in spawning stock biomass. The assumption of stock-independent recruitment may be reasonable in this case because the projection is short term; and stock sizes are likely to be similar to those observed between 1984-1993.

Two F options were considered: 1) maintenance of 1993 status quo F levels in 1994-1995; and 2) 10% reduction in status quo F in 1994-1995.

Partial recruitment for the projection was set equal to that used in VPA (Table E11). Weights at age in the landings were based on geometric means of weights in landings from 1990-1993. Mean weights in discards were estimated as the average weight at age of fish less than 33 cm from autumn NEFSC survey length frequency distributions, 1990-1993, and provide a minimum

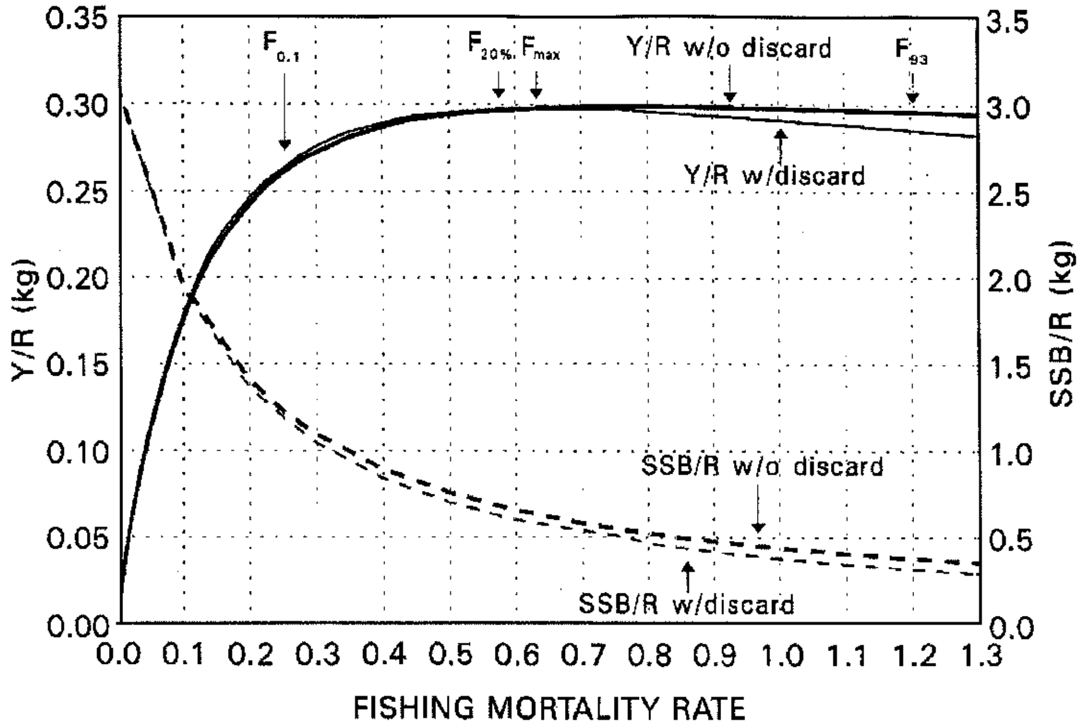

Figure E11. Yield and spawning stock biomass per recruit, including and excluding discards, from Conser *et al.* 1991

Table E11. Input parameters and projection results for Georges Bank yellowtail flounder, landings, discard and spawning stock biomass (thousands of metric tons)

Age	**Fishing Mortality Pattern**	**Proportion Discarded**	**Proportion Mature**	**Mean Weight Stock**	**Mean Weight Landings**	**Mean Weight Discards**
2	0.14	0.583	0.88	0.315	0.315	0.157
3	0.51	0.261	1.00	0.393	0.393	0.256
4	1.00	0.072	1.00	0.526	0.526	0.313
5	1.00	0.000	1.00	0.656	0.656	0.656
6+	1.00	0.000	1.00	0.939	0.939	0.939

F_{94}	F_{95}		**1994**			**1995**		
			Landings	**Discard**	**SSB**	**Landings**	**Discard**	**SSB**
1.20	1.20	10%	1063	155	2660	1236	227	3497
(SQ)	(SQ)	Median	1512	255	4402	1886	387	5635
		Mean	1562	287	5013	2093	432	5958
		90%	2124	465	8144	3222	703	8876
1.08	1.08	10%	991	142	2725	1212	211	3646
(-10%)	(-10%)	Median	1411	233	4492	1832	360	5846
		Mean	1457	262	5101	2024	403	6187
		90%	1978	423	8232	3085	655	9224

Notes: Stock size in 1994 is based on results of bootstrap replications. Recruitment is generated randomly from and empirical cumulative distribution function based on recruitment from 1984-1993, from virtual population time series. Results are based on 200 simulations from 500 bootstrapped observations. Proportion of F, M before spawning =0.4167 (peak spawning 1 May). Proportion discarded based on 1990-1993 averages. Mean weights at age in landings and stock based on geometric mean of weights in landings 1990-1993. Mean weights in discards based on average mean weight at age of fish in NEFSC survey less than 33 cm, 1991-1993.

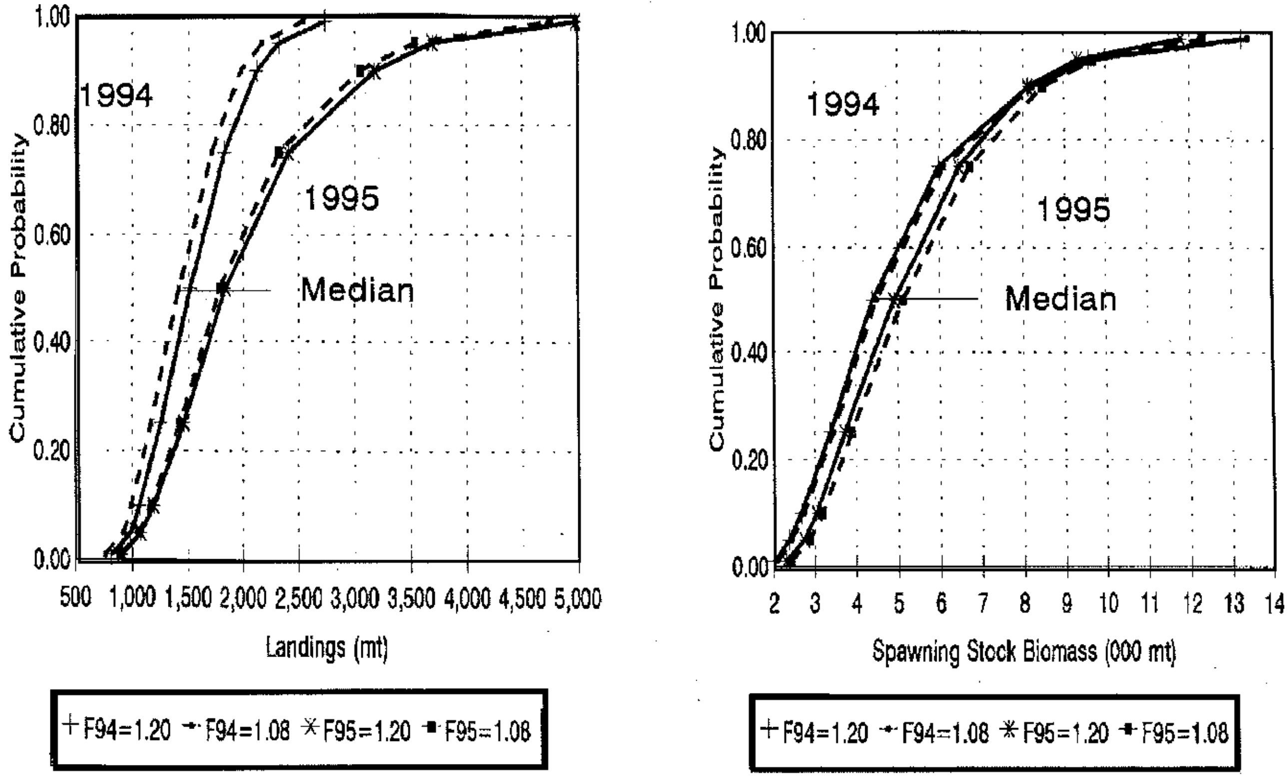

Figure E12. Distribution of projected short-term landings (left panel) and spawning stock biomass (right panel) and from stochastic projections, 1994-1995. Lines give the probability that spawning stock biomass or landings are less than the value on the X axis.

estimate. Proportion discarded was estimated as the average of proportions discarded at age between 1990-1993. Proportion mature at age was set equal to that used in VPA (Conser, *et al.* 1991). Characteristics of the distributions of results aresummarized in Table E11: the 10% and 90% percentiles of the distributions of landings, discards and spawning stock biomass as well as the mean and median of those distributions are included.

Landings in 1994 were predicted to decline to about 1600 mt (about 25%) under status quo conditions (F=1.20), and then return to 1993 levels in 1995 (2100 mt). Spawning stock biomass was predicted to increase to 5000 mt, returning to 1992 levels in 1994 and to increase to 6000 mt in 1995 (as the 1992 year class recruited).

With a 10% reduction in F in 1994-1995, landings were predicted to decline to about 1500 mt in 1994 and increase to about 2000 mt in 1995. Spawning stock biomass was predicted to increase to 5100 mt in 1994 and to 6200 mt in 1995.

The results of the stochastic projection indicate that it will be difficult to detect an effect of a 10% reduction in F on spawning stock biomass and landings, given the uncertainty in the estimated stock sizes. The "within scenario" variability (*e.g.*, as described by approximate 80% confidence intervals, as the 10th and 90th percentiles) was much larger than the anticipated "between scenario" differences (Figure E12).

Hindcast Estimation of Abundance

Results of the VPA of yellowtail flounder show a marked decline in population biomass since 1973. Survey indices prior to 1973, however, were much higher than any values used in the current assessment. The SARC requested additional information on potential population size from 1963-1972.

Linear regression analysis was used to investigate the relation between total stock biomass (from the VPA assessment) and mean weight per tow from the NEFSC research survey. The general model can be written as:

$$(6) \qquad B_{VPA,y} = a\, I_y^b$$

$$(7) \qquad \ln(B_{VPA,y}) = \ln(a) + b \ln(I_y)$$

where B_{VPA} is the VPA-based estimate of population biomass (thousands of metric tons) in year y, I_y is the research survey index (kg/tow) in year y, and a and b are parameters. Standard linear regression techniques can be applied to Eq. 7 to generate prediction intervals for individual survey estimates prior to 1973. The prediction interval half width in the log scale is defined as

$$(8)\ PI_{half} = t_{0.95,n-2}\sqrt{MSE + \frac{MSE}{n} + s^2(b)(I_{yt} - \bar{I})^2}$$

where *MSE* is the mean square error of the regression, $s^2(b)$ is the standard error of the *b* parameter, I_y is the survey index for a year not included in the regression.

The linear regression between estimated biomass and the NEFSC fall survey was highly significant (Figure E13, r^2=0.79, P<0.0005). Residual analyses revealed no major outliers, no significant autocorrelation (Durbin Watson statistic =2.128) and close correspondence to the underlying normality assumption. The resulting asymmetrical prediction intervals (Figure E14) suggest that yellowtail flounder biomass on Georges Bank exceeded 35,000 mt in the early 1960s and exceeded 20,000 mt prior to 1973. The resulting prediction intervals are wide but all values exceed those observed since 1980.

DISCUSSION

Discards of age 1 fish cannot be estimated with the current method, because observations of landings of age 1 fish are required. Sea sampling data for direct estimation of discards, while preferable, are presently sparse. The use of existing yield-per-recruit and spawning-stock-biomass-per-recruit calculations is relatively unaffected by the absence of age 1 fish in the catch data and analysis, however, because no age 1 fish appear in landings (as yield), no age 1 fish are sexually mature, and separable virtual population analysis indicated very low partial recruitment values when age 1 fish did occur in landings and discards.

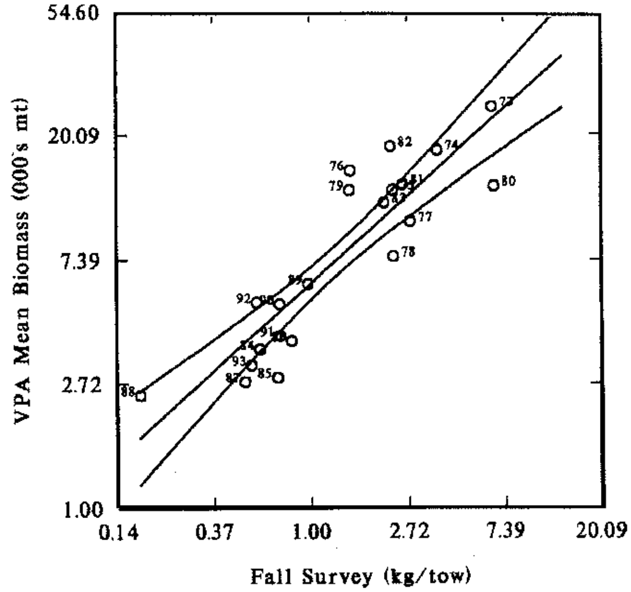

Figure E13. Regression relationship between NEFSC autumn bottom trawl survey catch, and VPA estimates of mean stock biomass, Georges Bank yellowtail flounder, 1973-1993.

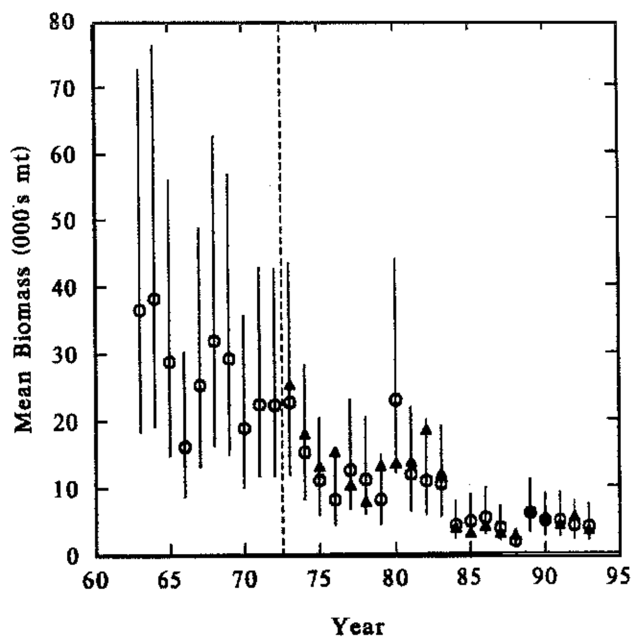

Figure E14. Hindcast estimates of stock biomass for Georges Bank yellowtail flounder (circles) and standard error of prediction (bars) from linear regression of NEFSC autumn bottom trawl survey indices of abundance and VPA estimates of mean stock biomass (Figure E13). and VPA estimates of abundance are designated by triangles.

The condition of other stocks (Cape Cod, Gulf of Maine, Mid-Atlantic) cannot be evaluated at the same level of detail currently used for Georges Bank and Southern New England stocks, due to data availability. Different patterns in survey abundance between Cape Cod and Georges Bank-Southern New England indicate that combining Cape Cod stock data with data from those areas is probably inappropriate. Other approaches may be feasible, such as using survey index-stock size relationships observed for Georges Bank and Southern New England stocks to scale survey indices from other stock areas into stock sizes. The SARC felt that it would be reasonable to assume that even in the unlikely event these smaller stocks were not currently overfished, any management measures designed to rebuild Southern New England and Georges Bank stocks should also be required to protect smaller stocks from re-allocated effort.

A decline in mean weights at age over time is reflected in both survey and landings at age data, but the mechanism responsible for that decline is unclear: temperature changes, overfishing of faster-growing fish, or allocation of energy to reproduction rather than somatic growth may be responsible.

The plotted relationships between survey indices and VPA estimates were linear, but with the potential for nonzero stock sizes at survey indexes of zero (positive y intercept) for this stock. If so, the calibration function may be misspecified, with bias in estimation of numbers and fishing mortality rates in the last year of the analysis. The SARC discussed in detail the potential for nonlinear effects to influence assessment results when stock sizes are low.

SUMMARY

1. Stock abundance has declined by more than 50% since the early 1970s and remained at low levels since 1984, based on results of research vessel surveys and virtual population analysis. The stock is considered collapsed, given former levels of abundance, recruitment, and yield.

2. Recruitment has declined from an average of 27.6 million age 2 fish from 1971-1981 year classes to an average of 8.4 million fish from the 1982-1992 year classes. Most of the 1987 and 1990 year classes, at about 15 million age 2 fish each, have been removed by the fishery in recent years. Although estimates of the size of the 1992 year class are uncertain, fall survey indices at age 1 for the year class are greater than recent averages.

3. The age structure of the stock has become truncated since the mid-1970s, to contain few or no fish older than age 5.

5. Fishing mortality rates are well in excess of biological reference levels, with exploitation rates of about 65% in 1991-1993.

6. Traditional analytic techniques including VPA, DeLury estimation, and separable models are compromised for this stock by its truncated age structure, and likely changing fishery targeting patterns with year class strength or regulation. Precision of assessment results is declining with stock status.

RESEARCH RECOMMENDATIONS

1. Evaluate potential changes in growth, sex ratios, and maturity related to increased fishing pressure, decreasing stock size, and possibly, water temperature.

2. Evaluate potential bias in length frequency distributions and age-length keys arising from cluster sampling by sex.

3. Develop sea sampling coverage to allow direct estimation of discards for all seasons of the fishery.

4. Monitor utility and spatial coverage of winter trawl survey for yellowtail flounder on Georges Bank.

5. Evaluate available Canadian survey data for yellowtail flounder.

6. Explore methods to scale survey indices into stock sizes, using observed relationships for Georges Bank and Southern New England.

7. Evaluate performance of existing and alternative VPA calibration functions over the range of stock sizes to investigate potential sources of bias.

8. Investigate alternative models for population assessment, including methods for assessing other smaller stocks of yellowtail flounder.

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F. GEORGES BANK COD

TERMS OF REFERENCE

The following terms of reference were addressed:

a. Assess the status of Georges Bank cod through 1993 and characterize the variability of estimates of stock abundance and fishing mortality rates.

b. Provide 1994 projected estimates of catch and 1995 SSB options at various levels of F.

c. Provide 1995 projected estimates of catch and 1996 SSB options for a range of expected 1994 catch.

THE FISHERY

Commercial Landings

Commercial landings in 1993 were 23,113 mt, 19% lower than in 1992 (Table F1, Figure F1). The U.S. and Canada, sole participants in the fishery since 1978, accounted for 63% and 37%, respectively, of the 1993 total. The 1993 U.S. landings (14,594 mt) were 13% less than in 1992, and the lowest U.S. total since 1972. Canadian 1993 landings totaled 8,519 mt, 27% lower than in 1992.

As in the past, otter trawl landings accounted for most (more than 70%) of the 1993 landings. The otter trawl fishery accounted for 80% of the 1993 U.S. landings (Table F2) and 57% of the Canadian landings (Hunt and Buzeta 1994). During 1978-1992, 85% of the U.S. landings and 61% of the Canadian landings was attributable to otter trawl gear. United States cod landings from Georges Bank have been dominated by 'market' cod, which historically has accounted for between 40 and 60% of the total landings by weight. The percentage of 'scrod' cod has increased from 10-20% during the 1960s and 1970s to 20-30% during the 1980s, or about the same as that for 'large' cod. 'Scrod' cod accounted for 29% of the U.S. landings by weight during 1993, but accounted for 51% of the landings in number of fish.

Discards

Discard estimates of Georges Bank cod are not available for either the U.S. or Canadian fisheries.

Recreational Catches

Catch Trends

An evaluation of the national saltwater angling surveys and the Marine Recreational Fishery Statistics Surveys (MRFSS) and a description of historic trends in recreational cod catches are provided by Serchuk *et al.* (1993). Between 1981 and 1985, annual recreational cod landings were relatively stable; apart from 1984, annual catches from the Georges Bank stock varied between 4500 and 5300 mt, and averaged 4400 mt per year. Recreational cod catches declined in 1986 and 1987 to about 1000 mt, increased to 4300 mt in 1988, but sequentially declined between 1989 and 1992. Recreational catch increased to more than 2200 mt in 1993 (Table F3). Methods for estimating catch are being revised and are expected to result in slightly lower estimates for all years in the times series.

Commercial Fishery Sampling Levels

A summary of U.S. and Canadian length frequency and age sampling of Georges Bank cod landings during 1978-1993 is presented in Table F4. From 1978 to 1981, U.S. length frequency sampling averaged one sample per 471 mt but, since 1982, has improved to one sample per 273 mt landed. In 1978-1981, sampling of the large market category was poor, but improved markedly since 1982. Sampling intensity in 1993 (1 sample per 178 mt) was greater than in preceding years (1990: 1 sample per 340 mt; 1991: 1 sample per 275 mt). In 1993, the distribution of samples

Table F1. Commercial landings (metric tons, live) of Atlantic cod from Georges Bank and South (Division 5Z and Subarea 6), 1960 - 1993

Year	Country						
	USA	Canada	USSR	Spain	Poland	Other	Total
1960	10834	19	-	-	-	-	10853
1961	14453	223	55	-	-	-	14731
1962	15637	2404	5302	-	143	-	23486
1963	14139	7832	5217	-	-	1	27189
1964	12325	7108	5428	18	48	238	25165
1965	11410	10598	14415	59	1851	-	38333
1966	11990	15601	16830	8375	269	69	53134
1967	13157	8232	511	14730	-	122	36752
1968	15279	9127	1459	14622	2611	38	43136
1969	16782	5997	646	13597	798	119	37939
1970	14899	2583	364	6874	784	148	25652
1971	16178	2979	1270	7460	256	36	28179
1972	13406	2545	1878	6704	271	255	25059
1973	16202	3220	2977	5980	430	114	28923
1974	18377	1374	476	6370	566	168	27331
1975	16017	1847	2403	4044	481	216	25008
1976	14906	2328	933	1633	90	36	19926
1977	21138	6173	54	2	-	-	27367
1978	26579	8778	-	-	-	-	35357
1979	32645	5978	-	-	-	-	38623
1980	40053	8063	-	-	-	-	48116
1981	33849	8499	-	-	-	-	42348
1982	39333	17824	-	-	-	-	57157
1983	36756	12130	-	-	-	-	48886
1984	32915	5763	-	-	-	-	38678
1985	26828	10443	-	-	-	-	37271
1986	17490	8411	-	-	-	-	25901
1987	19035	11845	-	-	-	-	30880
1988	26310	12932	-	-	-	-	39242
1989	25097	8001	-	-	-	-	33098
1990	28193	14310	-	-	-	-	42503
1991	24175	13455	-	-	-	-	37630
1992	16855	11712	-	-	-	-	28567
1993*	14594	8519	-	-	-	-	23113

*Provisional

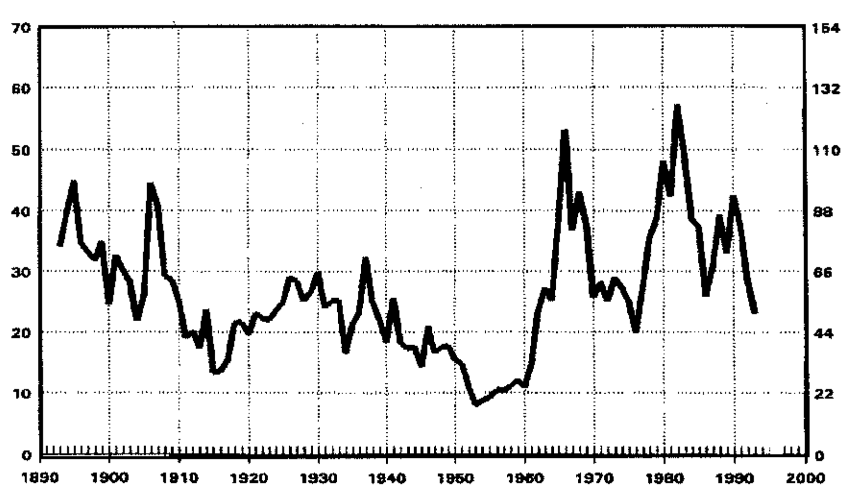


Figure F1. Total commercial landings of Georges Bank cod (Divisions 5Z and 6), 1893-1993

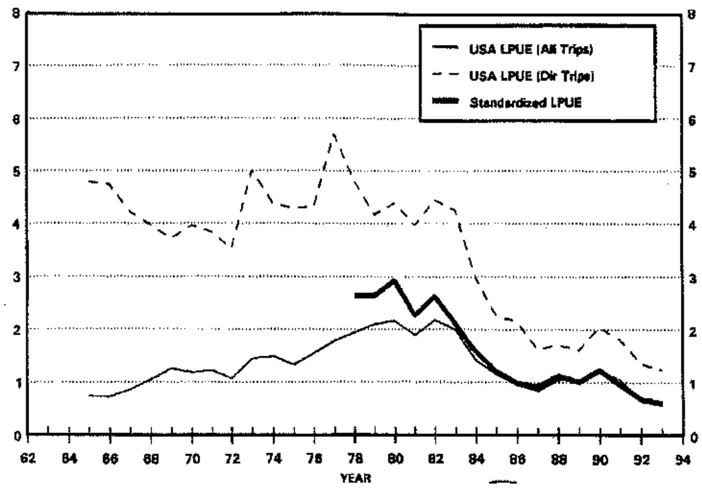


Figure F2. Trends in U.S. LPUE (landings per day fished) of Georges Bank cod. The 1965-1993 indices are based on all otter trawl trips landing cod (all trips), and on otter trawl trips in which cod constituted 50% or more of trip landings by weight (dir trips). A standardized LPUE series from 1978-1992 based on a GLM incorporating year, tonnage class, area, quarter, and depth is also included.

Table F2. Distribution of U.S. commercial landings (metric tons, live) of Atlantic cod from Georges Bank (Area 5Ze), by gear type, 1965 - 1993.

Year	Landings (metric tons, live)						Percentage of Annual Landings					
	Otter Trawl	Sink Gill Net	Line Trawl	Handline	Other Gear	Total	Otter Trawl	Sink Gill Net	Line Trawl	Handline	Other Gear	Total
1965	10251	0	582	505	9	11347	90.3	-	5.1	4.5	0.1	100.0
1966	10206	0	787	757	19	11769	86.7	-	6.7	6.4	0.2	100.0
1967	10915	0	894	704	9	12522	87.2	-	7.1	5.6	0.1	100.0
1968	12084	0	936	524	<1	13544	89.2	-	6.9	3.9	-	100.0
1969	13194	0	1371	387	<1	14952	88.2	-	9.2	2.6	-	100.0
1970	11270	0	1676	404	<1	13350	84.4	-	12.6	3.0	-	100.0
1971	12436	0	2334	230	2	15002	82.9	-	15.6	1.5	-	100.0
1972	10179	0	2071	217	10	12477	81.6	-	16.6	1.7	0.1	100.0
1973	12431	3	2185	206	21	14846	83.7	-	14.7	1.4	0.2	100.0
1974	14078	3	2548	11	9	16649	84.6	-	15.3	0.1	-	100.0
1975	12069	0	2435	84	4	14592	82.7	-	16.7	0.6	-	100.0
1976	12257	4	1519	153	5	13938	88.0	-	10.9	1.1	-	100.0
1977	18529	30	912	83	22	19576	94.7	0.2	4.7	0.4	0.1	100.0
1978	20862	81	1569	1180	59	23751	87.8	0.3	6.6	5.0	0.3	100.0
1979	26562	620	2707	860	159	30908	85.9	2.0	8.8	2.8	0.5	100.0
1980	32479	4491	1102	0	273	38345	84.7	11.7	2.9	-	0.7	100.0
1981	27694	3515	120	584	197	32110	86.2	10.9	0.4	1.8	0.6	100.0
1982	33371	2935	385	624	210	37525	88.9	7.8	1.0	1.7	0.6	100.0
1983	30981	1812	831	441	81	34146	90.7	5.3	2.4	1.3	0.3	100.0
1984	26161	2573	366	753	197	30050	87.1	8.6	1.2	2.5	0.6	100.0
1985	21444	2482	436	284	163	24809	86.4	10.0	1.8	1.1	0.7	100.0
1986	13576	1679	692	305	95	16347	83.0	10.3	4.2	1.9	0.6	100.0
1987	13711	1522	1636	222	71	17162	79.9	8.9	9.5	1.3	0.4	100.0
1988	20296	1864	1950	232	116	24458	83.0	7.6	8.0	0.9	0.5	100.0
1989	17946	3150	1583	119	91	22889	78.4	13.8	6.9	0.5	0.4	100.0
1990	21707[1]	2316	1252	395	133	25803	84.1	9.0	4.9	1.5	0.5	100.0
1991	17892[2]	2171	1919	286	180	22448	79.7	9.7	8.5	1.3	0.8	100.0
1992	11696[3]	1747	1709	186	114	15452	75.7	11.3	11.1	1.2	0.7	100.0
1993	10893[4]	1321	1316	62	78	13670	79.7	9.7	9.6	0.4	0.6	100.0

Notes: The percentage of total U.S. commercial landings of Atlantic cod from Georges Bank, by gear type, is also presented for each year. Data only reflect Georges Bank cod landings that could be identified by gear type.

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

[2] Includes 1068 tons taken by pair-trawl

[3] Includes 1149 tons taken by pair-trawl

[4] Includes 1352 tons taken by pair-trawl

Table F3. Estimated number (thousands) and weight (metric tons, live) of Atlantic cod caught by marine recreational fishermen, in 1960, 1965, 1970, 1974, and 1979 - 1993[1]

Year	All Regions		Georges Bank Stock	
	No. of Cod (thousands)	Wt. of Cod (mt)	No. of Cod (thousands)	Wt. of Cod (mt)
1960	4791	14016	Not Estimated	
1965	5032	13565	Not Estimated	
1970	3844	16292	Not Estimated	
1974	2901	12368	Not Estimated	
1979	3091	4026	393	580
1980	2440	7331	186	471
1981	4845	9712	1605	4677
1982	3250	8244	1453	5296
1983	3747	7542	1693	4920
1984	2562	5080	832	2406
1985	3674	7664	1998	4635
1986	1548	3510	331	1092
1987	2063	3779	467	1168
1988	2966	7327	1494	4284
1989	2463	6119	538	1875
1990	2635	5144	690	1696
1991	1854	3727	444	1255
1992	720	1516	209	507
1993	2282	4918	890	2207

[1] From 1979-1993 Marine Recreational Fishery Statistics Survey expanded catch estimates.

by market category, *i.e.* 42% scrod, 44% market, and 14% large, approximated the distribution of landings in number by market category. Prior to 1985, Canadian sampling coverage averaged about one sample per 1000 mt landed (Hunt and Buzeta 1994). Sampling intensity has markedly improved since 1985 and has averaged one sample per 290 mt landed during the 1986-1992 period. Canadian sampling intensity in 1993 was 1 sample per 167 mt.

Commercial Catch at Age

Commercial landings in 1993 were dominated by the 1989 and 1990 year classes (Table F5). Together, these two cohorts accounted for 70% of the landings by number and 57% by weight. The 1990 year class dominated both of the 1993 U.S. (62% by number, 49% by weight) and the 1993 Canadian landings (42% by number; 29% by weight). The 1989 year class was the second most important in terms of biomass, 13% and 22% respectively. Unlike the 1988-1992 period when the Canadian landings of age 4 averaged 30 percent of the total age 4 landings, Canadian landings of age 4 fish during 1993 exceed 50 percent of the total landings by number.

Table F4. United States and Canadian sampling of commercial Atlantic cod landings from the Georges Bank and South cod stock (NAFO Division 5Z and Statistical Area 6), 1978 - 1993

Year	United States				Canada			
	Length Samples		Age Samples		Length Samples		Age Samples	
	No.	# Fish Measured	No.	# Fish Aged	No.	# Fish Measured	No.	# Fish Aged
1978	88	6841	76	1463	29	7684	29	1308
1979	80	6973	79	1647	13	3991	12	656
1980	69	4990	67	1119	10	2784	10	536
1981	57	4304	57	1231	17	4147	16	842
1982	151	11970	147	2579	17	4756	8	858
1983	146	12544	138	2945	15	3822	14	604
1984	100	8721	100	2431	7	1889	7	385
1985	100	8366	100	2321	29	7644	20	1062
1986	94	7515	94	2222	19	5745	19	888
1987	80	6395	79	1704	33	9477	33	1288
1988	76	6483	76	1576	40	11709	40	1984
1989	66	5547	66	1350	32	8716	32	156
1990	83	7158	83	1700	40	9901	40	2012
1991	88	7708	88	1865	45	10873	45	1782
1992	77	6549	77	1631	48	10878	48	1906
1993	82	6636	82	1598	51	12158	51	2146

Table F5. Landings at age (thousands of fish; metric tons) and mean weight (kilograms) and mean length (cm) at age of total commercial landings of Atlantic cod from the Georges Bank and South cod stock (NAFO Division 5Z and Statistical Area 6), 1978 - 1993

Year	**Age**										**Total**	**% of Total Landings**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**		**USA**	**Canada**
Total Commercial Landings in Numbers (Thousands) at Age													
1978	2	393	7748	2303	830	131	345	47	40	15	11854	73.7	26.3
1979	34	1989	900	4870	1212	458	77	253	4	48	9845	81.2	18.8
1980	89	3777	5828	500	2308	1076	445	87	167	10	14287	80.9	19.1
1981	27	3205	4221	2464	235	1406	417	123	130	62	12290	84.1	15.9
1982	331	9138	3824	2787	2000	281	673	213	71	83	19401	74.1	25.9
1983	108	4286	8063	2456	1055	776	95	235	100	65	17239	72.2	27.8
1984	81	1307	3423	3336	840	516	458	44	171	121	10297	89.0	11.0
1985	134	6426	2443	1368	1885	412	218	203	21	97	13207	68.4	31.6
1986	156	1326	4573	797	480	627	87	72	47	29	8194	71.7	28.3
1987	26	7473	1406	2121	279	252	270	63	38	24	11952	64.2	35.8
1988	10	1577	8022	1012	1497	244	161	197	50	47	12817	71.6	28.4
1989	-	2088	2922	4155	331	541	82	43	50	18	10230	81.1	18.9
1990	7	4942	5042	1882	2264	229	245	36	17	38	14702	74.3	25.7
1991	52	1525	3243	3281	1458	1088	126	70	23	23	10889	67.7	32.3
1992	70	4177	2170	1038	1482	404	309	34	33	10	9727	58.7	41.3
1993	4	1033	4246	1115	440	472	159	143	32	17	7661	67.0	33.0
Total Commercial Landings in Weight (Tons) at Age													
1978	1	515	18890	7990	3597	757	2549	395	465	198	35357	75.2	24.8
1979	30	2970	1936	20504	5923	3288	711	2611	44	606	38623	84.5	15.5
1980	75	5516	14382	1833	13036	7184	3735	793	1408	154	48116	83.2	16.8
1981	24	4789	9953	8416	1224	10156	3575	1212	1848	1151	42348	79.9	20.1
1982	253	12812	10187	10681	10705	1827	6303	2110	891	1388	57157	68.8	31.2
1983	105	6387	19167	8126	4891	4963	763	2418	1120	946	48886	75.2	24.8
1984	85	2137	8389	12074	4271	3401	4078	447	1938	1858	38678	85.1	14.9
1985	121	9111	5095	5319	9588	2644	1765	2073	246	1309	37271	72.0	28.0
1986	145	1955	11189	2917	2692	4505	776	717	596	409	25901	67.5	32.5
1987	19	11071	3509	8882	1619	1945	2416	633	426	360	30880	61.6	38.4
1988	8	2399	18923	3552	8085	1618	1412	1960	566	719	39242	67.0	33.0
1989	-	3375	6633	15673	1783	3625	669	455	588	298	33098	75.8	24.2
1990	5	7709	12412	6629	11075	1448	2069	382	222	552	42503	66.3	33.7
1991	59	2481	8265	11221	6955	6411	933	736	223	346	37630	64.2	35.8
1992	80	6441	5348	3991	6971	2486	2322	334	402	192	28567	59.0	41.0
1993	3	1585	9566	3717	2184	3012	1195	1315	316	220	23113	63.1	36.9
Total Commercial Landings Mean Weight (Kilograms) at Age													
1978	0.707	1.310	2.461	3.469	4.336	5.787	7.374	8.492	11.785	13.200	2.983		
1979	0.889	1.494	2.149	4.211	4.888	7.178	9.183	10.313	11.699	12.625	3.923		
1980	0.836	1.460	2.468	3.668	5.647	6.676	8.390	9.089	8.432	15.400	3.368		
1981	0.882	1.495	2.358	3.415	5.213	7.222	8.565	9.888	14.170	18.565	3.446		
82	0.765	1.402	2.664	3.834	5.352	6.511	9.363	9.897	12.503	16.723	2.946		
83	0.971	1.490	2.377	3.309	4.637	6.393	7.964	10.286	11.227	14.554	2.836		
84	1.053	1.635	2.451	3.619	5.083	6.582	8.909	10.104	11.303	15.356	3.756		
85	0.907	1.418	2.086	3.887	5.087	6.412	8.097	10.236	11.418	13.494	2.822		
86	0.929	1.475	2.447	3.660	5.603	7.191	8.915	9.955	12.687	14.104	3.161		
87	0.726	1.481	2.495	4.187	5.810	7.726	8.949	10.013	11.414	15.000	2.584		
88	0.786	1.520	2.359	3.511	5.401	6.647	8.776	9.987	11.143	15.298	3.062		
89	-	1.617	2.269	3.772	5.396	6.694	8.222	10.718	11.665	17.111	3.235		
90	0.831	1.560	2.462	3.522	4.892	6.333	8.456	10.648	12.580	14.526	2.891		
91	1.114	1.627	2.548	3.420	4.769	5.891	7.410	10.520	9.686	15.373	3.456		
92	1.148	1.542	2.464	3.843	4.704	6.156	7.509	9.846	12.059	19.025	2.937		
93	0.872	1.534	2.253	3.333	4.967	6.379	7.510	9.217	9.699	13.236	3.017		
Total Commercial Landings Mean Length (Centimeters) at Age													
78	39.5	50.0	60.8	67.9	72.7	80.4	80.2	93.1	103.4	106.5	64.1		
79	44.7	52.2	57.7	73.2	76.8	87.5	95.3	99.5	103.4	106.4	69.6		
80	43.8	51.8	61.2	69.7	80.9	86.0	92.4	93.8	92.4	114.6	65.6		
81	44.4	52.2	60.2	68.4	78.2	88.0	93.5	97.5	110.3	119.5	65.6		
82	42.2	51.2	62.4	70.5	79.1	84.3	96.0	97.4	105.8	115.0	61.9		
83	45.5	52.3	60.4	67.0	75.3	84.4	90.7	99.1	101.9	111.4	62.4		
84	47.2	54.0	61.5	69.8	77.8	85.5	94.4	98.6	102.3	112.8	68.6		
85	44.9	51.1	57.5	71.4	78.0	84.3	91.3	98.8	102.3	108.2	61.1		
86	45.0	51.9	61.1	69.2	80.7	87.7	94.4	98.0	105.9	108.4	64.3		
87	40.7	51.8	61.2	73.0	81.8	90.1	94.5	98.2	102.5	111.2	59.7		
88	40.8	52.8	60.4	68.5	79.5	85.3	93.6	97.7	101.5	111.2	64.1		
89	-	53.8	60.0	70.4	79.2	85.2	91.7	100.3	103.2	113.3	65.7		
90	41.7	53.5	61.0	68.7	76.6	83.2	92.1	100.2	106.0	110.8	62.9		
91	47.7	53.6	62.2	67.7	75.8	80.9	87.8	99.4	95.9	113.9	67.0		
92	46.2	52.4	60.8	70.6	75.1	82.2	87.9	96.0	104.3	116.0	62.4		
93	42.2	52.7	59.6	67.0	76.3	83.6	88.2	95.1	95.9	107.0	63.0		

Table F6. Mean weight at age (kilograms) at the beginning of the year (January 1) for Georges Bank and South cod stock (NAFO Division 5Z and Subarea 6), 1978 - 1993

Age	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.486	0.694	0.625	0.700	0.548	0.748	0.907	0.711	0.736	0.502	0.548	0.583	0.594	0.947	0.993	0.573
2	1.023	1.028	1.139	1.118	1.112	1.068	1.260	1.222	1.157	1.173	1.050	1.127	1.123	1.163	1.311	1.327
3	1.881	1.678	1.920	1.855	1.996	1.826	1.911	1.847	1.863	1.918	1.869	1.857	1.995	1.994	2.002	1.864
4	2.922	3.219	2.808	2.903	3.007	2.969	2.933	3.087	2.763	3.201	2.960	2.983	2.827	2.902	3.129	2.866
5	3.370	4.118	4.876	4.373	4.275	4.216	4.101	4.291	4.667	4.611	4.755	4.353	4.296	4.098	4.011	4.369
6	4.594	5.579	5.712	6.386	5.826	5.849	5.525	5.709	6.048	6.579	6.214	6.013	5.846	5.368	5.418	5.478
7	6.235	7.290	7.760	7.562	8.223	7.201	7.547	7.300	7.561	8.022	8.234	7.393	7.524	6.850	6.651	6.799
8	7.235	8.721	9.136	9.108	9.207	9.814	8.970	9.549	8.978	9.448	9.454	9.699	9.357	9.432	8.542	8.319
9	10.004	9.967	9.325	11.349	11.119	10.541	10.783	10.741	11.396	10.660	10.563	10.793	11.612	10.156	11.263	9.772
10+	13.200	12.625	15.400	18.565	16.723	14.554	15.356	13.494	14.104	15.000	15.298	17.111	14.526	15.373	19.025	13.236

Note: Values derived from landings mean weights-at-age using the procedures described by Rivard (1980).

Commercial Mean Weights at Age

Mean weights at age in the landings for ages 1-10+ during 1978-1993 are given in Table F5 and, based on landings patterns, are considered mid-year values. Although no consistent trends in size or weight at age are evident over the 16-year time series, mean weights in 1990-1993 are below the long-term average.

Mean weights at age for calculating stock biomass at the beginning of the year are provided in Table F6. These values were derived from the catch mean weights at age data (Table F5) using the procedures described by Rivard (1980).

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial Catch per Unit Effort

United States commercial LPUE indices (landings per unit effort, expressed in metric tons landed per day fished) were calculated, by tonnage class (Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT), from otter trawl trips landing cod from Georges Bank (Subdivision 5Ze). Indices were derived based on all trips landing cod, and for 'directed trips' in which cod constituted 50% or more of the total trip catch by weight (Table F7). 'Directed trips' have accounted for more than 50% (and as high as 79%) of U.S. Georges Bank otter trawl landings of cod since 1973 (Table F8). In 1993, 'directed trips' accounted for 58% of the U.S. landings. During 1988-1991, the U.S. fishery for cod had become highly directed (*i.e.*, nearly 75% of the U.S. otter trawl landings of cod were taken in 'directed trips'). The sharp decline in the percentage of cod taken on directed trips in 1992 and 1993 is a substantial departure from the recent four years.

Since 1970, both total and directed U.S. LPUE indices have generally exhibited similar trends (Table F7; Figure F2). The LPUE values generally increased during the early 1970s, leveled off during the mid-1970s, and then sharply increased attaining peak levels in the late 1970s. Subsequently, LPUE indices decreased until 1988 when both total and directed indices increased. In 1990, LPUE values again increased, but both LPUE indices declined in the latest three years to record low levels. In terms of 'calculated effort' (total U.S. landings/U.S. LPUE index), U.S. fishing effort peaked in 1988, declined in 1989 and 1990, but has since increased to about the 1988 level (Table F9; Figure F3).

Table F7. United States commercial landings (L)[1], days fished (DF)[2], and landings per day fished (L/DF), by vessel tonnage class (Class 2: 5-50 GRT; Class 3: 51-150 GRT; Class 4: 151-500 GRT), of Atlantic cod for otter trawl trips catching cod from Georges Bank (NAFO Subdivision 5Ze), 1965 - 1993

Year	Class 2			Class 3			Class 4			Total	
	L	DF	L/DF	L	DF	L/DF	L	DF	L/DF	L	L/DF[3]
						ALL TRIPS					
1965	487	1661	0.29	5201	9719	0.54	4351	4175	1.04	10039	0.74
1966	386	1555	0.25	4754	10505	0.45	4731	4510	1.05	9871	0.73
1967	437	1069	0.41	5292	8570	0.62	4519	3789	1.19	10248	0.86
1968	321	570	0.56	6861	8534	0.80	4903	3397	1.44	12085	1.05
1969	433	500	0.87	7942	7953	1.00	4819	2783	1.73	13194	1.26
1970	508	535	0.95	6729	8296	0.81	4033	2218	1.82	11270	1.18
1971	563	681	0.83	7652	8808	0.87	4215	2195	1.92	12430	1.22
1972	524	721	0.73	6382	9257	0.69	3274	1766	1.85	10180	1.07
1973	322	550	0.59	7814	8668	0.90	4295	1701	2.52	12431	1.45
1974	585	617	0.95	8222	9438	0.87	5266	2097	2.51	14073	1.49
1975	509	534	0.95	7029	8684	0.81	4527	2085	2.17	12065	1.33
1976	421	474	0.89	7861	7791	1.01	3969	1469	2.70	12251	1.55
1977	850	607	1.40	13250	9492	1.40	4423	1472	3.00	18523	1.78
1978	1165	715	1.63	14853	9411	1.58	4829	1551	3.11	20847	1.94
1979	956	658	1.45	18377	9924	1.85	7116	2507	2.84	26449	2.10
1980	1062	882	1.20	21331	10961	1.95	10053	3726	2.70	32446	2.16
1981	1184	845	1.40	17025	10615	1.60	9404	3797	2.48	27613	1.89
1982	1406	695	2.02	20468	10717	1.91	11450	4296	2.67	33324	2.18
1983	835	429	1.95	17112	10694	1.60	13011	5116	2.54	30958	2.00
1984	375	427	0.88	14883	13605	1.09	10899	5746	1.90	26157	1.42
1985	370	453	0.82	12852	13629	0.94	8215	5501	1.49	21437	1.15
1986	150	233	0.64	8014	10442	0.77	5411	4354	1.24	13575	0.96
1987	108	220	0.49	8505	12067	0.70	5090	4770	1.07	13703	0.84
1988	100	233	0.43	12808	13791	0.93	7345	5799	1.27	20253	1.05
1989	144	320	0.45	10104	13142	0.77	7676	5269	1.46	17924	1.06
1990	141	260	0.54	11496	13557	0.85	9345	5497	1.70	20982	1.23
1991	89	239	0.37	8867	12825	0.69	7887	5398	1.46	16843	1.05
1992	42	170	0.25	5757	12707	0.45	4734	5261	0.90	10533	0.65
1993	15	105	0.14	5077	13263	0.38	4437	5476	0.81	9529	0.58
						50% TRIPS					
1965	18	8	2.25	353	86	4.10	819	159	5.15	1190	4.79
1966	7	<1	-	370	88	4.20	991	199	4.98	1368	4.74
1967	33	17	1.94	874	238	3.67	1464	318	4.60	2371	4.22
1968	16	3	5.33	1665	464	3.59	1442	328	4.40	3123	3.97
1969	73	9	8.11	2612	773	3.38	1475	359	4.11	4160	3.72
1970	164	25	6.56	1695	534	3.17	1739	388	4.48	3598	3.96
1971	117	15	7.80	2232	721	3.10	2163	494	4.38	4512	3.84
1972	152	54	2.81	2137	716	2.98	1879	445	4.22	4168	3.53
1973	52	16	3.25	3242	820	3.95	3010	486	6.19	6304	5.01
1974	259	119	2.18	3707	1115	3.32	3899	703	5.55	7865	4.39
1975	246	85	2.89	2678	842	3.18	3128	585	5.35	6052	4.29
1976	159	66	2.41	3665	1089	3.37	2664	464	5.74	6488	4.32
1977	502	120	4.18	6595	1342	4.91	2899	373	7.77	9996	5.70
1978	846	215	3.93	6554	1644	3.99	2427	330	7.35	9827	4.81
1979	612	168	3.64	9714	2558	3.80	4270	840	5.08	14596	4.17
1980	644	196	3.29	11727	2909	4.03	5616	1067	5.26	17987	4.39
1981	766	153	5.01	9414	2591	3.63	4312	953	4.52	14492	3.97
1982	1046	212	4.93	14724	3631	4.06	7791	1521	5.12	23561	4.45
1983	566	130	4.35	11884	3033	3.92	8795	1872	4.70	21245	4.25
1984	140	55	2.55	9156	3454	2.65	6620	1918	3.45	15916	2.98
1985	184	65	2.83	8725	4346	2.01	6053	2330	2.60	14962	2.26
1986	58	18	3.22	5258	2969	1.77	3755	1406	2.67	9071	2.15
1987	36	18	2.00	5743	3874	1.48	3354	1781	1.88	9133	1.63
1988	37	22	1.68	9974	6457	1.54	5527	2731	2.02	15538	1.71
1989	66	56	1.18	7866	6021	1.31	6252	3097	2.02	14184	1.62
1990	61	16	3.81	8401	4954	1.70	7629	3153	2.42	16091	2.05
1991	27	12	2.25	5910	4339	1.36	5817	2559	2.27	11754	1.81
1992	4	7	0.57	3159	2957	1.07	2722	1605	1.70	5885	1.36
1993	4	6	0.67	2804	3061	0.92	2711	1712	1.58	5519	1.24

Note: Data are also provided for otter trawl trips in which cod constituted 50% or more of the total trip catch, by weight ['directed trips'].

[1] Metric tons, live weight.

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

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

Table F8. Percentage, within vessel tonnage class[1], of Atlantic cod otter trawl landings (L)[2], vessel trips (T) and effort (DF)[3] from Georges Bank (NAFO Subdivision 5Ze) accounted for by otter-trawl trips in which cod constituted 50% or more of the total trip catch, by weight ['directed trips'], 1965 - 1993

Year	Class 2			Class 3			Class 4			Totals		
	L	T	DF	L	T	DF	L	T	DF	L	T	DF
1965	3.7	1.0	0.5	6.8	1.9	0.9	18.8	5.3	3.8	11.9	2.4	1.6
1966	1.8	0.1	<0.1	7.8	1.4	0.8	20.9	6.5	4.4	13.9	2.2	1.7
1967	7.6	1.3	1.6	16.5	4.0	2.8	32.4	11.5	8.4	23.1	4.9	4.3
1968	5.0	1.0	0.5	24.3	5.9	5.4	29.4	12.3	9.7	25.8	6.5	6.4
1969	16.9	5.2	1.8	32.9	10.0	9.7	30.6	13.8	12.9	31.5	10.3	10.2
1970	32.3	10.4	4.7	25.2	7.3	6.4	43.1	19.5	17.5	31.9	9.7	8.6
1971	20.8	6.9	2.2	29.2	8.3	8.2	51.3	24.2	22.5	36.3	10.3	10.5
1972	29.0	8.8	7.5	33.5	9.7	7.7	57.4	25.2	25.2	40.9	11.5	10.3
1973	16.1	3.4	2.9	41.5	10.7	9.5	70.1	31.4	28.6	50.7	12.9	12.1
1974	44.3	11.1	19.3	45.1	13.9	11.8	74.0	37.8	33.5	55.9	17.3	15.9
1975	48.3	10.6	15.9	38.1	12.3	9.7	69.1	32.8	28.1	50.2	15.7	13.4
1976	37.8	11.1	13.9	46.6	16.9	14.0	67.1	35.1	31.6	53.0	19.1	16.6
1977	59.1	15.5	19.8	49.8	18.9	14.1	65.5	29.2	25.3	54.0	19.8	15.9
1978	72.6	22.0	30.1	44.1	22.6	17.5	50.3	28.1	21.3	47.1	23.2	18.7
1979	64.0	21.0	25.5	52.9	28.0	25.8	60.0	35.4	33.5	55.2	28.7	27.2
1980	60.6	21.1	22.2	55.0	26.9	26.5	55.9	34.5	28.6	55.4	27.7	26.8
1981	64.7	21.1	18.1	55.3	26.0	24.4	45.9	27.3	25.1	52.5	25.6	24.2
1982	74.4	23.9	30.5	71.9	34.1	33.9	68.0	38.8	35.4	70.7	33.7	34.1
1983	67.8	19.5	30.3	69.4	29.1	28.4	67.6	38.9	36.6	68.6	30.6	31.0
1984	37.3	7.0	12.9	61.5	25.9	25.4	60.7	35.2	33.4	60.8	26.4	27.4
1985	49.7	8.7	14.3	67.9	29.8	31.9	73.7	41.9	42.4	69.8	30.9	34.4
1986	38.7	7.9	7.7	65.6	27.6	28.4	69.4	32.5	32.3	66.8	27.2	29.2
1987	33.3	3.5	8.2	67.5	29.1	32.1	65.9	36.3	37.3	66.6	29.1	33.3
1988	37.0	5.4	9.4	77.9	43.3	46.8	75.2	45.9	47.1	76.7	41.8	46.5
1989	45.8	8.6	17.5	77.9	43.1	45.8	81.4	57.1	58.8	79.1	44.3	49.0
1990	43.3	8.5	6.2	73.1	37.1	36.5	81.6	55.3	57.4	76.7	40.4	42.1
1991	30.3	7.9	5.0	66.7	34.4	33.8	73.8	50.5	47.4	69.8	37.8	37.4
1992	9.5	3.9	4.1	54.9	24.7	23.3	57.5	33.1	30.5	55.9	26.4	25.2
1993	26.7	2.9	5.7	55.2	22.7	23.1	61.1	34.1	31.3	57.9	25.4	25.4

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

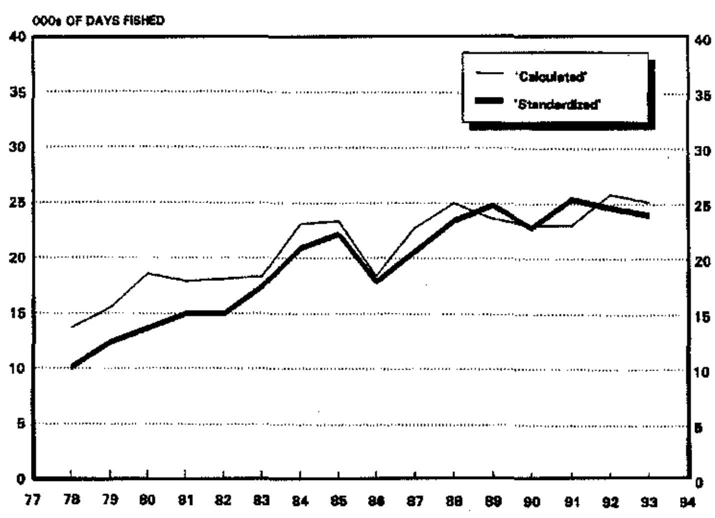


Figure F3. Trends in U.S. fishing effort (days fished) on Georges Bank cod, 1978-1993. Results are based on all otter trawl trips landing cod. A standardized effort series based on a GLM incorporating year, tonnage class, area, quarter, and depth is also included.

Table F9. Total and U.S. commercial landings (metric tons), U.S. landings-per-unit of effort indices (LPUE: all cod trips), and derived effort indices for Georges Bank cod, 1965 - 1993

Year	Total Landings (mt)	U.S. Landings (mt)	U.S. LPUE (All Cod Trips)	Total Calc. DF	U.S. Calc. DF
1965	38333	11410	0.745	51483	15324
1966	53134	11990	0.730	72811	16430
1967	36752	13157	0.862	42616	15256
1968	43136	15279	1.053	40954	14506
1969	37939	16782	1.262	30054	13294
1970	25652	14899	1.178	21781	12650
1971	28179	16178	1.224	23018	13215
1972	25059	13406	1.065	23527	12586
1973	28923	16202	1.452	19924	11161
1974	27331	18377	1.487	18380	12358
1975	25008	16017	1.326	18857	12077
1976	19926	14906	1.553	12827	9596
1977	27367	21138	1.782	15357	11862
1978	35357	26579	1.937	18252	13720
1979	38623	32645	2.102	18375	15531
1980	48116	40053	2.158	22298	18562
1981	42348	33849	1.891	22393	17899
1982	57157	39333	2.176	26270	18078
1983	48886	36756	2.005	24388	18337
1984	38678	32915	1.424	27152	23106
1985	37271	26828	1.149	32446	23355
1986	25901	17490	0.956	27096	18386
1987	30880	19035	0.836	36947	22775
1988	39242	26310	1.051	37344	25037
1989	33098	25097	1.063	31139	23611
1990	42503	28193	1.226	34654	22987
1991	37630	24175	1.049	35877	23049
1992	28567	16855	0.651	43851	25873
1993	23113	14594	0.580	39861	25169

Table F10. Georges Bank cod landings (metric tons), nominal and standardized effort (days fished) and landings per day fished (LPUE), United States only

Year	U.S. Landings Used in GLM (mt)	Nominal		Standardized		
		Effort	LPUE	Effort	LPUE	Raised Effort
1978	15776	8078	1.953	5982	2.637	10079
1979	20584	9547	2.156	7788	2.643	12394
1980	25213	10217	2.468	8600	2.932	13661
1981	18340	9149	2.005	8113	2.260	14977
1982	23292	10051	2.317	8859	2.629	14961
1983	22072	11668	1.892	10456	2.111	17412
1984	19669	14641	1.343	12495	1.574	20912
1985	18012	16447	1.095	14892	1.209	22190
1986	11572	12520	0.924	11834	0.978	17883
1987	12731	14945	0.852	13791	0.923	20622
1988	19010	17769	1.070	16911	1.124	23407
1989	15557	15834	0.983	15407	1.010	24849
1990	18358	15882	1.156	14836	1.237	22791
1991	14173	14857	0.954	14917	0.950	25447
1992	8786	13606	0.646	12845	0.684	24642
1993	7749	12957	0.598	12736	0.608	24003

Standardized fishing effort and LPUE was estimated for a sub-fleet by applying a five-factor (year, area, quarter, tonnage class and depth) General Linear Model (GLM) to log LPUE data derived for all interviewed otter trawl trips taking cod from 1978 through 1992. Details regarding data selection and preparation and model formulation are provided by Mayo *et al.* (1994b). Standardized (raised) U.S. effort doubled between 1978 and 1984, then stabilized during 1984-1987 and has remained at historically high levels since 1988. Both series of U.S. effort estimates (Tables F9 and F10) show the same trends over time - an increase throughout the 1980s with peak effort occurring in 1988-89 followed by a period of high, relatively stable, effort through 1993 (Figure F3).

The age composition of the landings corresponding to the effort subfleet was estimated and used with standardized effort estimates to calculate a LPUE at age index for calibrating the VPA. Details regarding data selection and preparation and estimation procedures are provided by Mayo *et al.* (1994b).

Research Vessel Survey Indices

NEFSC spring and autumn offshore catch per tow indices for Georges Bank cod have exhibited similar trends, both in abundance and biomass, throughout the survey time series (Table F11). Survey biomass indices were relatively low and stable during 1963-1971, fluctuated at a generally higher level between 1972 and 1981, but have since declined to record-low levels (Figure F4). The abundance and biomass indices from the spring 1994 survey indicate a stock decline to record low levels. Large increases in the number per tow indices in 1967, 1972-73, 1976, 1978, 1981, 1985, and 1988-89 (Table F11) reflect above average recruitment of the 1966, 1971, 1975, 1977, 1978, 1980, 1983, 1985, and 1987 year classes at ages 1 and 2 (Table F12, Figure F5).

MORTALITY

Total Mortality

Pooled estimates of instantaneous total mortality (Z) were calculated for eight time periods encompassed by the NEFSC autumn and spring offshore surveys: 1964-1967, 1968-1972, 1973-1976, 1977-1981, 1982-1984, 1985-1987, 1988-

Table F11. Standardized stratified mean catch per tow in numbers and weight (kilograms) for Atlantic cod in NEFSC offshore spring and autumn research vessel bottom trawl surveys on Georges Bank (Strata 13-25), 1963 - 1994 [a,b,c]

Year	Spring		Autumn	
	No/Tow	Wt/Tow	No/Tow	Wt/Tow
1963	-	-	4.37	17.8
1964	-	-	2.98	11.6
1965	-	-	4.25	11.7
1966	-	-	4.81	8.1
1967	-	-	10.38	13.6
1968	4.72	12.6	3.30	8.6
1969	4.64	17.8	2.20	8.0
1970	4.34	15.6	5.07	12.5
1971	3.39	14.2	3.19	9.9
1972	8.97	19.0	13.09	23.0
1973	18.68[d]	39.7[d]	12.28	30.8
1974	14.75	36.4	3.49	8.2
1975	6.89	26.0	6.41	14.1
1976	7.06	18.6	10.44	17.7
1977	6.30	15.4	5.45	12.5
1978	12.31	31.2	8.59	23.3
1979	5.16	16.9	5.95	16.5
1980	7.75	24.9	2.91	6.7
1981	10.44	26.1	9.04	19.0
1982	8.20[e]	15.4[e]	3.71	6.9
1983	7.70	24.0	3.64	6.5
1984	4.08	15.4	4.75	10.3
1985	6.94	21.5	2.43	3.5
1986	5.04	16.7	3.12	4.7
1987	3.26	10.3	2.33	4.4
1988	5.86	13.5	3.11	5.8
1989	4.80	10.8	4.78	4.6
1990	4.74	11.6	3.62[f]	7.1[f]
1991	4.39	9.0	0.96	1.4
1992	2.67	7.5	1.84	3.1
1993	2.48	7.3	2.15	2.2
1994*	0.97	1.2		

* Provisional

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

[b] Spring surveys during 1981-1982, 1989-1991 and 1994 and autumn surveys during 1977-1981 and 1989-1991 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data to standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

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

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

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

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

1990, and 1991-1993. Total mortality was calculated from survey catch per tow at age data for fully recruited age groups (age 3+) by the $\log_e$ ratio of the pooled age 3+/age 4+ indices in the autumn surveys, and the pooled age 4+/age 5+ indices in the spring surveys. For example, the 1988-1990 values were derived from:

Autumn: ln (Σ age 3+ for 1987-89 / Σ age 4+ for 1988-90)

Spring: ln (Σ age 4+ for 1988-90 / Σ age 5+ for 1989-91)

Different age groups were used in the autumn and spring analyses so that Z could be evaluated over identical year classes within each time period. Values of Z derived from the spring surveys are generally lower than those calculated from the autumn data. Rather than selecting one survey series over the other, total mortality was calculated by taking a geometric mean of the spring and autumn estimates in each time period.

Total mortality was high (0.73) during 1964-1967, declined significantly during 1968-1972 (0.34), increased to between 0.56 and 0.63 during 1973-1981, and peaked at record-high levels (0.68-1.10) during 1982-1987. Total mortality subsequently declined to 0.60 during 1988-1990, but increased to 1.46 for the most recent 1991-1993 period.

Natural Mortality

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

ESTIMATES OF STOCK SIZE AND FISHING MORTALITY

Virtual Population Analysis (VPA) Calibration

The ADAPT (Parrack 1986, Gavaris 1988, Conser and Powers 1990) calibration method was used to derive estimates of terminal F values in 1993. The total stock catch at age (Table F5) was included in the VPA with true ages 1-9 and a 10+ group represented from 1978 through 1993. As in previous assessments, age-disaggregated calibrations were performed.

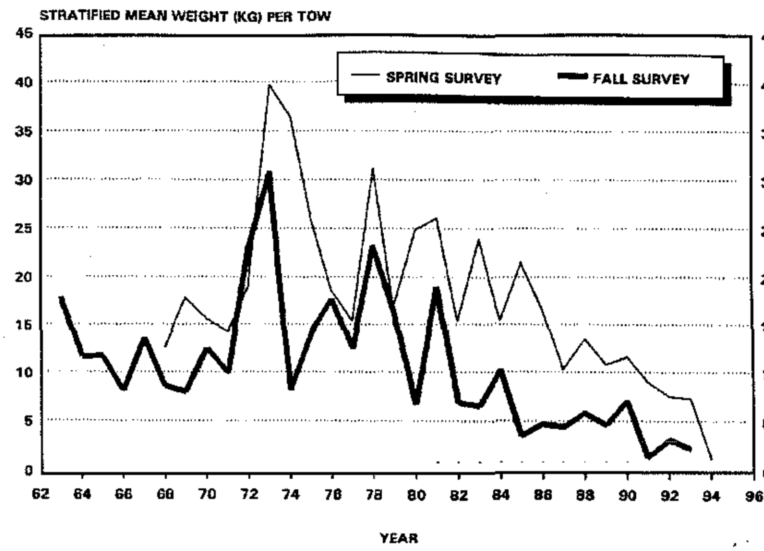


Figure F4. Standardized stratified mean catch per tow (kilograms) of Atlantic cod in NEFSC spring and autumn research vessel bottom trawl surveys on Georges Bank, 1963-1994.

An initial ADAPT calibration was performed with the 1978-1994 NEFSC and the 1986-1994 Canadian spring survey abundance indices for ages 1-8 (Hunt and Buzeta 1994), the 1977-1993 NEFSC autumn survey abundance indices for ages 1-6 and the 1978-1993 U.S. standardized commercial LPUE indices for ages 2-6. The NEFSC autumn survey was lagged by one age and year whereby age 0-5 indices were related to age 1-6 stock sizes in the subsequent year for corresponding cohorts.

Since F on age 1 is negligible, the age 1 stock size estimate was tuned to the autumn index for the prior year. The most recent spring survey indices were used to estimate recruitment in 1994. To eliminate duplication, the age 1 index was not related to the age 2 stock sizes in the subsequent year. All NEFSC and Canadian indices were related to January 1 stock sizes and the U.S. commercial LPUE indices were related to mid-year stock sizes. Because the Canadian survey did not consistently sample the US portion of Georges Bank, the tuning indices used for calibration included the stratified mean catch per tow only for strata on the eastern portion of Georges Bank (Table F13). All indices and years received equal weight. The age 9 survey indices were too variable to be useful for calibration.

In addition to the initial run, two exploratory ADAPT calibrations were performed to evaluate the high age 3 F in 1993. These runs also used the NEFSC spring, the NEFSC autumn, and the Canadian spring survey abundance indices, as well as the U.S. commercial LPUE indices to estimate stock sizes for ages 1-8 in 1994. They differed, however, by excluding the direct estimate of age 4 F in 1993 and by excluding the 1978-1981 period from the calibration. The two trial runs, however, produced similar results with a high F on age 4 in 1993. The residual patterns appeared to be identical and there did not appear to be any benefits in terms of improved precision.

The ADAPT formulation employed in the initial VPA calibration provided direct stock size estimates for ages 1 through 8 in 1994 and corresponding estimates of F on ages 1 through 7 in 1993. Since the age at full recruitment was defined as 4 years in the input (flat-topped) partial recruitment vector, Fs on ages 8 and 9 in the terminal year were estimated as the mean of the age 4 through 7 Fs. In all years prior to the terminal year, F on the oldest true age (9) was determined from weighted estimates of the Z for ages 4 through 9. In all years, the age 9 F was applied to the 10+ group. Spawning stock biomass (SSB) was calculated at spawning time (March 1) by applying maturity ogives for 1978-1981, 1982-1985, and 1986-1993 derived from O'Brien (1990).

Results from the final VPA calibration including estimates of F, stock size and spawning stock biomass at age are given in Table F14. The final calibration exhibited very low correlations (< 0.10) among estimates of slopes (q), and moderately low correlations (< 0.20) between stock sizes and q's. The CVs on age 1-8 abundance estimates were less than 0.40 for ages 1-6, but

Table F12. Standardized stratified mean catch per tow at age (numbers) of Atlantic cod in NEFC offshore spring and autumn bottom trawl on Georges Bank, 1963 - 1994. [a,b,c]

Year	Age Group											Totals					
	0	1	2	3	4	5	6	7	8	9	10+	0+	1+	2+	3+	4+	5+
Spring																	
1968	0.513	0.136	1.615	0.825	0.665	0.385	0.246	0.140	0.083	0.056	0.058	4.722	4.209	4.073	2.459	1.633	0.969
1969	0.000	0.123	0.546	1.780	0.888	0.451	0.326	0.215	0.128	0.072	0.112	4.641	4.641	4.518	3.972	2.192	1.304
1970	0.000	0.381	0.814	0.480	1.295	0.162	0.655	0.275	0.061	0.136	0.083	4.34	14.341	3.961	3.147	2.666	1.371
1971	0.000	0.207	0.819	0.502	0.223	0.585	0.142	0.351	0.304	0.080	0.175	3.388	3.388	3.181	2.362	1.860	1.636
1972	0.056	2.902	1.833	2.641	0.510	0.119	0.324	0.122	0.220	0.115	0.125	8.967	8.911	6.009	4.176	1.535	1.025
1973 [d]	0.056	0.521	11.644	2.189	2.540	0.426	0.314	0.354	0.050	0.203	0.388	18.684	18.628	18.107	6.463	4.274	1.735
1974	0.000	0.446	4.557	5.972	0.761	2.003	0.440	0.101	0.257	0.034	0.175	14.747	14.747	14.301	9.744	3.772	3.011
1975	0.000	0.064	0.378	2.042	3.092	0.261	0.686	0.129	0.094	0.108	0.039	6.892	6.892	6.828	6.451	4.409	1.317
1976	0.111	1.301	1.922	0.944	0.691	1.572	0.164	0.262	0.036	0.000	0.055	7.057	6.947	5.646	3.724	2.780	2.089
1977	0.000	0.028	3.527	1.080	0.523	0.279	0.727	0.051	0.066	0.000	0.020	6.301	6.301	6.273	2.746	1.666	1.143
1978	3.312	0.376	0.187	5.530	0.969	0.778	0.144	0.713	0.051	0.142	0.109	12.312	9.000	8.624	8.436	2.906	1.938
1979	0.109	0.435	1.359	0.298	1.913	0.541	0.234	0.087	0.145	0.012	0.022	5.156	5.047	4.611	3.253	2.955	1.042
1980	0.105	0.039	2.265	2.688	0.209	1.482	0.597	0.192	0.031	0.030	0.111	7.749	7.644	7.605	5.340	2.652	2.443
1981	0.301	2.303	1.916	2.779	1.667	0.100	0.870	0.269	0.144	0.000	0.085	10.435	10.134	7.831	5.914	3.135	1.468
1982 [e]	0.148	0.488	3.395	1.406	1.295	1.039	0.016	0.298	0.064	0.016	0.035	8.200	8.053	7.564	4.169	2.763	1.468
1983	0.081	0.329	1.967	3.048	0.766	0.697	0.431	0.055	0.192	0.000	0.136	7.702	7.621	7.291	5.324	2.276	1.510
1984	0.000	0.402	0.462	0.797	1.161	0.446	0.424	0.223	0.000	0.156	0.008	4.079	4.079	3.677	3.215	2.418	1.257
1985	0.244	0.098	2.633	0.757	1.058	1.328	0.270	0.203	0.172	0.025	0.150	6.938	6.694	6.596	3.963	3.206	2.148
1986	0.092	0.871	0.423	1.824	0.360	0.545	0.633	0.063	0.119	0.095	0.015	5.040	4.948	4.077	3.654	1.830	1.470
1987	0.000	0.034	1.612	0.403	0.752	0.060	0.179	0.147	0.016	0.027	0.025	3.255	3.255	3.221	1.609	1.206	0.454
1988	0.180	0.700	0.684	3.115	0.413	0.645	0.045	0.020	0.052	0.000	0.007	5.861	5.681	4.981	4.297	1.182	0.769
1989	0.000	0.380	1.334	0.743	1.532	0.228	0.344	0.051	0.040	0.081	0.067	4.798	4.798	4.418	3.084	2.342	0.810
1990	0.041	0.194	0.926	1.707	0.653	0.896	0.125	0.139	0.013	0.016	0.027	4.736	4.695	4.501	3.575	1.868	1.215
1991	0.195	1.068	0.511	0.807	0.883	0.464	0.336	0.039	0.041	0.000	0.045	4.389	4.194	3.126	2.615	1.808	0.925
1992	0.000	0.123	1.255	0.470	0.163	0.270	0.144	0.161	0.020	0.037	0.028	2.671	2.671	2.548	1.293	0.823	0.660
1993	0.115	0.017	0.398	1.347	0.222	0.107	0.120	0.037	0.037	0.021	0.055	2.476	2.361	2.344	1.946	0.599	0.377
1994	(0.030)	(0.151)	(0.267)									0.967	(0.937)	(0.786)	(0.519)		(0.085)

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

[b] Spring surveys during 1981-1982, 1989-1991 and 1994, and autumn surveys during 1977-1981 and 1989-1991 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data t standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

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

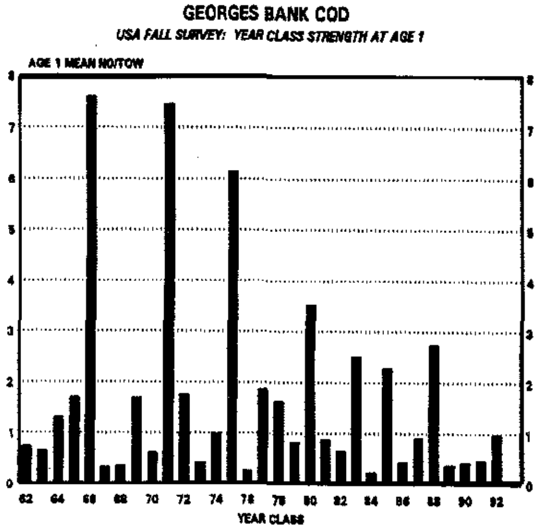
[d] Excludes unusually high catch of 1894 cod (2558 kg) at Station 230 (Strata tow 20-4).

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

Table F12. Continued.

Year	Age Group											Totals					
	0	1	2	3	4	5	6	7	8	9	10+	0+	1+	2+	3+	4+	5+
Autumn																	
1963	0.019	0.719	0.778	0.920	0.897	0.354	0.326	0.175	0.103	0.014	0.069	4.374	4.356	3.636	2.858	1.938	1.041
1964	0.009	0.640	0.699	0.588	0.538	0.145	0.136	0.062	0.050	0.030	0.083	2.980	2.970	2.331	1.632	1.044	0.505
1965	0.173	1.299	0.998	0.707	0.484	0.167	0.179	0.112	0.081	0.023	0.023	4.248	4.075	2.775	1.777	1.070	0.587
1966	1.025	1.693	1.000	0.515	0.264	0.100	0.095	0.062	0.039	0.002	0.017	4.811	3.786	2.094	1.094	0.579	0.315
1967	0.072	7.596	1.334	0.523	0.406	0.133	0.133	0.055	0.051	0.012	0.070	10.383	10.312	2.716	1.382	0.860	0.454
1968	0.070	0.314	1.611	0.783	0.271	0.073	0.067	0.027	0.023	0.008	0.048	3.296	3.226	2.913	1.301	0.518	0.246
1969	0.000	0.343	0.622	0.626	0.331	0.094	0.061	0.019	0.023	0.022	0.059	2.200	2.200	1.856	1.234	0.608	0.278
1970	0.413	1.688	1.353	0.524	0.694	0.153	0.000	0.033	0.055	0.055	0.098	5.065	4.652	2.964	1.611	1.087	0.393
1971	0.399	0.602	0.632	0.390	0.301	0.476	0.183	0.042	0.089	0.000	0.075	3.189	2.789	2.187	1.555	1.165	0.864
1972	0.947	7.443	1.295	1.771	0.399	0.243	0.571	0.109	0.204	0.022	0.083	13.087	12.140	4.697	3.402	1.632	1.232
1973	0.203	1.749	6.070	1.182	2.012	0.211	0.226	0.175	0.062	0.139	0.251	12.280	12.078	10.329	4.259	3.076	1.064
1974	0.462	0.409	0.654	1.521	0.164	0.114	0.103	0.000	0.069	0.000	0.000	3.494	3.033	2.624	1.970	0.449	0.285
1975	2.377	0.994	0.421	0.624	1.685	0.112	0.156	0.000	0.000	0.000	0.037	6.407	4.029	3.036	2.615	1.991	0.306
1976	0.000	6.148	2.072	0.763	0.278	0.739	0.055	0.270	0.039	0.053	0.020	10.436	10.436	4.288	2.217	1.454	1.176
1977	0.152	0.237	3.424	0.702	0.251	0.174	0.396	0.007	0.027	0.000	0.078	5.447	5.296	5.059	1.635	0.933	0.682
1978	0.396	1.855	0.255	4.180	0.964	0.335	0.165	0.344	0.051	0.030	0.014	8.587	8.192	6.337	6.082	1.902	0.938
1979	0.118	1.619	1.717	0.224	1.613	0.296	0.180	0.036	0.115	0.007	0.022	5.948	5.829	4.210	2.493	2.269	0.656
1980	0.280	0.818	0.564	0.774	0.076	0.251	0.053	0.067	0.025	0.000	0.000	2.908	2.629	1.810	1.246	0.472	0.396
1981	0.261	3.525	2.250	1.559	0.589	0.054	0.579	0.057	0.064	0.018	0.083	9.040	8.778	5.254	3.003	1.444	0.855
1982	0.320	0.875	2.094	0.220	0.069	0.097	0.000	0.016	0.000	0.000	0.022	3.711	3.391	2.516	0.423	0.203	0.134
1983	1.031	0.647	1.022	0.796	0.055	0.047	0.003	0.000	0.012	0.000	0.023	3.636	2.605	1.958	0.936	0.140	0.086
1984	0.186	2.496	0.101	0.886	0.870	0.017	0.062	0.039	0.006	0.039	0.044	4.747	4.561	2.065	1.964	1.078	0.207
1985	1.084	0.220	0.803	0.103	0.115	0.101	0.000	0.000	0.004	0.000	0.000	2.430	1.346	1.126	0.323	0.220	0.105
1986	0.096	2.280	0.153	0.382	0.010	0.061	0.090	0.016	0.000	0.008	0.028	3.124	3.028	0.748	0.595	0.213	0.203
1987	0.204	0.414	1.353	0.112	0.195	0.028	0.012	0.000	0.000	0.007	0.000	2.325	2.121	1.707	0.354	0.242	0.047
1988	0.549	0.903	0.433	0.909	0.091	0.178	0.000	0.011	0.039	0.000	0.000	3.113	2.564	1.661	1.228	0.319	0.228
1989	0.262	2.738	1.030	0.183	0.499	0.055	0.008	0.004	0.000	0.000	0.000	4.780	4.518	1.780	0.750	0.566	0.067
1990 [f]	0.156	0.362	1.534	1.164	0.209	0.145	0.012	0.013	0.000	0.000	0.022	3.617	3.460	3.098	1.564	0.401	0.192
1991	0.040	0.415	0.168	0.277	0.028	0.029	0.000	0.000	0.000	0.000	0.000	0.957	0.917	0.502	0.334	0.057	0.029
1992	0.033	0.454	1.024	0.180	0.112	0.030	0.010	0.000	0.000	0.000	0.000	1.843	1.810	1.356	0.332	0.152	0.040
1993	0.178	0.969	0.531	0.382	0.017	0.026	0.000	0.000	0.026	0.020	0.000	2.149	1.971	1.002	0.471	0.089	0.072

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



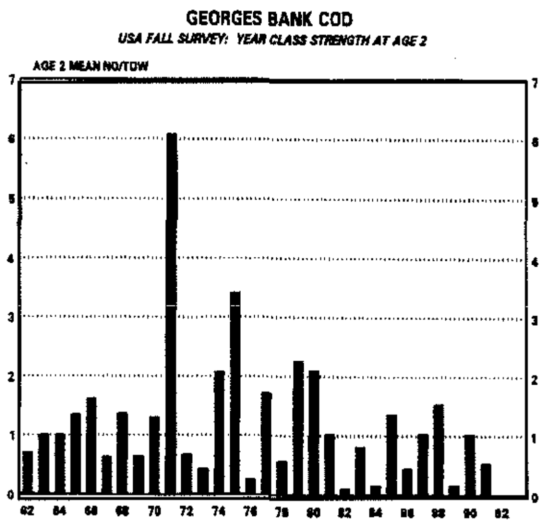


Figure F5. Relative year class strengths of Georges Bank cod at (a) age 1 and (b) age 2 based on stanardized catch per tow (number) indices from NEFSC autumn research vessel bottom trawl surveys, 1962-1993.

the estimates of age 7 and age 8 abundance were less precise, having CVs of 0.45 and 0.55, respectively.

Fishing Mortality Estimates

Average fishing mortality (ages 4-8, unweighted) in 1993 was estimated at 0.91 (Table F14, Figure F6). Excluding the unusually high estimate of the age 8 F in 1978, mean (ages 4-8, unweighted) fishing mortality increased from 0.3 in 1978 to a record high of 0.9 in 1993.

Stock Size and Spawning Stock Biomass Estimates

Spawning stock biomass declined from more than 90,000 mt during the early 1980s to about 56,000 mt in 1985 and 1986. Following the recruitment and maturation of the strong 1983 and 1985 year classes, SSB increased to about 73,000 mt in 1988 and 1989 (Table F14, Figure F7). Since 1990, SSB has declined to a record-low 37,000 mt in 1993. This is 45% lower than the lowest SSB observed between 1978 and 1990.

Recruitment Estimates

Since 1978 recruitment at age 1 has ranged from approximately 4 million (1992 year class) to 43 million (1985 year class) with most estimates between 16 and 27 million fish (Table F14, Figure F7). Over the 1978-1992 period, geometric mean recruitment for the 1977-1991 year classes equaled 18 million fish. Except for the slightly above average 1990 year class, recruitment since 1989 has been poor, with the 1991, 1992 and

Table F13. Stratified mean catch per tow at age (numbers) of Atlantic cod in Canadian spring bottom trawl surveys on Eastern Georges Bank, 1986 - 1994

Year	Age Group									Totals				
	1	2	3	4	5	6	7	8	9+	1+	2+	3+	4+	5+
1986	1.81	8.33	7.50	0.76	1.61	1.04	0.52	0.08	0.17	21.82	20.01	11.68	4.18	3.42
1987	0.12	4.31	1.55	1.81	0.39	0.21	0.44	0.21	0.13	9.17	9.05	4.74	3.19	1.38
1988	0.36	1.08	12.85	1.36	2.02	0.23	0.19	0.43	0.12	18.64	18.28	17.20	4.35	2.99
1989	0.84	5.01	1.77	3.90	0.58	0.76	0.09	0.19	0.36	13.50	12.66	7.65	5.88	1.98
1990	0.26	1.81	7.97	4.49	10.11	1.23	2.51	0.33	1.36	30.07	29.81	28.00	20.03	15.54
1991	2.75	2.31	3.23	3.74	1.99	2.70	0.33	0.56	0.31	17.92	15.17	12.86	9.63	5.89
1992	0.12	4.69	2.81	0.94	1.48	1.04	0.69	0.21	0.15	12.13	12.01	7.32	4.51	3.57
1993	0.07	0.82	3.96	1.43	0.85	1.73	0.63	0.61	0.25	10.35	10.28	9.46	5.50	4.07
1994	0.03	1.45	1.59	2.90	1.90	0.42	0.83	0.19	0.33	9.64	9.61	8.16	6.57	3.67

Table F14. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F) and spawning stock biomass (metric tons) for Georges Bank cod, estimated from virtual population analysis (VPA) calibrated using the ADAPT procedure, 1978-1994.

STOCK NUMBERS (Jan 1) in thousands

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	27714	23515	20107	41398	17473	9621	27420	8704	42895	16504	23774	16273	9044	22169	6328	4046	5456
2	4268	22689	19222	16382	33869	14007	7779	22377	7005	34978	13489	19456	13323	7399	18104	5118	3309
3	25527	3139	16776	12320	10512	19461	7589	5186	12506	4535	21876	9617	14040	6436	4678	11042	3255
4	7947	13889	1756	8462	6267	5147	8638	3116	2036	6101	2441	10652	5230	6932	2335	1866	5199
5	2878	4422	6965	985	4698	2609	1992	4054	1314	945	3076	1083	4961	2579	2707	973	519
6	1124	1605	2524	3614	594	2037	1182	870	1613	641	522	1164	587	2014	792	875	398
7	1434	802	900	1093	1686	232	966	501	340	753	297	206	463	273	664	283	290
8	67	862	587	334	518	772	104	376	213	200	373	97	95	158	110	264	88
9	146	12	477	402	162	231	419	45	124	109	106	127	41	45	66	59	87
10	54	148	28	190	187	148	293	206	76	68	99	45	90	44	20	31	30
1+	71160	71083	69341	85178	75968	54265	56382	45435	68121	64835	66052	58719	47875	48049	35803	24557	18630
2+	43245	47408	48729	43189	58145	44265	28249	36480	25025	48154	42073	42275	38699	25791	29389	20422	13058
3+	38977	24719	29507	26807	24276	30258	20470	14104	18021	13176	28584	22819	25376	18392	11286	15304	9749
4+	13450	21580	12731	14487	13763	10797	12881	8917	5515	8641	6708	13202	11336	11956	6608	4261	6494

FISHING MORTALITY

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
2	0.11	0.10	0.24	0.24	0.35	0.41	0.21	0.38	0.23	0.27	0.14	0.13	0.53	0.26	0.29	0.25
3	0.41	0.38	0.48	0.48	0.51	0.61	0.69	0.74	0.52	0.42	0.52	0.41	0.51	0.81	0.72	0.55
4	0.39	0.49	0.38	0.39	0.68	0.75	0.56	0.66	0.57	0.48	0.61	0.56	0.51	0.74	0.68	1.08
5	0.38	0.36	0.46	0.31	0.64	0.59	0.63	0.72	0.52	0.39	0.77	0.41	0.70	0.98	0.93	0.69
6	0.14	0.38	0.64	0.56	0.74	0.55	0.66	0.74	0.56	0.57	0.73	0.72	0.56	0.91	0.83	0.91
7	0.31	0.11	0.79	0.55	0.58	0.60	0.74	0.66	0.33	0.50	0.91	0.58	0.88	0.71	0.72	0.97
8	1.48	0.39	0.18	0.52	0.61	0.41	0.63	0.91	0.47	0.43	0.88	0.67	0.54	0.67	0.42	0.91
9	0.36	0.44	0.49	0.44	0.66	0.65	0.60	0.72	0.54	0.49	0.73	0.57	0.61	0.83	0.81	0.91
10	0.36	0.44	0.49	0.44	0.66	0.65	0.60	0.72	0.54	0.49	0.73	0.57	0.61	0.83	0.81	0.91
4-8	0.54	0.35	0.49	0.47	0.65	0.58	0.64	0.74	0.49	0.48	0.78	0.59	0.64	0.80	0.72	0.91

SSB AT THE START OF THE SPAWNING SEASON - males & females (metric tons)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	913	1104	850	1961	1200	903	3127	776	7016	1842	2898	2109	1195	4668	1395	516
2	1410	7539	6913	5783	16140	6346	4306	11663	4823	24282	8571	13294	8485	5101	13984	4031
3	33845	3729	22418	15930	15645	26063	10503	6884	18808	7140	33003	14683	22662	9862	7312	16519
4	20220	38257	4297	21380	15795	12653	21663	8079	4851	17074	6182	27415	12877	16853	6189	4234
5	8798	16586	30443	3958	17475	9641	7115	14916	5440	3948	12440	4255	18338	8681	8995	3662
6	4883	8131	12541	20324	2957	10522	5658	4248	8594	3711	2777	6002	3021	8984	3615	3988
7	8215	5550	5919	7297	12174	1460	6228	3169	2351	5374	2031	1340	2913	1608	3787	1583
8	367	6810	5034	2696	4166	6842	811	2987	1708	1698	2942	818	783	1286	846	1825
9	1331	112	3964	4097	1561	2113	3957	417	1252	1036	962	1202	415	385	626	480
10	653	1681	388	3168	2711	1873	3942	2386	946	912	1291	679	1146	573	316	940
Tot	80634	89499	92768	86595	89822	78416	67308	55525	55789	67016	73098	71798	71834	58000	47066	37177

1993 year classes appearing to be the poorest on record.

Precision of F and SSB

The uncertainty associated with the estimates of stock size and fishing mortality from the final VPA was evaluated using a bootstrap procedure (Efron 1982). Two hundred bootstrap iterations were performed to derive standard errors, coefficients of variation (CVs) and bias estimates for the age 1-8 stock size estimates at the start of 1994, the catchability estimates (q) for each index of abundance used in calibrating the VPA, and the age 1-7 Fs in 1993. Frequency distributions of the 1993 age 4-8 mean fishing mortality and spawning stock biomass bootstrap estimates were generated and cumulative probability curves were produced (Figures F8 and F9).

The bootstrap results indicate that, except for age 8, age-specific stock sizes in 1994 were well estimated, with CVs ranging from 0.28 to 0.46. Coefficients of variation on the catchability estimates of the indices of abundance used in the final ADAPT calibration ranged from 0.14 to 0.16 for the U.S. spring and autumn bottom trawl survey indices and the five U.S. commercial LPUE

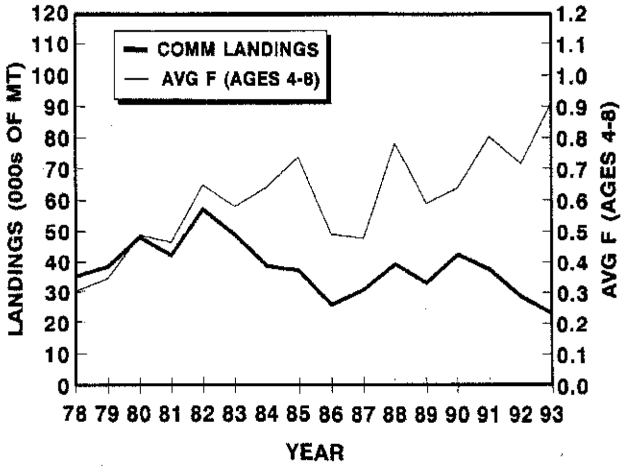


Figure F6. Trends in total commercial landings and fishing mortality for Georges Bank cod, 1978-1993.

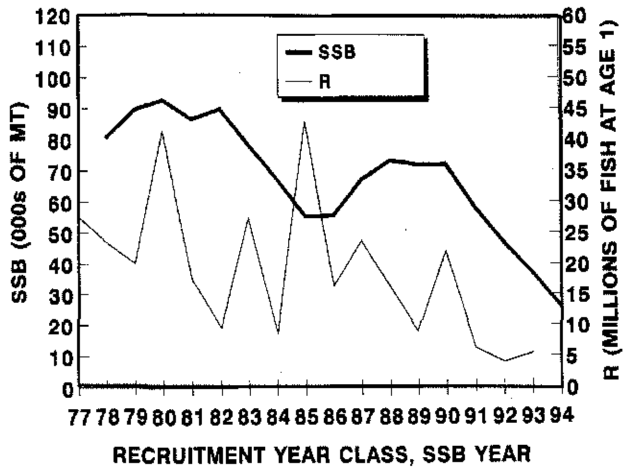


Figure F7. Trends in spawning stock biomass and recruitment for Georges Bank cod.

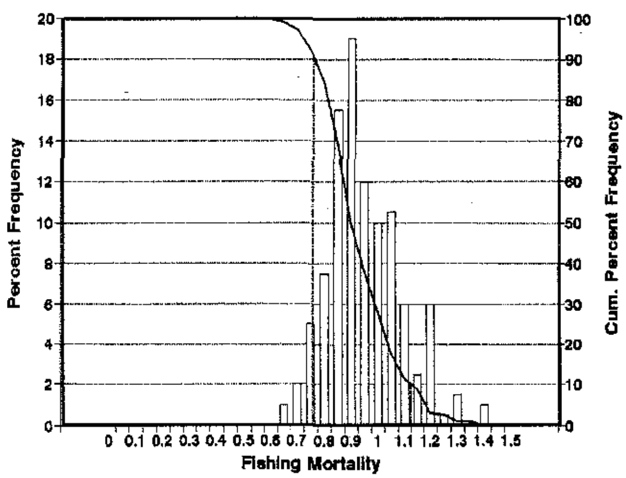


Figure F8. Precision of the estimates of the instantaneous rate of fishing mortality (F) on the fully recruited ages (ages 4+) in 1993 for Georges Bank cod. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that F is greater than any selected value within the range. The solid line gives the probability that F is greater than any selected value on the X-axis. The precision estimates were derived from 200 bootstrap replication of the final ADAPT VPA formulation.

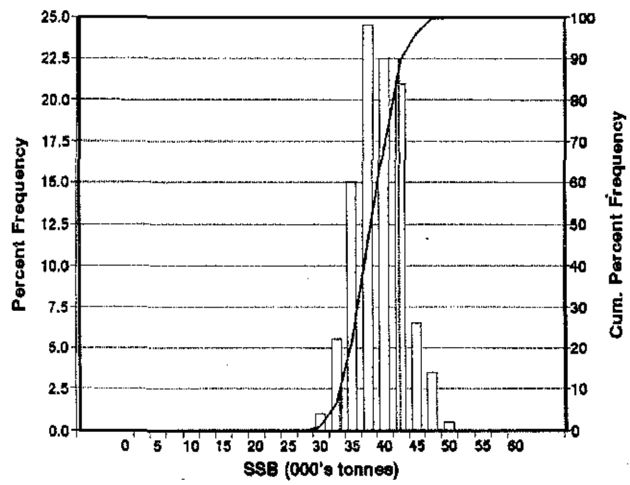


Figure F9. Precision of the estimates of spawning stock biomass (SSB) at the beginning of the spawning season (March 1) for Georges Bank cod, 1993. The vertical bars display both the range of the estimator and the probability of individual values within the range. The solid line gives the probability that F is greater than any selected value within the range. The solid line gives the probability that SSB is less than any selected value on the X-axis. The precision estimates were derived from 200 bootstrap replication of the final ADAPT VPA formulation.

indices. The Canadian bottom trawl indices had CVs ranging from 0.19 to 0.22, perhaps due to the shorter time series of this survey.

The age-specific Fs for ages 1-7 in 1993 were reasonably well estimated with CVs ranging from 0.22 to 0.31, as was the mean (ages 4-8) fully recruited fishing mortality (CV = 0.16). The mean bootstrap estimate of the fully recruited F in 1993 (F_{1993} = 0.928) was slightly higher than the VPA point estimate (F_{1993} = 0.912). The distribution of the F_{1993} estimates obtained from the 200 bootstrap replications ranged between F=0.63 and F=1.38 (Figure F8). Based on the cumulative probability curve (Figure F8), there is an 80% probability that the 1993 F lies between 0.77 and 1.12. This implies that there is a 90% probability that the 1993 F was greater than 0.77 (*i.e.*, about two times the overfishing definition of F*20%* = 0.36).

The bootstrap mean of spawning stock biomass in 1993 (37,600 mt) was rather precise (CV = 0.10) and slightly higher than the VPA point estimate (37,200 mt). Estimates of SSB in 1993 obtained from the 200 individual bootstrap replicates ranged from 29,800 mt to 48,900 mt (Figure F9). Based on the cumulative probability curve (Figure F9), there is an 80% probability that the 1993 SSB was between 33,400 mt and 42,400 mt.

Retrospective Analysis

Retrospective analyses (Mayo *et al.* 1994a) of the Georges Bank cod VPA were carried out using the final ADAPT formulation with the terminal year ranging from 1992 back to 1985. Mean (ages 4-8, unweighted) F was generally overestimated by the ADAPT calibration in most years and total stock size and SSB was most often under-estimated. Terminal Fs appear to have been well estimated in the more recent years since 1989, but estimates for 1985-1988 are considerably different from the estimates derived from the converged portions of the longer series.

BIOLOGICAL REFERENCE POINTS

Yield and Spawning Stock Biomass per Recruit

Yield-per-recruit (Y/R), total stock biomass per recruit, and spawning stock biomass per recruit (SSB/R) analyses were performed using the Thompson and Bell (1934) method. The exploitation pattern for input to the yield and SSB per recruit analyses and short-term projections was computed from the most recent five years of the F matrix derived from the VPA (Table F14). Geometric mean F at age was computed for the 1988-1992 period and divided by the geometric mean of the 4-8 unweighted F to derive the partial recruitment vector. The final exploitation pattern was smoothed, applying full exploitation on ages 4 and older. The final exploitation pattern was as follows:

Age 1:	0.0027	Age 3:	0.8209
Age 2:	0.3340	Ages 4+:	1.0000.

This pattern is similar to that obtained from the separable VPA presented in the 1992 U.S. cod assessment (Serchuk *et al.* 1993; NEFSC 1993) and represents no appreciable change from that used by Mayo *et al.* (1994a). This exploitation pattern was used in the Y/R and SSB/R analyses and for the catch and stock size projections for 1994 and 1995.

Mean weights at age used in the Y/R analyses were computed as a four-year arithmetic average of landings mean weights at age (Table F5) over the 1990-1993 period. Mean weights at age for use in the SSB/R analyses were computed as the four-year arithmetic average of stock mean weights at age (Table F6) over the period 1990-1993. The maturation ogive was taken from O'Brien (1990). The input data for the Y/R and SSB/R analyses are given in Table F15, and the results are presented in Table F15 and in Figure F10. The results indicate that $F_{0.1}$ = 0.16, F_{max} = 0.30, and $F_{20\%}$ = 0.36. These values are identical to those presented in the 1993 U.S. cod assessment (*i.e.*, $F_{0.1}$ = 0.16, F_{max} = 0.29, and $F_{20\%}$ = 0.35) (Mayo *et al.* 1994a).

SHORT-TERM PROJECTIONS

Recruitment

A five-year stochastic projection sequence was performed beginning in 1994, based on methods described by Brodziak and Rago (1994). The distribution of stock sizes at the beginning of 1994 for ages 1-10+ was derived from the 200 bootstrap replications of the final ADAPT VPA calibration formulation. Recruitment at age 1 for 1995-1998 were obtained by first sampling a non-parametric R/SSB distribution derived from 1979 through 1993 (1978-1992 year classes; the

Table F15. Yield and SSB per recruit results for Georges Bank cod.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
Run Date: 28- 6-1994; Time: 11:21:21.75
GEORGES BANK COD (5Z + 6) -1993 UPDATED AVE WTS, FPAT AND MAT VECT

Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Natural Mortality is Constant at: .200
Initial age is: 1; Last age is:10
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file: > YRCODGBA.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	.0027	1.0000	.2300	.991	.777
2	.3340	1.0000	.6400	1.566	1.231
3	.8209	1.0000	.9100	2.432	1.965
4	1.0000	1.0000	.9800	3.530	2.931
5	1.0000	1.0000	1.0000	4.833	4.194
6	1.0000	1.0000	1.0000	6.190	5.528
7	1.0000	1.0000	1.0000	7.721	6.956
8	1.0000	1.0000	1.0000	10.058	8.913
9	1.0000	1.0000	1.0000	11.006	10.701
10+	1.0000	1.0000	1.0000	15.224	15.224

Summary of Yield per Recruit Analysis for:
GEORGES BANK COD (5Z + 6) -1993 UPDATED AVE WTS, FPAT AND MAT VECT

Slope of the Yield/Recruit Curve at F0.00: —> 26.3416
F level at slope1/10 of the above slope (F0.1): ——> .158
Yield/Recruit corresponding to F0.1: ——> 1.6110
F level to produce Maximum Yield/Recruit (Fmax): ——> .302
Yield/Recruit corresponding to Fmax: ——> 1.7458
F level at 20 % of Max Spawning Potential (F20): ——> .365
SSB/Recruit corresponding to F20: ————> 5.3877

Listing of Yield per Recruit Results for:
GEORGES BANK COD (5Z + 6) -1993 UPDATED AVE WTS, FPAT AND MAT VECT

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.00	.00000	.00000	5.5167	28.9650	4.2370	26.9398	100.00
	.09	.21937	1.31045	4.4249	16.8237	3.1459	14.9863	55.63
F0.1	.16	.31094	1.61095	3.9707	12.5034	2.6922	10.7623	39.95
	.18	.33554	1.66276	3.8490	11.4449	2.5706	9.7314	36.12
	.27	.40799	1.74247	3.4912	8.6223	2.2134	6.9932	25.96
Fmax	.30	.42565	1.74582	3.4043	8.0076	2.1267	6.3996	23.76
	.36	.45785	1.73692	3.2463	6.9666	1.9690	5.3972	20.03
F20%	.36	.45817	1.73674	3.2447	6.9568	1.9674	5.3877	20.00
	.46	.49448	1.70561	3.0673	5.9122	1.7904	4.3863	16.28
	.55	.52269	1.66868	2.9301	5.1962	1.6537	3.7031	13.75
	.64	.54520	1.63293	2.8213	4.6841	1.5452	3.2167	11.94
	.73	.56367	1.60040	2.7325	4.3023	1.4568	2.8554	10.60
	.82	.57915	1.57140	2.6585	4.0076	1.3830	2.5775	9.57
	.91	.59237	1.54571	2.5956	3.7737	1.3205	2.3577	8.75
	1.00	.60382	1.52292	2.5414	3.5835	1.2665	2.1795	8.09
	1.09	.61387	1.50263	2.4942	3.4258	1.2195	2.0321	7.54
	1.18	.62279	1.48447	2.4525	3.2928	1.1780	1.9083	7.08
	1.27	.63077	1.46814	2.4153	3.1790	1.1410	1.8026	6.69
	1.37	.63797	1.45338	2.3820	3.0805	1.1078	1.7113	6.35
	1.46	.64451	1.43997	2.3518	2.9942	1.0778	1.6316	6.06
	1.55	.65049	1.42773	2.3244	2.9180	1.0504	1.5613	5.80
	1.64	.65599	1.41652	2.2993	2.8502	1.0254	1.4988	5.56
	1.73	.66106	1.40620	2.2762	2.7892	1.0024	1.4428	5.36
	1.82	.66577	1.39667	2.2549	2.7342	.9812	1.3924	5.17

realized recruitment for a given year class was then estimated as a function of the computed SSB for that year and the distribution of R/SSB ratios.

Input data for the projections, including the partial recruitment vector, maturity schedule and means weights at age for the stock and catch are listed in Table F16. The five-year forecasts were performed under several fishing mortality scenarios beginning in 1994 including: applying status quo F_{93} (0.91); a 10% reduction per year from 0.91 in 1994 to 0.55 in 1998, and an immediate reduction to $F_{20\%}$ (0.36) from 1995 through 1998, given F_{94} equalled F_{93} = 0.91.

Catch and Stock Size Projections

Continued fishing at the 1993 level (F = 0.91) will lead to an 8% decline in total landings in 1994 to 21,300 mt (Table F16). At this level of F, SSB will decline sharply from 37,200 mt in 1993 to a record-low of 20,000 mt in 1995 (Figure F11) and will continue to decline to unprecedented low levels of 13,000 to 17,000 mt in 1996-1998 (Table F16). As stock biomass declines, total landings will decrease sharply to 14,000 mt in 1995 and to less than 9,000 mt by 1998. If F is reduced by 10% per year between 1995 and 1998, landings will continue to decline to 8,000-9,000 mt and SSB will stabilize at a record-low 17,000 mt in 1997-1998.
Given the slight probability of good recruitment at these low SSB levels, even if F is reduced sharply in 1995 to $F_{20\%}$ (0.36) and remains at this level, the decline in SSB will be halted at 22,000 mt in 1995 and recovery will commence in 1996, leading to a slight increase to 29,000 mt by 1998 (Table F16).

CONCLUSIONS

The Georges Bank cod stock is at a record low biomass level and is overexploited. Fishing mortality in 1993 was at a record high, and well above the reference levels used by the U.S. and Canada. Because of the high exploitation rate and poor recruitment, spawning stock biomass will continue to decline to unprecedented record low levels in 1995 and 1996. Without significant declines in fishing mortality, the likelihood of a stock collapse in the foreseeable future cannot be dismissed. This stock is clearly transboundary and would benefit from joint assessment.

SUBCOMMITTEE COMMENTS

The subcommittee reviewed results from the 1993 U.S. cod assessment for Georges Bank. Background data and the methodology describing the estimates of standardized CPUE at age were presented. The subcommittee agreed that the GLM method used to standardize effort was acceptable and that the revised standard effort series revealed a similar trend to the prior series. Estimates of landings at age based on the corresponding otter trawl effort fleet was also accepted by the committee. Apart from age group 2, where there were slightly higher proportions in the sub-fleet landings at age, most ages were equally represented in the sub-fleet and the full landings at age matrices.

The subcommittee examined the commercial landings and mean weights at age and the commercial and research vessel abundance indices and accepted all input data to the VPA. For reasons identified in previous assessments, recreational landings were not incorporated into the VPA. Some measure of precision (*i.e.* sample size) would be useful to better evaluate trends in the landings estimates obtained from the MRFSS surveys.

The initial calibration runs presented to the subcommittee employed the same formulation as used by Mayo *et al.* (1994a), *i.e.* equal weighting of the U.S. spring survey (ages 1-8), the U.S. fall survey (ages 0-5 tuned against the 1-6 stock size estimates in the subsequent year), the 1986-1993 Canadian survey (ages 1-8), and the GLM standardized LPUE for the otter trawl fleet by age (2-6). Because of the greater catchability of the Canadian survey gear, particularly for older fish, inclusion of the Canadian survey indices may have provided a better index of abundance for the older ages. Previous results indicating full recruitment at age 4 were used as the exploitation pattern for the terminal year calibration.

Age samples from the commercial landings during 1978-1981 were lacking for many quarters and market categories and the resultant pooling may have resulted in anomalous fishing mortality patterns. Since the calibration had sufficient data to shorten the time series, the subcommittee conducted an alternative VPA beginning in 1982. These results were similar to those obtained for the full time series.

Time trends in the residuals were evident for the survey and U.S. commercial LPUE indices; however, these were in opposite directions, with the Canadian survey indicating positive residuals in the later years and the U.S. CPUE and

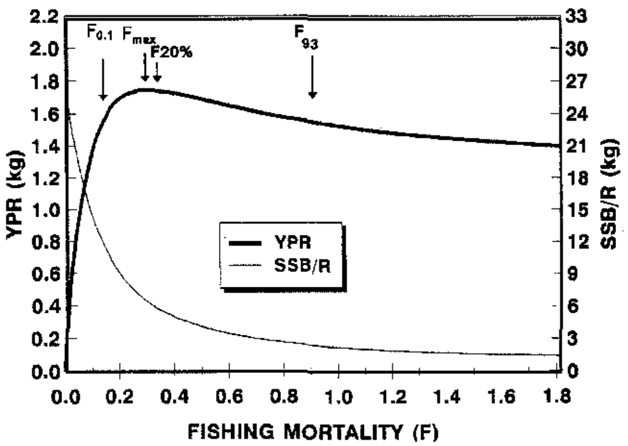


Figure F10. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for Georges Bank.

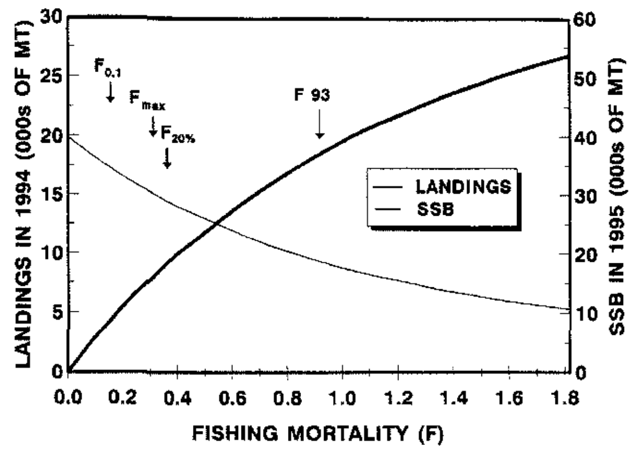


Figure F11. Predicted catches in 1994 and spawning stock biomasses in 1995 of Georges Bank cod over a range of fishing mortalities in 1994 from F=0 to F=1.80.

Table F16. Summary of short-term stochastic projections for Georges Bank cod

Input for Projections:
Number of Years: 5; Initial year: 1994; Final year: 1998
Number of Ages : 10; age at recruitment: 1; Last Age: 10
Natural Mortality is assumed constant over time at: .200
Proportion of F before spawning: .1667
Proportion of M before spawning: .1667
Last age is a PLUS group.

Age	Stock Size in 1994	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	5456.	.0027	1.0000	.2300	.991	.777
2	3309.	.3340	1.0000	.6400	1.566	1.231
3	3255.	.8209	1.0000	.9100	2.432	1.965
4	5199.	1.0000	1.0000	.9800	3.530	2.931
5	519.	1.0000	1.0000	1.0000	4.833	4.194
6	398.	1.0000	1.0000	1.0000	6.190	5.528
7	290.	1.0000	1.0000	1.0000	7.721	6.956
8	88.	1.0000	1.0000	1.0000	10.058	8.913
9	87.	1.0000	1.0000	1.0000	11.006	10.701
10+	30.	1.0000	1.0000	1.0000	15.224	15.224

SSB in 1993 was estimated at 37,177 t
Landings in 1993 were estimated at 23,100 t
F(4-8, unweighted) in 1993 was estimated at 0.91

Projection results

Year	F	Landings	SSB	F	Landings	SSB	F	Landings	SSB
1994	0.91	21324	29194	0.91	21324	29194	0.91	21324	29194
1995	0.91	13815	20465	0.82	12852	20711	0.36	6739	22037
1996	0.91	11115	16783	0.73	10018	17997	0.36	7650	24632
1997	0.91	10078	14812	0.64	8904	17328	0.36	8571	27026
1998	0.91	8735	12690	0.55	7766	16919	0.36	9196	28942

Notes: Variability about the 1994 stock size estimates is derived from 200 bootstrap iterations of the final VPA, and recruitment variability is based on the relationship between age 1 recruitment and SSB over the 1978-1993 period. Tabulated landings and SSB surveys indicating negative residuals in the later years. The CPUE indices usually exhibit artificially low standard errors because the catch at age used in the CPUE indices is often a derivative of the full catch at age used in the VPA. Calibrations without weighting options were, therefore, believed to be more appropriate. High partial sum of squares were noted for the spring age 1 index, particularly in 1980 and 1987. The subcommittee, therefore, felt that the spring age 1 and probably the fall age 0 provided a less robust index of abundance than survey indices for older ages. The partial sum of squares for the fall age 5 index in 1987 was also noted. To evaluate the cause of the high sum of squares, the subcommittee examined the age-length key data for 1980 and 1987 but no anomalies were detected.

The relationship between the proportion of landings of age 4 fish taken by Canada *vs* the U.S. seemed to have changed in 1993. The age-length key for Canadian landings was examined for potential sources of error, but the sample sizes for these catches appeared to be sufficient. The inconsistent proportions of age 4 fish landed in the respective countries may be attributable to changes in the exploitation pattern in Canada based on slight shifts in the distribution of effort by gear and season.

The initial calibration gave a high estimate of fishing mortality on age 4 (1.08) in 1993 that was inconsistent with the exploitation pattern evident for earlier years in this VPA. This estimate was also anomalous because targeting by the fishing fleet usually occurs on strong year classes and would be unlikely on the weak 1989 year class. This anomaly, however, was noted in previous assessments at ages 4 or 5 and may be contributing to the overestimates of F in the terminal year as illustrated by retrospective analyses. The subcommittee conducted an alternative calibration, removing the age 5 parameter estimate from the formulation and estimating the F on age 4 from the partial recruitment vector. The revised calibrations did not significantly improve the precision of the parameter estimates, nor did they completely remove the problematic exploitation patterns observed by the subcommittee. The initial run was therefore accepted.

SARC COMMENTS

The lack of discards in the catch-at-age matrix was noted. Given that the Sea Sampling Program is not based on any statistical design and that the large mesh fishery is known to be poorly sampled, estimation of discards from directed cod trips would most likely not be representative. A recent analysis of directed cod trips in the haddock closed areas, not presented at this SARC, indicated that discards of cod would be less than 10%. In the most recent years, given the poor recruitment, discarding of cod has most likely been negligible. The SARC did agree, however, that the sea sampling data base should be examined to determine if there is sufficient data to estimate discards.

After a discussion on using the average recruitment of the 1989-1992 year classes for the 1994 projections, the SARC concluded that stochastic recruitment and projections would be more appropriate since they account for the variability in the terminal population estimates and incorporate stock recruitment considerations. These procedures should also be followed in future assessments.

The SARC noted that the preferred timing of the assessment would be in the autumn rather than in the spring. In the autumn, landings for at least half or three quarters of the year would be available, thus making projections of the landings more reliable.

Sources of Uncertainty

Landings data for 1993 are provisional.

The cause of the trend in residuals for the Canadian survey is not known, but addition of these indices allow better estimation of stock sizes at older ages. It is possible that availability of older ages to the Canadian survey within Eastern Georges Bank strata is not constant and contributes to the trend.

RESEARCH RECOMMENDATIONS

1. Factors that persistently cause the high terminal F estimates for ages 4 or 5 should be investigated.

2. Although sampling intensity is only somewhat lower for the large cod market category, the more heterogenous age structure of large cod landings requires additional sampling emphasis to improve the estimation of age composition of older fish.

3. Catch in the current year cannot be estimated in the spring and little new informa-

tion can be included compared to a fall assessment. In future years, fall assessments would provide the most up-to-date information because the seasonal pattern of catch allows dependable estimation of total catch during the latest year.

4. The sensitivity of the VPA to low sampling intensity for older ages during 1978-1981 should be further evaluated *via* retrospective analyses to determine if the retrospective pattern is changed by removing earlier data.

5. Incorporate the bootstrap estimates of recruitment generated from the ADAPT output into stochastic projections of catch and SSB that accounts for stock recruitment considerations.

6. Investigate the Sea Sampling data base to determine if cod discards are adequately sampled in the large mesh fishery and generate discard estimates if appropriate.

7. Survey biomass indices are available from 1963, however, the current assessment only provides stock size estimates from 1978 to the present since landings statistics are not available for the earlier years. The SARC recommended that the historical stock sizes be estimated by applying the relationship between current VPA stock size and survey biomass estimates to the 1963-1977 survey biomass indices.

8. Appropriate target stock size or SSB be determined and that the length of time to attain these targets be estimated *via* stochastic projections.

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G. ASSESSMENT METHODS

TERMS OF REFERENCE

The terms of reference delineated by the SAW Steering Committee for Assessment Methods[1] were:

a. Potential biases in SARC assessment results, including uncertainty in catch-at-age, construction of CPUE indices, and retrospective analyses of assessment performance; and

b. Methods for medium-term stochastic projections, including recruitment time trends and variability, and trends in effort and catchability; and to design 'user friendly' ADAPT software

INTRODUCTION

The terms of reference include timely research topics, operational considerations often encountered when carrying out assessments, and scientific programming issues. The work involved in fully addressing the terms of reference is considerable, and well beyond what could be accomplish during this SARC cycle. It was noted that this is often the case for assessment methods-related issues (*e.g.* those considered by the ICES Working Group on Assessment Methods). The SARC attempted to carve out the sub-items that could be effectively addressed during this cycle, and to make clear recommendations concerning the products and resources (*e.g.* software) needed to address the remaining items at a future a future meeting. From the terms of reference, the SARC identified three distinct topics:

(1) Bias in SARC Assessment Results
(2) Stochastic Projections
(3) Assessment Methods Software

BIAS IN SARC ASSESSMENT RESULTS

Over the past few years, considerable attention has been given to the precision of the SARC assessment results. Age-structured assessments are generally carried out using ADAPT (Parrack 1986; Gavaris 1988; Conser and Powers 1990). The NEFSC version of the ADAPT software (Conser and Powers 1990) provides precision estimates via bootstrapping for all state variables of interest, and the associated uncertainty has been routinely provided as an integral part of the management advice since SARC 13 (December 1991). When age-structured modelling is not practical due to either sampling shortcomings or difficulties in routine ageing, simpler models have been used for assessment (*e.g.* DeLury models). Even in these cases, however, precision estimates similar to those from ADAPT have been developed and incorporated into the management advice (*e.g.* Conser and Idoine 1992; Murawski *et al.* 1993).

Although the bootstrapping mentioned above also provides some estimates of bias, bias considerations have not been examined routinely by the SARC (as have precision considerations), and bias issues have not been incorporated into management advice. The first term of reference, above, explicitly mentions three aspects of bias, *i.e.*

(i) biases resulting from uncertainty in the catch-at-age data;
(ii) biases resulting from construction of CPUE indices (either lack of precision or bias in the indices); and
(iii) retrospective analysis as a tool for uncovering biases (usually for SPA-based models) - including historical and residual analyses as adjuncts.

The SARC noted that (i) and (ii) as well as other explicit sources of potential bias are best examined using simulation modelling of an age-structured population for which the true population size and other characteristics are known. Such software is not currently available, nor could it be written during this SARC cycle. Consequently, examination of (i) and (ii) were tabled, while (iii) was undertaken during this meeting. It was also noted that ICES (1994) recently examined uncertainty in catch-at-age data as a potential source of bias in SPA results.

1 Report of the 17th Northeast Regional Stock Assessment Workshop: the Plenary. WoodsHole, MA: NOAA/NMFS/NEFSC. Center Ref. Doc. 94-07.

Retrospective Analysis

Retrospective analysis has become the most commonly used diagnostic procedure for examining the internal consistency of SPA-based assessments. The motivation for retrospective analysis comes from the annual cycle of updating data and conducting new age-structured assessments that is common for many stocks. In doing so, age-specific stock sizes and F's in a given year (generally near the end of the time series) are often quite different from the corresponding estimates the previous year. When these differences tend to have a common direction (*e.g.* when the later assessments tend to give smaller F's in a given year), the assessments are said to exhibit a retrospective pattern. Retrospective analysis is simply the process of stepping back through the years of available data and conducting an assessment at each step (*e.g.* with ADAPT), while ignoring all data in the subsequent years. All of the assumptions, model parameters, and other conditions under which the assessment is carried out are held constant throughout this process.

Sinclair *et al.* (1990) demonstrated that clear retrospective patterns are not uncommon for Canadian stocks. ICES (1991) and ICES (1993) reported similar findings for many stocks in the ICES areas. Retrospective analysis has since become a natural adjunct for age-structured assessments in Canada, at ICES, and in several other stock assessment environments. However, stocks reviewed by the SARC have not been examined systematically for retrospective patterns.

The SARC examined stocks that are routinely reviewed during its meetings, and for which recent age-structured assessments were available. To the extent possible, a species mix was selected that included both groundfish (roundfish and flatfish) and pelagics: (1) Georges Bank cod; (2) pollock; (3) American plaice; (4) summer flounder; (5) Atlantic sea herring. This species mix also offered good contrast with respect to the length of the available time series of catch-at-age data. The American plaice and summer flounder assessments are based on a relatively short time series while pollock and sea herring have relatively long time series available (Appendix Table G1). All of these stocks are currently assessed using ADAPT. A summary of the catch-at-age data, indices of abundance, and other details of the ADAPT model formulation used for the most recent assessment of Georges Bank cod, pollock, American plaice, summer flounder, and sea herring is provided in Appendix Table G1. The SARC noted that many of the entries in the table were not documented in the recent SARC reports, and recommends that a table similar to Appendix Table G1 be included in the SARC Report for each SARC-reviewed assessment.

Retrospective analyses were carried out for all of the above stocks. Two of these stocks (summer flounder and sea herring) are assessed using iterative re-weighting in ADAPT (Conser and Powers 1990) -- see Appendix Table G1. For these two stocks and for American plaice, retrospective analyses were carried out using both the weighted and unweighted options to measure the effect (if any) of weighting on retrospective patterns. In total, eight retrospective analyses were carried out (Appendix Table G2). The ADAPT software was modified to automatically carry out the retrospective runs. For each terminal year within a retrospective analysis, estimates of recruitment (age 1), fishing mortality rate on the fully-recruited ages, and spawning stock biomass were recorded.

Detailed results of the retrospective analysis, including additional background and graphical displays of all results, are provided by Conser *et all* (1994). Only highlights and an overview of the results are presented here. In the case of Georges Bank cod, for example, Appendix Figure G1 shows the time series of recruitment, full F, and SSB estimates for a single retrospective analysis which represents eight different assessments, *i.e.* assessments for which the terminal year was 1992, 1991, ..., 1986, 1985. These results indicate a tendency to underestimate SSB and to overestimate recruitment (in recent years).

An overview of all retrospective results is given in Appendix Table G2. In many cases where retrospective patterns are apparent, it is not straightforward to identify the causative factor(s) from retrospective analysis alone. Rather a retrospective pattern is a flag that identifies a lack of internal consistency which may warrant more detailed examination of the attributes used in the assessment. In some cases, however, the retrospective results alone do provide a perspective that directly identifies a problem in the assessment attributes. For example, a strong retrospective pattern is seen in herring recruitment (Appendix Figure G2). The currently used assessment attributes cause recruitment to be overestimated generally, and the overestimates exceed 50 billion fish in three of the terminal years. For the herring assessment, recruitment in the terminal year is not specified as an estimable parameter in ADAPT (Appendix Table G1). Rather recruitment (in the terminal year) is calculated from an input partial recruitment (PR) value, the catch at age 1, and the estimated full F. The retrospective results indicate that the input partial recruitment (PR=0.01) is too small, and that the overestimation can be rectified simply by specifying a large input PR.

Generally no consistent pattern over stocks or management state variables is evident (Appendix Table G2). Also for the cases examined, whether or not iterative re-weighting was used in ADAPT had little effect on the presence or absence of retrospective patterns. This contrasts with other studies of retrospective tendencies where more consistent and general patterns were found when using the same method on stocks from similar areas. For example, Sinclair *et al.* (1990) showed a general tendency to underestimate fishing mortality rates on Canadian groundfish stocks (using ADAPT). Similar general tendencies were also shown for North Sea stocks (ICES 1991).

The SARC found the retrospective analyses to be quite informative, and recommends that retrospective analysis be carried out routinely as an integral part of all age-structured assessments. Although general patterns were not found overall, some of the patterns demonstrated may warrant further examination for some stocks. Further a broader base of stocks with routine retrospective results may, over time, establish more general patterns that were not evident from the species mix used here.

However, an important cautionary note is appropriate. The use of terms such as *underestimate* or *overestimate* in interpreting retrospective results is commonplace here and in other studies. These are useful descriptive terms, but whether or not they can be equated with bias in assessment results is entirely dependent on the strength of the baseline SPA results. When examining deviations from the baseline (whether quantitatively in the form of residuals or more qualitatively in comparing time series plots), we are tacitly assuming the baseline SPA results represent the *'truth'*. For reasons too numerous to detail here, this is usually not the case (*e.g.* see Sampson 1987). While the presence of retrospective patterns in an assessment may or may not indicate bias, it does establish an internal consistency problem that usually warrants further investigation. Lack of internal consistency may be caused by data problems, erroneous assumptions, methods shortcomings, or a combination of all three. It is generally premature to use retrospective analysis results to modify management advice until the source of the internal inconsistency is clearly identified

Historical Analysis

Retrospective analysis provides insight on the internal consistency of the currently used assessment process, *i.e.* data, methods used, assumptions invoked, *etc.* By holding all of these attributes constant (*e.g.* those given in Appendix Table G1) and measuring the performance of the process had it been applied in the same way over time, we obtain a measure of the accuracy of the currently-used assessment process (subject to the caveats above). Although the retrospective baseline assessment corresponds to the most recent assessment for a stock, the retrospective assessments for earlier years will often differ (sometimes substantially) from the assessments that were actually carried out by working groups or individuals in the corresponding years. There are, in general, many reasons why assessment attributes change over time. Principally,

(1) Significant advances in age-structured methods for assessment have occurred over the past decade. The methods used for operational assessment work have changed accordingly.
(2) Based on the evaluation of results from preliminary runs, working groups or individuals often re-evaluate their input data, model formulations, and/or assumptions. Final results are then based on runs using attributes that have been adjusted accordingly. In general, this process cannot be described in a sufficiently analytical fashion that it could be incorporated into a retrospective analysis.
(3) Management regulations can change the assumptions invoked in doing assessments over time, *e.g.* changes in mesh regulations can result in differing assumptions about partial recruitment of the youngest ages in the terminal year.

Examples of (1) and (2), above, can be seen by examining the attributes of the age-structured Georges Bank cod assessments that have been carried out since the initiation of the Northeast Regional Stock Assessment Workshop (SAW) process (Appendix Table G3).

Historical analysis uses the same baseline as retrospective analysis, *i.e.* the most recent assessment. However, instead of iterating through earlier years, re-assessing the stock, and comparing to the baseline, historical analysis simply compares the historical assessments with the baseline. Whereas retrospective analysis emphasizes current assessment attributes and their likely performance now and in the future, historical analysis is designed to examine the past performance of assessments. In this sense, it is a useful adjunct to retrospective analysis.

As an example, historical analysis was carried out for Georges Bank cod. Age-structured assessments have been carried out far more regularly for cod over the past decade than for any of the other stocks examined in the **Retrospective Analysis** section on page 145. Additionally, the Georges Bank cod assessment history is particularly well suited for historical analysis in that three different assessment methods have been employed, the number of abundance indices used has varied widely, and various combinations of weighting have been employed (Appendix Table G3). This rich mixture of attributes over time provides good contrast with the retrospective analysis where all attributes are held constant.

The historical age-structured cod assessments (Appendix Table G3) provided five assessments (*i.e.* terminal years 1985, 1987, 1989, 1990, and 1991) that could be compared with the baseline assessment (terminal year 1992). The baseline assessment is identical to the baseline used in the retrospective analysis. The historical analysis results are presented in a fashion parallel to the retrospective results in Conser *et al.* (1994). An overview of the results is given in Appendix Table G2. Although corresponding year differences are evident, generally the patterns from the historical analysis are similar to those from retrospective analysis (Appendix Figure G3). Recruitment appears to be overestimated in recent years (Appendix Figure G3a); the fully-recruited F tends to be overestimated - somewhat more so in the historical analysis (Appendix Figure G3b); and SSB is generally underestimated - somewhat more so in the historical analysis (Appendix Figure G3c).

The fully-recruited F from the 1987 historical assessment (*i.e.* the assessment using 1987 as the terminal year) is a particularly large outlier (Appendix Figure G3b). The full F from the 1987 retrospective assessment was also overestimated, but much less so. This may be a result of the improvement in the assessment methods used for cod assessment. The 1987 historical assessment used *ad hoc* assessment methods, whereas all retrospective assessments used ADAPT. Residuals are generally smaller for retrospective SSB estimates as well (Appendix Figure G3c).
It is also noteworthy that for cod and for other SARC-reviewed groundfish stocks, recruitment in the terminal year is often estimated using a two-stage optimization procedure:

(1) ADAPT is used to obtain recruitment estimates for all years (including the terminal year); then

(2) the ADAPT recruitment estimate for the terminal is discarded, and another calibration procedure, RCT3 (formerly called RCRTINX2), is used to estimate terminal year recruitment. In some cases, additional ADAPT recruitment estimates are also replaced by RCT3 estimates.

The two-stage procedure is awkward in that output from ADAPT (*i.e.* recruitment estimates that were not discarded) along with the recruitment indices used in ADAPT must be entered into an input file for RCT3. RCT3 recruitment estimates are then manually superimposed over the original values in ADAPT output tables. Perhaps more important than the awkwardness, however, are the resulting inconsistencies with regard to precision estimates and probability profiles, since the currently-used bootstrapping procedure does not account for the RCT3 step. These complications are added to the assessment in the hope of obtaining a better recruitment estimate in the terminal year. However, a comparison of the historical and retrospective recruitment residuals indicates that the retrospective residuals (which do not use the two-stage procedure) have similar or smaller absolute value than the historical residuals in corresponding terminal years (Fig G3a). It would appear that at least for Georges Bank cod assessments, adding the RCT3 step is an unnecessary complication.

The SARC found the historical analysis of the Georges Bank cod assessments to be quite informative, and recommends that historical analysis be carried out routinely as an integral part of all age-structured assessments. Historical analysis can be used in its own right as an assessment quality control check, but it offers particularly useful insight when combined with retrospective analysis.

Residual Analysis

In both the retrospective and historical analyses, the process used to identify patterns was largely qualitative, *i.e.* visual interpretation from the plotted results. In several cases, the traditional presentation of retrospective results was difficult to use for pattern identification. A more quantitative approach coupled with the visual pattern identification process has several advantages:

(a) While visual interpretation easily identifies clear patterns, it can be somewhat subjective when the underestimation or overestimate is small, or when it is inconsistent over the time series.
(b) Quantification allows testing results for statistical significance (provided the normality assumptions are met).
(c) Quantification provides for straightforward comparisons among stocks or even between retrospective and historical results, *e.g.* does cod SSB tend to be underestimated to a greater extent by the historical analysis than by the retrospective analysis?

Using sea herring as an example, the SARC carried out a residual analysis on the retrospective results. Using the 1992 assessment (*i.e.* the assessment using 1992 as the terminal year) as the baseline, the following two statistics pertaining to recruitment (R) were computed for each retrospective assessment (*i.e.* for t = 1991, 1990, ..., 1981, 1980):

$$\Delta R_{t,t+k} = R_{t,t+k} - R_{t,1992} \quad \text{for } k=0,\ldots,(1991-t);\ \text{s.t. } k \leq 5$$

$$\lambda R_{t,t+k} = \text{loge} \frac{R_{t,t+k}}{R_{t,1992}}$$

where:

$R_{t,1992}$ = Recruitment (age 1) in year t as estimated from the assessment with 1992 serving as the terminal year, *i.e.* as estimated from the baseline assessment.

$R_{t,t+k}$ = Recruitment in year t as estimated from the assessment with year t+k serving as the terminal year.

k = Lag (in years) between the year of interest and the terminal year of the assessment, *i.e.* the number of backcalculations carried out to arrive at the recruitment estimate of interest. Statistics are only computed for five backcalculations, *i.e.* k $\leq$5.

Then proceeding similarly for the fully-recruited fishing mortality rate estimates (F):

$$\Delta F_{t,t+k} = F_{t,t+k} - F_{t,1992} \quad \text{for } k=0,\ldots,(1991-t);\ \text{s.t. } k \leq 5$$

$$\lambda F_{t,t+k} = \text{loge} \frac{F_{t,t+k}}{F_{t,1992}}$$

and finally for spawning stock biomass (SSB):

$$\Delta SSB_{t,t+k} = SSB_{t,t+k} - SSB_{t,1992} \quad \text{for } k=0,\ldots,(1991-t);\ \text{s.t. } k \leq 5$$

$$\lambda SSB_{t,t+k} = \text{loge} \frac{SSB_{t,t+k}}{SSB_{t,1992}}$$

The results for the sea herring example are not presented here. See Conser *et al.* (1994) for details. The SARC recommends that residual analysis be carried out routinely as an integral part of retrospective and historical analyses.

STOCHASTIC PREDICTIONS

The SARC discussed the basic principles involved in formulating stochastic projections of stock status over the short (1-3 years), medium (4-10 years) and long (>10 years) term. SARC assessments usually include a short term forecast of stock abundance under a variety of management scenarios expressed as different fishing mortality rates. These forecasts generally are made based on calibrated survey estimates of the next year's recruiting year class abundance or when indices are not available, by simply using average recruitment. The recruitment point estimate as well as high and low recruitment levels (*e.g.* one standard deviation above and below the point estimate) are typically assumed and projected forward in time. This procedure is limited to short term forecasts. It does not account for error in the stock size estimates used to initiate the projection, nor does it characterize the probability of future stock abundance levels. In addition, if the same recruitment level is carried forward beyond the year for which the survey applies, it assumes no effect of stock on recruitment (*i.e.*, constant recruitment over time).

It was agreed that there is a need for management purposes to make projections on all three time scales (*i.e.* short, medium, and long term). In all cases, it is important that the projections are stochastic and at least include estimation error from the assessment as well as process error in the form of variable recruitment. Estimation errors are available for all of the analytical assessments performed and reviewed by the SARC, including bootstrap confidence regions on current stock abundance and fishing mortality rates. Generally these errors are not included in current SARC projections but should be. Brodziak and Rago (1994) provide a good example of a stochastic projection including flexible procedures for recruitment generation and incorporation of estimation errors from the assessment.

Recruitment variability is a key component of stochasticity in stock abundance. The SARC agreed that constant recruitment scenarios are inappropriate in almost all cases. In addition, projecting recruitment independent of stock abundance is also inappropriate, particularly when the stock is at a low abundance. Modelling recruitment independent of stock abundance implies that the stock can infinitely compensate for any increased mortality (*e.g.* even if stock abundance is zero, recruits will be generated). Furthermore, constant recruitment may be overly optimistic on recovery projections for a stock starting at very low abundance. Therefore, some relationship between stock and recruitment is needed for all stochastic projections beyond one year. Brodziak and Rago (1994) presented three different methods for calculating recruitment distributions based on: (1) developing a Markov matrix of recruitment probabilities at different spawning stock sizes; (2) developing a nonparametric distribution of R/SSB; and (3) a simple bootstrap model of recruitment.

For any method of stochastic projection, the recruitment distributions must be developed from the available information on stock and recruitment. In this regard, the SARC noted the importance of extending the assessments of stocks as far back in time as possible. Even when a long time series of survey data are available, early years are often truncated in the assessment because of concerns about the quality of the catch, length sampling, age data, *etc.* While this may be necessary for producing the estimates of current status, it may be appropriate to utilize less stringent methods to produce as long a time series of stock and recruitment data as possible. For example, a simple calibration of the assessment results with survey indices may allow estimation of earlier stock abundance and recruitment extending back to the beginning of the survey period. This could greatly improve the projection of recruitment by allowing better estimates of any stock-recruitment relationship and variability at a given stock size to be made. The SARC recommends that this item be given high priority in the terms of reference for the next meeting of the Assessment Methods Subcommittee.

The output from stochastic projections are possible future trajectories for the stock. It is important to realize that it is inappropriate to portray the upper or lower part of the distribution of projected stock sizes in each year as if it were a single trajectory. To avoid this interpretation, it is advisable to plot some sample trajectories along with the envelope of future stock status that results from the projections.

The SARC briefly discussed software options for making stochastic projections. Brodziak and Rago (1994) have developed a FORTRAN program (AGEPRO) for the methods described in their paper. It is a research software, not designed for general use, but is available as needed. Several SARC members are currently using the @RISK spreadsheet software (in conjunction with Excel or Lotus) for projections. An example of its use is provided in ICES (1994b). Although it would be difficult to use @RISK to model future recruitment at the level of sophistication used in AGEPRO, it is simple, flexible, and can be used to incorporate other errors not modelled in the AGEPRO program, *e.g.* error in target F, partial recruitment, *etc.* (Appendix Table G4). The SARC species subcommittees could easily incorporate the available information on uncertainty into a spreadsheet for producing projections. This could also be used by Plan Development Teams to investigate management options.

Although additional sources of error may be desirable to incorporate into projection software at some point in the future (Appendix Table G4), the currently available software (either @RISK or the AGEPRO program) should be adequate for all SARC assessments. The SARC recommends that all SARC assessments include both short and medium term stochastic projections.

ASSESSMENT METHODS SOFTWARE

The terms of reference included the request '... *to design 'user friendly' ADAPT software.*' However, it was not practical to discuss *'user friendly'* ADAPT software separate and apart from the broader issues regarding all assessment methods software used in the SARC process. However, a *strawman* proposal to make the ADAPT software more user friendly is put forth next.

Methods Software and the SARC Process

The Role of Software

Assessment methods software is a keystone in the process of providing scientific advice (Fig G4). Its role is to integrate (i) fisheries-independent data, (ii) fisheries-dependent data, and (iii) results of biological studies to provide scientific advice on the status of stocks. In Fig G4, it is depicted as the *Calibration* function (in the center of the diagram). Its importance is apparent from the information flow shown in Fig G4. The data collection and biological studies used for assessment are costly undertakings, but their value is greatly diminished if they are not properly integrated to provide a quantitatively-based assessment of stock status. For SARC assessments, *'calibration'* has generally been done using ADAPT for age-structured assessments or DeLury models for non-age-structured assessments.

Software Taxonomy

The SARC identified three generations of assessment methods software:

(1) *Research and Development (R&D) Software (1st Generation).* Software written for methods research, *e.g.* development of new methods, enhancement of existing methods, testing effectiveness of methods, *etc.* This software can take on many forms ranging from programs written in formal programming languages (*e.g.* APL, SPlus, FORTRAN, C, *etc*) to complex spreadsheet macros. It must be very flexible and easily modified by the author, but generally will not be easily used by others.

(2) *Operational Assessment Software (2nd Generation).* Software that may have had its origin as R&D software (developed either at NEFSC or elsewhere) but once its utility is establish, it is re-written in a standard programming language so that it is modular and easy to modify and maintain. While the operational software may not contain all of the options found in the corresponding R&D software, a complete suite of model diagnostics and graphical displays are fully integrated. A users' guide is available including references to formal literature or working documents that fully describe the assessment method implemented by the software.

(3) *User Friendly Software (3rd Generation).* Operational software, as described in (2) above, but with a considerably enhanced user interface (*e.g.* pull-down menus, dialogue boxes, *etc.*) and more complete documentation.

The ADAPT software, along with most other assessment methods software used in the SARC process, is R&D software (*i.e.* 1st generation). Before moving toward *'user friendly'* software (3rd generation), it will be necessary to fully develop operational software (2nd generation) for implementing the commonly used assessment methods. Although there were differences of opinion within the SARC regarding the cost/benefit tradeoffs of developing user friendly software (3rd generation), there was clear consensus that operational software (2nd generation) needs to be developed. The current practice of carrying out stock assessments using R&D software is inefficient, error-prone, and frustrating for both the software users and the developers. It also prevents non-NEFSC scientists from participating more fully in the SARC process since they do not generally have access to the R&D software. These problems are likely to be further exacerbated should the semi-annual SARC's review an increased number of stock assessments in the future.

Design for Improved Software

In order to structure the discussion of designing better assessment methods software for the SARC process, the SARC addressed three questions:

(1) Do we need to have locally developed and maintained assessment methods software?

(2) How do we write software that can be used for both operational and research needs? How do we create automatic feedback between them?

(3) Can we develop, support, and maintain *'user friendly'* software?

Locally Developed Software

Assessment methods software is developed regularly within most major fisheries research organizations throughout the world. Many new assessment methods are introduced in the fisheries literature each year, and most authors offer free or low cost software to implement their methods. Given that software development and maintenance are time and resource consuming endeavors, can we simply acquire and use software developed elsewhere? Will this tack meet our needs or do we need to develop and maintain methods software locally?

For a variety of reasons, the SARC strongly recommends that assessment methods software be developed and maintained locally:

(a) Most methods developed by other research organizations are tailored to their local circumstances, *i.e.* the combination of species, fishing practices, data availability, *etc.* that characterizes their local situation. Without modifications, these methods are unlikely to work well for our assessment problems.

(b) Software modification by individuals not completely familiar with the code is time-consuming, error-prone, and quite risky given the keystone role of such software in the SARC process (Appendix Figure G4).

(c) A local methods software infrastructure provides the ability to tailor methods to our specific needs (as discussed in (a), above). This infrastructure requires a critical mass of staff scientists with the right skills and interests, advanced computer hardware, specialized software tools, *etc.* This infrastructure is a valuable part of a research organization generally and if lost or not fully-developed, cannot be re-established easily.

(d) Although additional resources above and beyond those now allocated are required to properly develop and maintain software locally, the cost is small relative to the other activities involved in the SARC stock assessment process (Appendix Figure G4).

The Research/Operational Software Interaction

Research software (1st generation) for implementing an assessment method is generally a necessary precursor for good operational software (2nd generation). Only in rare circumstances is it possible to write good operational software straightaway for a newly developed assessment method. It is clear, therefore, that if operational software is desired, then support must also be provided for good research software. Although not so readily apparent, good operational software is also vital for the continued improvement of assessment methods (and the research software that supports them). Good operational software leads to wide usage of a method, exercising its various options, and generally pushing the limits under which the method was designed. Only with such usage will the desired feedback between methods development and their operational application be achieved.

Appendix Figure G5 depicts a model under which a natural transition from research software to operational software would occur (with requisite feedback). The model also provides for flow into the SARC process of ideas, software, *etc.* from outside NEFSC (with feedback). In contrast, the current model (Appendix Figure G6) is characterized by a more parallel flow of ideas, software, *etc.* into the research and operational areas. While interaction and some feedback do occur, the paths are informal and more importantly, there is no explicit methods development activity (only methods research). With this model, neither operational nor user friendly software are likely to be developed. It will be necessary for the SARC process to move more toward the ideal model (Appendix Figure G5) for this to occur.

The SARC recommends that a study group be formed to develop a prototype for the routine development of operational software using the Appendix Figure G5 paradigm. The study group will use the ADAPT software as a working example. The group will develop operational ADAPT software using the existing research software as its basis, and establish the feedback mechanisms needed to enhance further development of the method. The study group's duration will be one year, and its activities will require resources above and beyond those now dedicated to assessment methods software. A *strawman* proposal for such a study group is provided in Appendix G1.

The Prospects for User-Friendly Software:

In principal, user friendly software could also be developed within the framework suggested in Appendix Figure G5. However while the study group recommended to develop an operational software prototype may be staffed by scientists currently onboard, the development, maintenance, and support of user friendly software would require additional staff and other resources well beyond those needed to develop operational software. The SARC suggests that it may be prudent to table the user friendly software issues until the Study Group has completed its work on operational software.

SARC DISCUSSION

Retrospective and Historical Analyses

The feasibility of identifying causal factor(s) for the retrospective/historical patterns was discussed by the SARC. In general, causal factors are difficult to identify from retrospective or historical analysis alone. Although the causal factor for the herring recruitment pattern (Appendix Figure G2) was clearly identified (*i.e.* PR was set too low), this is the exception rather than the norm. Generally these analyses only draw attention to an internal inconsistency problem, and then serve as a stepping off point for a more detailed investigation of methods, assumptions, data, *etc.* The discussants did suggest, however, that inclusion of the Canadian survey indices in the latter years of the cod assessment may have been responsible for reducing the degree of retrospective pattern in F and SSB (Appendix Figures G1 and G3).

It was also suggested that routine examination of Display Type III - developed by the Assessment Methods Subcommittee (see Conser *et all.* 1994) but not shown in this report - may help to identify situations where catchability is not constant with time and/or population size, *e.g.* as discussed for bluefish at this SARC meeting.

Assessment Methods Software

The SARC discussion with regard to the methods software topic focused on the proposed study group to develop operational software (Appendix G1).

(i) The importance of formal software validation and testing was raised, particularly when results from the software are to be used for important decision making (*e.g.* in the provision of management advice). This activity differs from the methods testing that is commonly used in Fisheries to compare the performance of different assessment methods. It specifically addresses whether coding errors or inconsistencies have been incorporated into the software. Although it is not a trivial task (probably will require parallel programming efforts), it is done routinely in other fields and should be added to the study group's terms of reference.

(ii) The SPlus programming language is powerful and well suited for developing operational software (Appendix G2). To some extent, its effectiveness for methods software development is due to its interpreted nature (*i.e.* SPlus is an interpreted rather than a compiled language). However, although it is available for both PC and Unix platforms, not all potential users have access to the SPlus system, *e.g.* biologists in some state agencies. It will be important to be able to distribute operational software to interested scientists whether or not they have the SPlus system on a computer at their laboratory. Within the proposed study group framework (Appendix G1), two tacks for accomplishing this were suggested (there may be others as well):

   (a) Run-time versions of SPlus code can be created. A run-time version will run on a machine that does not have the SPlus system giving full output and graphics, but no interactive capability is provided for the user (*i.e.* only '*batch mode*' is provided).

   (b) The computational functions of the operational software can be coded in a compiled language (*e.g.* FORTRAN or C). These compiled modules can then be called from SPlus, which will carry out I/O, statistical analysis of results, visualization via graphics, *etc.* A '*plain vanilla*' version of the software incorporating the compiled functions and a main driver program can then be distributed to users who do not have SPlus.

(iii) It was suggested that at least with respect to ADAPT, NEFSC Population Dynamics Branch staff have used the R&D software for all age-structured assessments conducted over the past several years. Although it is awkward and difficult to get accustomed to, the job is getting done. Others suggested that current assessments were not taking full advantage of ADAPT's capabilities due to the limitations of the R&D software (*e.g.* the bluefish assessment). Further the R&D software has not been modified or enhanced in any way for more than two years - implying that no feedback is occurring between operational assessments and methods development (as depicted in Appendix Figure G5).

(iv) The study group proposal (Appendix G1) suggests that a core group of three people will be required to develop a prototype for the routine development of operational software - using the ADAPT software as a working example. The effort requires a half-time commitment from each member of the core group for one year. Several issues were raised:

(a) Should the three people be new hires or should current staff be used to accomplish the work?
(b) Can some or all of the work be done by contracting?
(c) With increasing demands for assessments, management support analyses, computer systems conversion, *etc.*, can we afford to develop operational software?

To varying degrees, all of these questions relate to resource allocation issues best left to NEFSC management. However, it was pointed out that whether the work is to be done by new hires or existing staff (with or without contracting help), the principal study group product is a prototype for operational software development in future years. As such, the concept of a core group of three people, who will be involved in similar activities on a continuing basis after the study group has been dissolved, is central to this initiative.

RESEARCH RECOMMENDATIONS

1. A table similar to Appendix Table G1 of this report be included in the SARC Report for each stock. Without these details, the assessments cannot be reproduced by others.

2. The species subcommittees carry out retrospective, historical, and residual analyses with each assessment.

3. Short and medium term stochastic projections be carried out for each assessment reviewed by the SARC.

4. A higher priority be given to extending the time series of stock-recruitment data (Candidate Terms of Reference #8 from SARC 17)

5. Assessment methods software be developed and maintained locally.

6. All research software (1st generation) currently being used for SARC assessments be upgraded to operational software (2nd generation).

7. A study group be formed and fully supported to develop a prototype for the interaction and feedback between research and operational software (using ADAPT as a case study).

TERMS OF REFERENCE FOR THE ASSESSMENT METHODS SUBCOMMITTEE

Using the experiences from the inaugural meeting of the Assessment Methods Subcommittee as background, the SARC discussed terms of reference (TOR) for the next Subcommittee meeting. The list of candidate TOR developed at SARC 17 (December 1993) was reviewed. It was noted that with a short meeting (3-5 days), a relatively small group of participants, and the amount of work associated with most of the candidate TOR, no more than two TOR should generally be taken on during a meeting, and these should be chosen carefully.

The full list of the current Candidate TOR for the Subcommittee is summarized below. The list includes all items delineated at SARC 17 plus two additional items suggested at this meeting (*i.e.* Items 10 and 11).

(1) Potential biases in sarc assessment results - *addressed partially during SARC 18*
(2) Methods for medium-term stochastic projections - *fully addressed during SARC 18*
(3) Multiple indices of abundance within the delury model
(4) 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
(8) Extending the time series of stock-recruitment data
(9) Designing user-friendly ADAPT software - *fully addressed during SARC 18*
(10) Comparing the performance of ADAPT and DeLury models, *i.e.* can we do as well (or nearly as well) with non-age-structured models in some of our assessments
(11) Incorporating regulation and other management effects (including spatial effects) into stochastic projections

It was suggested that Candidate TOR 4, 5, 6, and 7 could be grouped into a heading '*Feedback From Operational Assessments.*' The Subcommittee could then tackle various aspects of this topic as it sees fit, given available software, interests of the members, and time constraints.

The SARC recommends the following terms of reference for the next meeting of the Assessment Methods Subcommittee:

(i) examine methods for extending the time series of stock-recruitment data (Candidate TOR 8); and

(ii) address various aspects of feedback from operational assessments (Candidate TOR 4-7), as feasible, with particular priority on developing CPUE-based indices of abundance.

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APPENDIX G1

A PROPOSAL TO FORM A STUDY GROUP ON THE DEVELOPMENT OF OPERATIONAL COMPUTER SOFTWARE FOR STOCK ASSESSMENT

BACKGROUND

The SARC identified three generations of assessment methods software:

(1) *Research and Development (R&D) Software (1st Generation).* Software written for methods research, *e.g.* development of new methods, enhancement of existing methods, testing effectiveness of methods, *etc.* This software can take on many forms ranging from programs written in formal programming languages (*e.g.* APL, SPlus, FORTRAN, C, *etc.*) to complex spreadsheet macros. It must be very flexible and easily modified by the author, but generally will not be easily used by others.

(2) *Operational Assessment Software (2nd Generation).* Software that may have had its origin as R&D software (developed either at NEFSC or elsewhere) but once its utility is established, it is re-written in a standard programming language so that it is modular and easy to modify and maintain. While the operational software may not contain all of the options found in the corresponding R&D software, a complete suite of model diagnostics and graphical displays are fully integrated. A users' guide is available including references to formal literature or working documents that fully describe the assessment method implemented by the software.

(3) *User Friendly Software (3rd Generation).* Operational software, as described in (2), but with a considerably enhanced user interface (*e.g.* pull-down menus, dialogue boxes, *etc.*) and more complete documentation.

The ADAPT software, along with most other assessment methods software used in the SARC process, is R&D software (*i.e.* 1st generation). Before moving toward *'user friendly'* software (3rd generation), it will be necessary to fully develop operational software (2nd generation) for implementing the commonly used assessment methods. The current practice of carrying out stock assessments using R&D software tends to be inefficient, error-prone, and frustrating for both the software users and the developers. It also prevents non-NEFSC scientists from participating more fully in the SARC process since they do not generally have access to the R&D software. These problems are likely to be further exacerbated should the semi-annual SARC's review an increased number of stock assessments in the future.

TERMS OF REFERENCE

The Study Group (SG) will develop a prototype for the routine development of operational software using the *'ideal model'* paradigm suggested by the Assessment Methods SARC (Figure G5). The ADAPT software will be used as a working example. The SG will develop operational ADAPT software using the existing research software as its basis, and establish the feedback mechanisms needed to enhance further development of the method. The SG's duration will be one year. More specifically, the SG will:

(i) Rewrite the existing ADAPT software in the SPlus[1] programming language so that it is modular and easy to modify and maintain. Include all of the options from the existing R&D software (*i.e.*, the APL version) that are currently being used for SARC assessments. Create linkages with APL version to promote feedback between the research and operational software. Include a complete suite of fully integrated model diagnostics and graphical displays.

(ii) Prepare a users' guide that serves as a stand-alone document on program usage. Include sample input files and expected results, examples of the interpretation of diagnostics, all principal model equations, *etc.*

(iii) Target the software for the Pentium chip operating under Windows NT or Chicago. The secondary target platform will be Sun Workstations operating under Sun O/S or Solaris.

1 See Appendix G2 for a description of the SPlus programming language, including the principal reasons for its selection as the language of choice for operational assessment methods software.

(iv) Upon completion, report back to the Assessment Methods SARC on the utility of the research/operational software paradigm; evaluate the utility of the SPlus and APL programming languages for this application; and recommend whether other R&D software should be made operational in the same way.

RESOURCES REQUIRED

A core group of three individuals, who are willing to spend a significant amount of time writing code, will form the kernel of the Study Group. Others may participate to varying degrees as their interests and available time warrant. At least half-time commitments will be required of the core group. Additionally, the following resources are required:

(a) Pentium-based computers for each member of the core group as well as Sun Workstations, if the secondary target platform is to be achieved.

(b) Current versions of SPlus, APL, and other miscellaneous software for the Pentium machines, as well as for the Sun Workstations, if the secondary target platform is to be achieved.

(c) SPlus and APL training courses for each member of the core group.

The Study Group should be able to complete its terms of reference within a one year period commencing when all of the required resources are in place.

APPENDIX G2

ATTRIBUTES OF THE SPLUS PROGRAMMING LANGUAGE

SPlus is a modern programming language as well as statistical and graphics package. Its principal attributes are:

(i) It is object-oriented and encourages the use of structured programming techniques.

(ii) SPlus fully integrates a suite of state-of-the-art exploratory data analysis, interactive graphics, and other statistical routines -- all callable from user-written SPlus programs.

(iii) It is an interpreted language that allows for interactive testing and debugging. Interpreted languages are also more amenable to interactive graphics and 'what if' analyses. While interpreters can be slow for intensive '*number crunching*' computing, calls can be made from SPlus to compiled FORTRAN or C subroutines as necessary to reduce run times.

(iv) SPlus was originally designed for Unix workstations and while its performance is optimized on that platform, a fully-functional PC-compatible version (MS Windows 3.1) is also available. Source code developed on either platform is transportable to the other without modification.

(v) It is the contemporary programming language of choice in the statistical modeling community, and users have contributed thousands of SPlus programs to a public domain library that can be easily accessed via Internet.

(vi) SPlus can be linked with the Arc-Info GIS.

(vii) Because of the depth of its capabilities, significant learning time is required before it can be fully and efficiently utilized for developing operational methods software. This learning time can be greatly reduced, however, by enrollment in the SPlus training courses offered by Statistical Sciences, Inc.

Table G1. Catch-at-age data (CAA), indices of abundance, and other details of the ADAPT (or other method) model formulation used for the assessment of Georges Bank cod, pollock, American plaice, summer flounder, and sea herring

	Georges Bank[1] Cod SARC 17	Pollock SARC 16	American[2] Plaice SARC 14	Summer Flounder SARC 16	Sea Herring SARC 16
Catch-at-age Data:					
Years in the CAA	1978-92	1970-92	1982-91	1982-93	1967-92
Ages in the original CAA	1-14+	1-12+	1-14+	0-5+	1-11+
Ages used for the plus group	10-14+	10-12+	9-14+	5+	11+
Discards included in CAA?	No	No	Yes	Yes	No
Indices of Abundance Used for Calibration:					
<u>Research Vessel Surveys (yr/age)</u>					
US spring (Jan 1 abundance)	1978-93/1-8	1974-92/2-10	1982-91/1-7	1982-92/0-3	1968-92/1-5
Canada summer (mid-yr abund.)		1974-92/2-10			
US autumn (mid-yr abundance)	1978-92/1				
US autumn (lagged to Jan 1)	1977-92/0,2-5	1974-92/1-9	1981-90/1-6		
US larval (mid-yr in weight)					1971-91/4-11
Canada spring (Jan 1)	1986-93/1-8				
Mass. spring (Jan 1)		1978-92/1-3		1982-1992/0-2	
Other states				many others	
<u>Commercial CPUE Data (yr/age)</u>					
US; age-specific (mid-yr)	1978-92/2-6	1972-92/4-9			
US; age-aggregated (mid-yr)		1974-92/6-11			
Canada; age-specific (mid-yr)		1974-92/4-9			
Canada; age-aggregated (mid-yr)		1974-92/6-11			
Model Formulation Details:					
Method used	ADAPT	ADAPT	ADAPT	ADAPT	ADAPT
Software used	Conser and Powers 1990	Conser and Powers 1990	Conser and Powers 1990	Conser and Powers 1990	Conser and Powers 1990
Natural mortality rate (yr^{-1})	0.2	0.2	0.2	0.2	0.2
Survivors were estimated for which ages in year t+1 ?	1-8	3-9	1-8[2]	1-3	4.6
Type of PR assumed	flat-topped	flat-topped	flat-topped	flat-topped	flat-topped
Ages used for determining F on the oldest true age	3-9	7-11	6-8	2-4	5-10
Indices normalized?	Yes	Yes	Yes	Yes	Yes
Earlier years downweighted?	No	No	No	No	No
Iterative re-weighting used?	No	No	No	Yes	Yes

[1] An age-structured assessment was prepared for SARC 17, but was not reviewed by the SARC. Assessment attributes and results were taken from Mayo *et al.* (1994).

[2] For the American plaice retrospective analysis with 1989 as the terminal year, only ages 1-7 were estimated.

Table G2. Overview of retrospective analysis and historical analysis results

	Recruitment (Age 1)	Fully Recruited Fishing Mortality Rate	Spawning Stock Biomass
Retrospective Analysis			
Georges Bank cod			
Unweighted	+ (recently)	0	-
Pollock			
Unweighted	0	++	+ (recently)
American plaice			
Unweighted	-	--	++
Weighted	-	-	+
	(other than 1989)	(other than 1989)	(other than 1989)
Summer flounder			
Unweighted	0	-	++
Weighted	0	--	++
Sea herring			
Unweighted	++	0	+
Weighted	++	0	+ (recently)
Historical analysis			
Georges Bank cod	+ (recently)	+	--

Note: Analyses were carried out, based on the latest assessment for Georges Bank cod, pollock, American plaice, summer flounder, and sea herring. In each case, internal consistency was gauged by examining recruitment at age 1, fishing mortality rate on fully recruited ages, and spawning stock biomass. The markers in the body of the table indicate the degree to which internal consistency problems were found.

Legend:
- ++ Strong tendency to overestimate (relative to the baseline)
- \+ Some tendency to overestimate (relative to the baseline)
- 0 No discernable pattern in estimates.
- \- Some tendency to underestimate (relative to the baseline)
- -- Strong tendency to underestimate (relative to the baseline)

Table G3. Selected attributes of the age-structured Georges Bank cod assessments that have been carried out since the initiation of the Northeast Regional Stock Assessment Workshop (SAW) process

	Terminal Year in Analysis (Y_{t+1})	Calibration Method Used	Number of Research Survey Indices Used	Number of CPUE Indices Used	Number of Survivors Estimated in Y_{t+1}	Fully Recruited Ages	Interative Reweighting Used	Down-Weighting Used for Early Years
SAW 3	1985	*ad hoc*	1	1	N/A	3+	N/A	N/A
SAW 7	1987	*ad hoc*	0	2	N/A	3+	N/A	N/A
SAW 11	1989	Laurec-Shepherd	18	9	N/A	3+	Yes	No
SAW 13	1990	ADAPT	20	5	7	4+	Yes	Yes
SAW 15	1991	ADAPT	12	4	6	4+	Yes	Yes
SAW 17[1]	1992	ADAPT	22	5	8	3+	No	No

[1] An age-structured assessment was prepared for SARC 17, but was not reviewed by the SARC. Assessment attributes and results were taken from Mayo *et al.* (1994)

Table G4. Sources of error incorporated into the stochastic projection software discussed by the SARC, and additional sources of error that may need to be incorporated in the future.

Source of Error in Projections	**Incorporated in the Agepro Program**	**Incorporated in the @Risk Application in ICES 1994b**
Estimation error in stock sizes used to initiate the projection	YES	YES
Process error in projected recruitment	YES	YES
Error in the target F or quota	NO	YES
Error in the partial recruitment specified for the projection years	NO	YES
Error in discard rates	NO	NO
Error in management actions due to differences in the perceived and true stock state	NO	NO

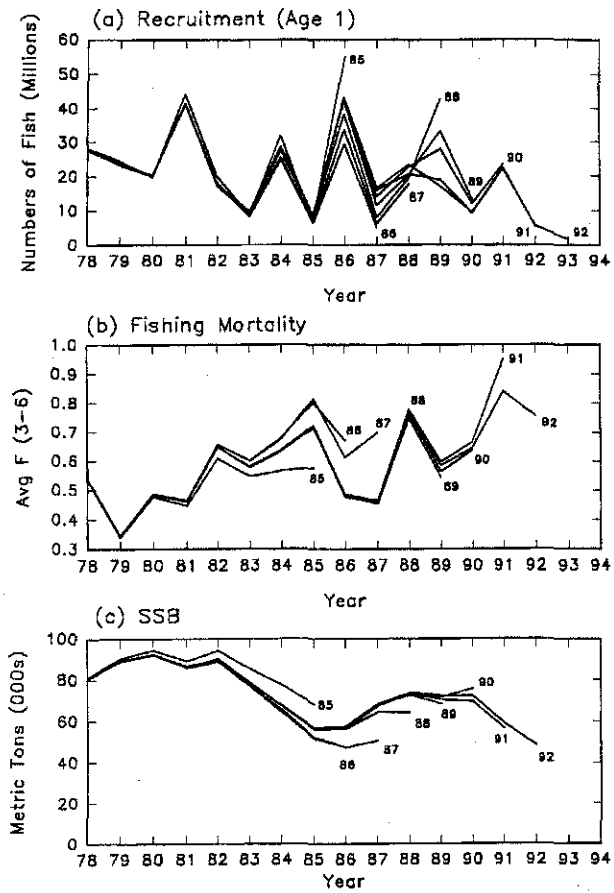

Figure G1. Retrospective analysis results for Georges Bank cod - display type I - for terminal years 1985-92 without weighting: (a) recruitment numbers; (b) fully-recruited fishing mortality rates; and (c) spawning biomass.

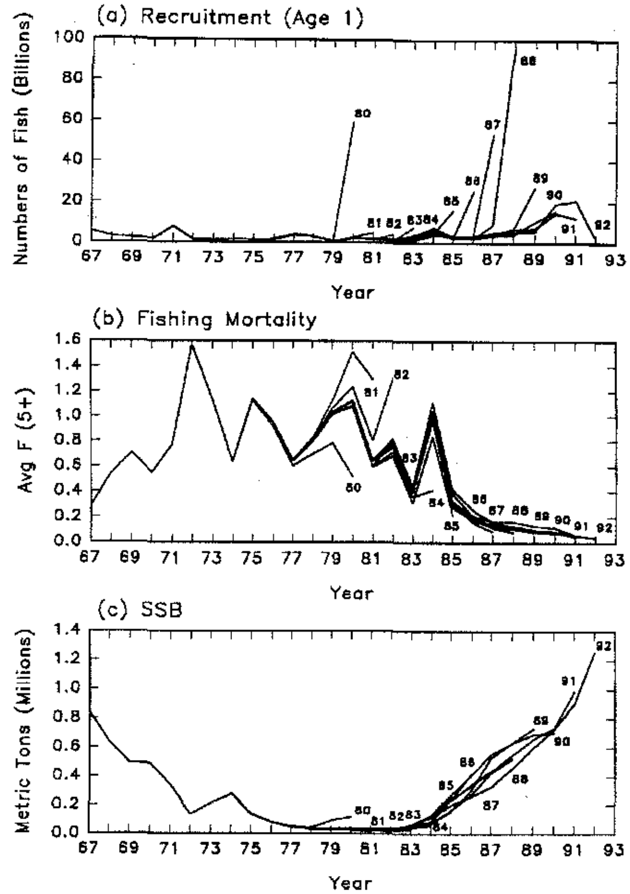

Figure G2. Retrospective analysis results for sea herring - display type I - for terminal years 1980-92 without weighting: (a) recruitment numbers; (b) fully-recruited fishing mortality rates; and (c) spawning biomass.

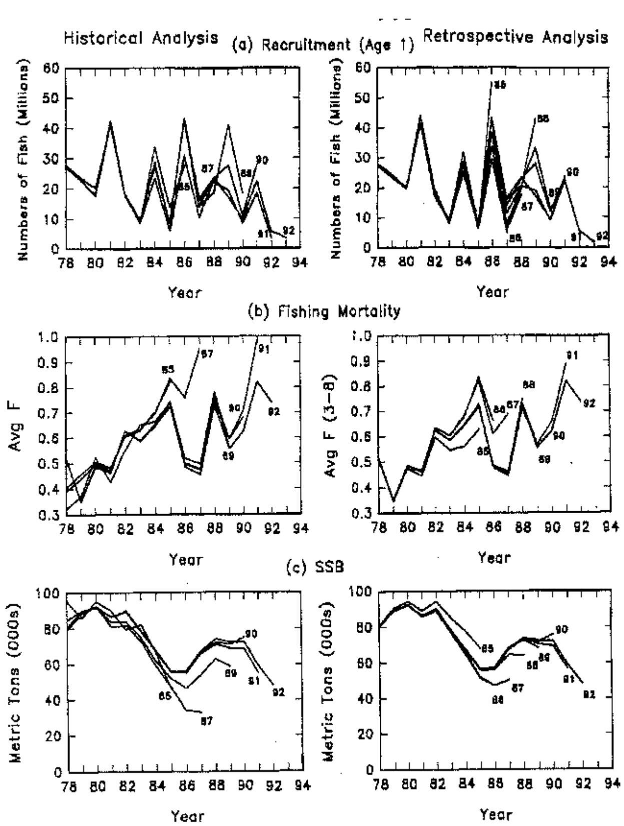

Figure G3. Comparison of historical and retrospective analysis results for Geroges Bank cod - display type I - for terminal years 1985-92 without weighting: (a) recruitment numbers; (b) fully-recruited fishing mortality rates; and (c) spawning biomass.

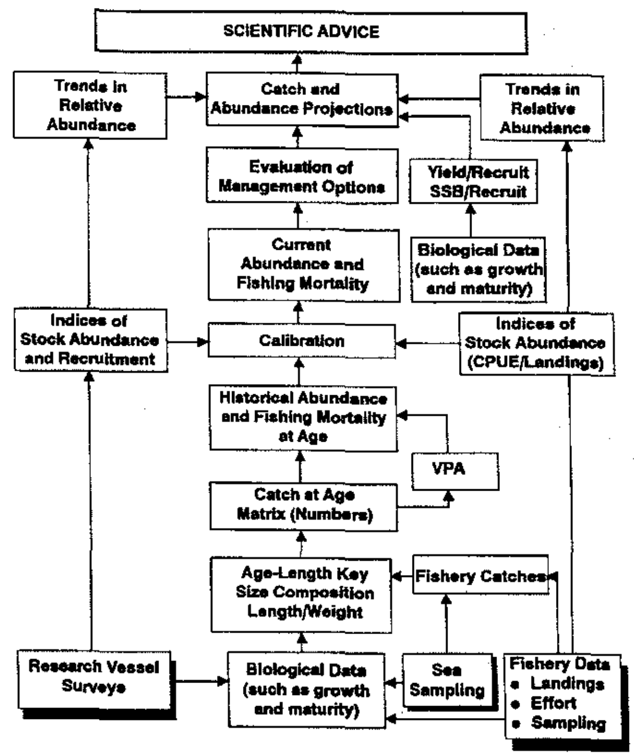

Figure G4. Flow diagram adapted from CUD 1992, illustrating the integration of (i) fisheries-independent data, (ii) fisheries-dependent data, and (iii) results of biological studies to provide scientific advice on the status of stocks. Calibration (in center of the diagram) is the keystone function of the entire process. For SARC assessments, calibration has generally been done using ASAPT for age-structured assessments or DeLury models for non-age-structured assessments.

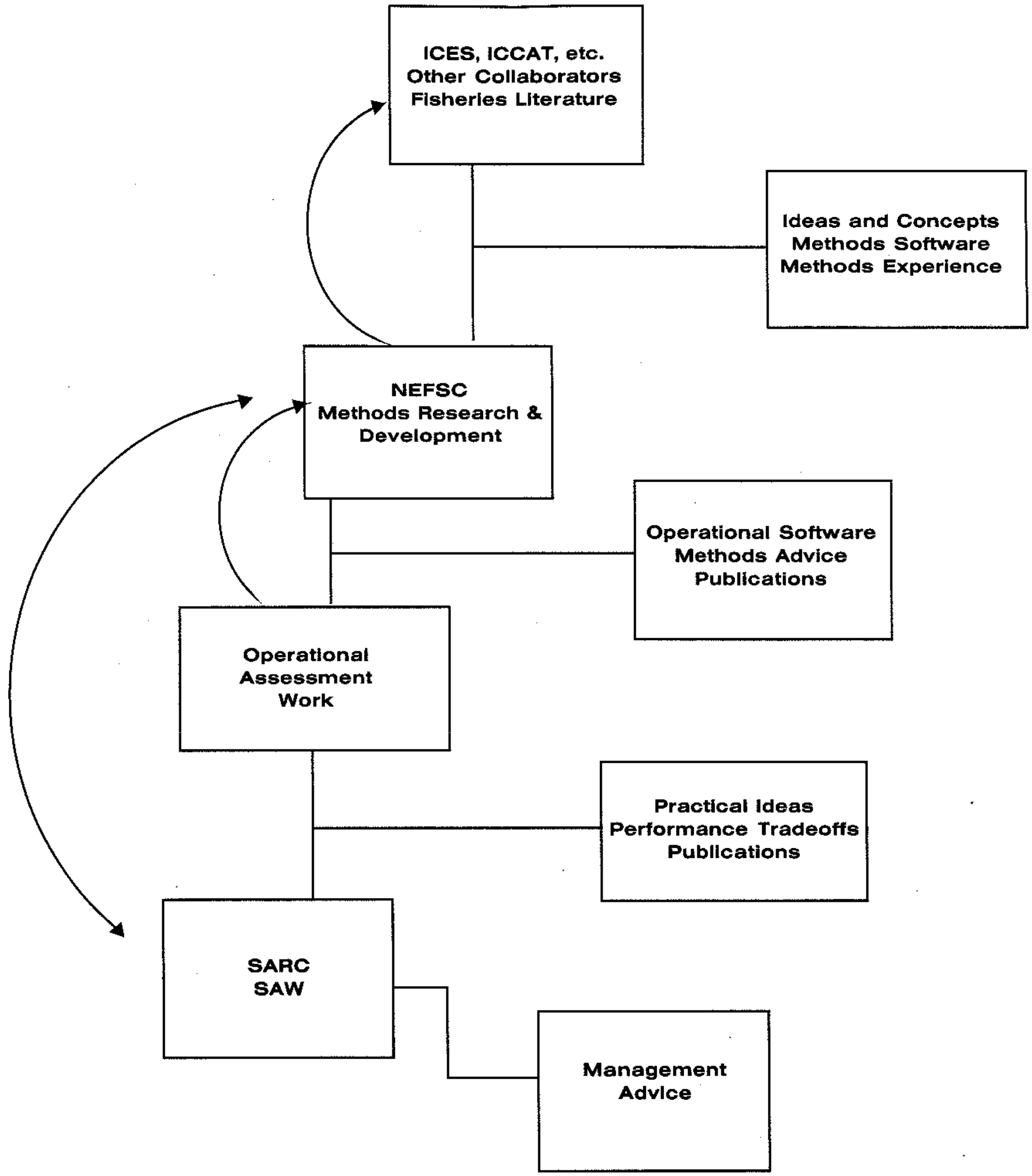

Figure G5. A model for integrating assessment methods research, development, and application into the SAW/SARC process. Information and products (including software) flow from top to bottom. Feedback loops are indicated by the directional arcs on the left side of the diagram.

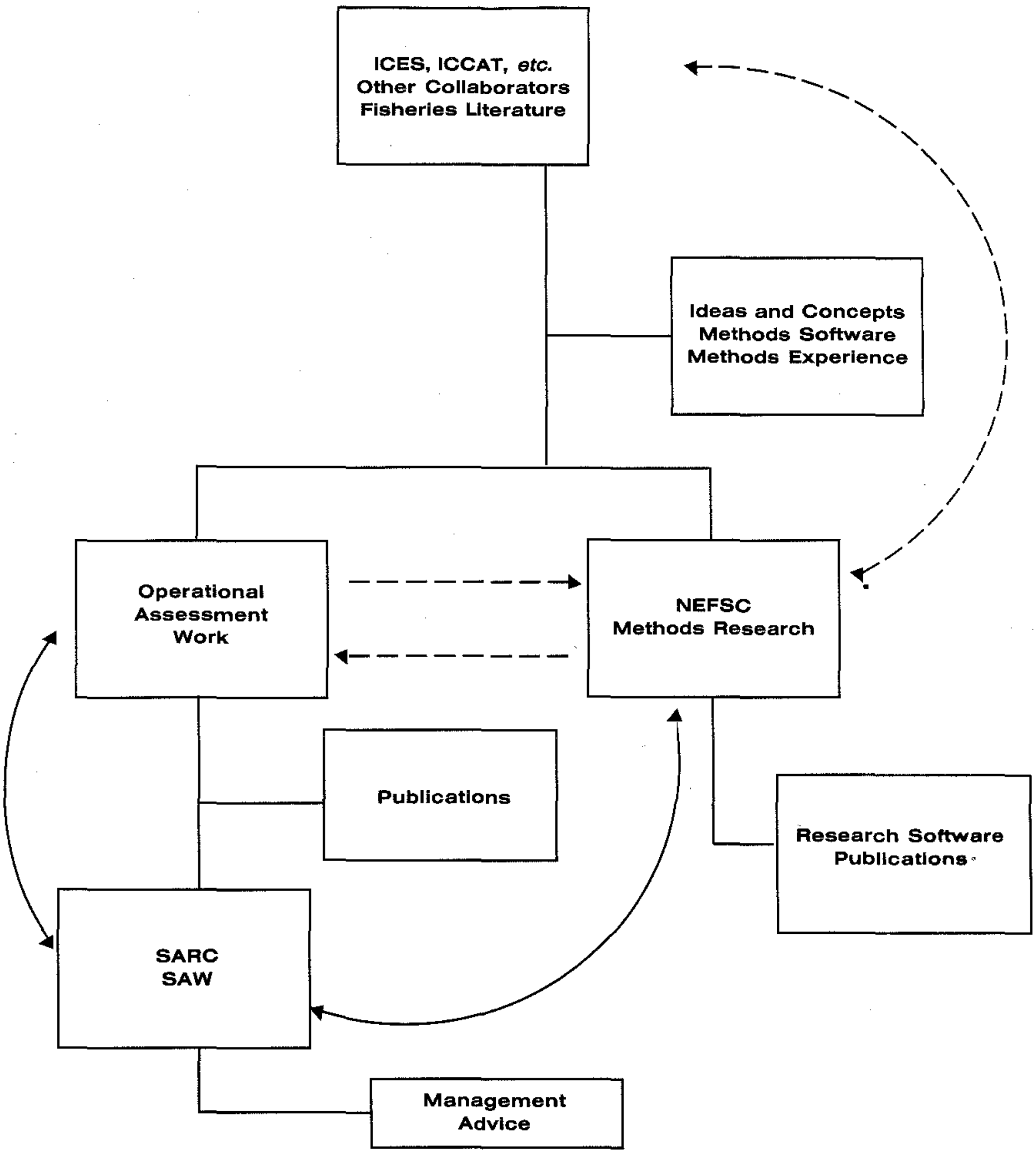

Figure G6. The current model for integrating assessment methods research into the SAW/SARC process. Information and products flow from top to bottom. formal feedback paths are indicated by the solid arcs in the diagram. Informal feedback paths are indicated by the dotted arcs. The extent to which informal feedback occurs often depends on the research interests of the scientists involved. travel funding for attending international meetings, *etc.*