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Historic and Recent Trends in the Population Dynamics of Redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine-Georges Bank Region

by

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Seven documents associated with the The 15th Regional Stock Assessment Workshop (15th SAW) have been published as Northeast Fisheries Science Center reference documents. For copies of these documents, contact the NMFS/NEFSC, Information Services Unit, 166 Water Street, Woods Hole, MA 02543-1097, (508)548-5123.

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Table of Contents

INTRODUCTION

Redfish, *Sebastes fasciatus* Storer, have supported a substantial domestic fishery in the Gulf of Maine and the Georges Bank (Great South Channel) regions off the northeast coast of the United States (Northwest Atlantic Fisheries Organization [NAFO] Subarea 5) since the late 1930s when the development of freezing techniques enabled a widespread distribution of the frozen product throughout the country. Landings by domestic vessels rose rapidly, peaking at 56,000 t in 1942 in Subarea 5, then declined throughout the 1940s and 1950s (Table 1, Figure 1). As landings declined in local waters, U.S. fishing effort began to expand to the Scotian Shelf and the Gulf of St. Lawrence (NAFO Subarea 4), and finally to the Grand Bank of Newfoundland (NAFO Subarea 3). This expansion continued throughout the 1940s and early 1950s, culminating with a peak U.S catch of 130,000 t in 1952 (Figure 1). By the mid-1950s, redfish stocks throughout the Northwest Atlantic were heavily exploited by U.S and Canadian fleets (Atkinson 1987), and total landings began to decline in all Subareas.

With the declaration of exclusive economic zones by the United States and Canada in 1977, U.S. vessels were prohibited from fishing in all but a small portion of Subarea 4 off Southwest Nova Scotia. Landings from the Gulf of Maine subsequently increased temporarily during the late 1970s, but have been declining throughout the 1980s. Recent landings from this stock are at their lowest level since the directed fishery commenced in 1934.

The status of this stock has been assessed since the 1970s with a variety of techniques including production models (Schaefer 1954, 1957; Pella and Tomlinson 1969; Fox 1975), yield per recruit (Beverton and Holt 1957) and virtual population analysis (VPA). By the late 1970s it was recognized within the International Commission for the Northwest Atlantic Fisheries (ICNAF) that then current catch levels were not sustainable. Preliminary production model results which suggested a long-term potential yield of 20,000 t from this stock (Mayo 1975) were modified to between 9,000 and 13,000 t (Mayo 1976) to account for nonequilibrium conditions (Walter 1976) and allow for recovery of the stock. With the inclusion of standardized fishing effort in the analysis, estimates of maximum yield at f_{msy} and two-thirds f_{msy} (Doubleday 1976), which would allow for potential recovery of the stock were estimated at 5,200 t and 3,500 t, respectively (Mayo *et al.* 1979).

Based on these analyses, ICNAF agreed on 9,000 t as the TAC for redfish in Subarea 5 for calendar year 1977. This TAC was never enforced due to extension of U.S. jurisdiction in early 1977. Since 1977, management of the stock has been the responsibility of the New England Fishery Management Council. Between 1977 and 1986, when redfish were first included in the Northeast Multi-species Fishery Management Plan (FMP), the U.S. redfish fishery remained essentially unregulated. Even since 1986, management measures incorporated in the FMP have not imposed restrictions on redfish catches or fishing mortality.

Virtual population analysis, which was first performed on this stock using catch at age data from 1969-1980, indicated that age 9+ fishing mortality rates, in the range of 0.18 to 0.28 throughout most of the 1970s, were accompanied by a 62% decline in exploitable (age 5+) biomass between 1969 and 1980 (Mayo *et al.* 1983). A subsequent analysis, which included additional catch at age data through 1983, indicated that although F had begun to decline from a maximum value of 0.26 in 1979 to 0.17 in 1983, exploitable biomass had been reduced by 75% from the 1969 level by 1984 (NEFC 1986). The VPA was discontinued after 1986, but further declines in redfish landings since then suggest that F is now likely to be rather low (possibly in the range of M), rendering the convergence of VPAs somewhat unlikely.

The potential for this stock to return to levels observed in the 1960s is limited, in part, by the combination of delayed maturation relative to the age at entry to the fishery. Even at relatively low levels of F, ranging from 0.03 to 0.05, Mayo (1987) noted that restoration of the 1969 age structure is not likely to occur except under extremely favorable recruitment conditions over the next 30 to 40 years.

COMMERCIAL FISHERY

Redfish have been harvested primarily by domestic vessels, although some distant-water fleets took considerable quantities for a brief period during the early 1970s (Table 1). Redfish are harvested almost exclusively by otter trawlers fishing out of Maine and Massachusetts ports. Landings in 1991 (525 t) were at an historic low level, although 1992 landings are estimated to have increased to about 900 t (Table 1).

Commercial catch per unit effort (CPUE) indices for directed redfish trips were standardized by vessel tonnage class as described by Mayo *et*

Table 1. Nominal redfish catches (metric tons), actual and standardized catch per unit effort, and calculated standardized U.S. and total effort for the Gulf of Maine-Georges Bank redfish fishery

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

* **Preliminary**

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

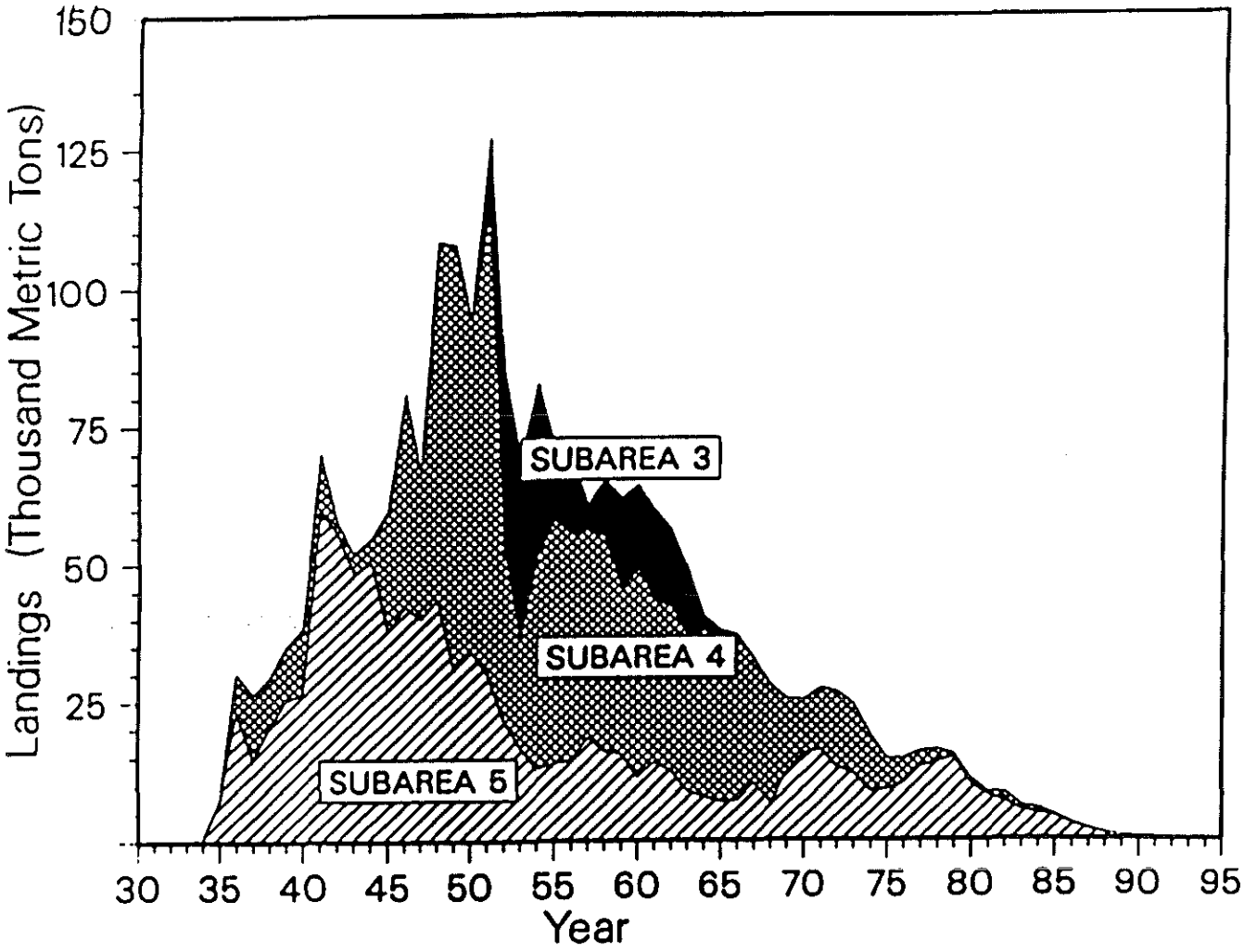


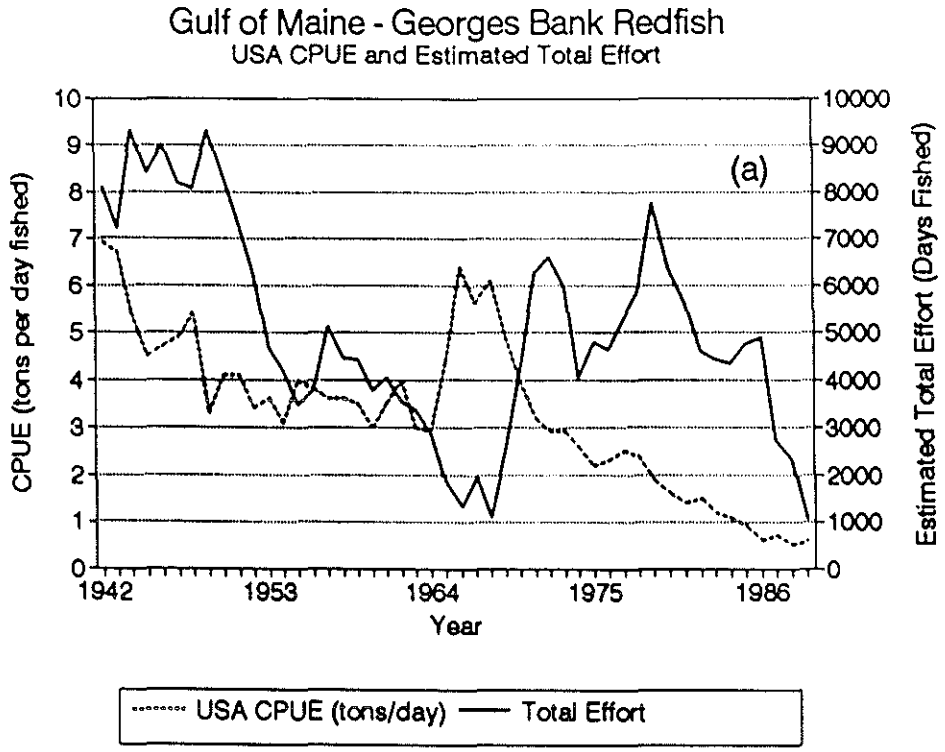
Figure 1. United States landings of redfish (metric tons) from the Northwest Atlantic, 1934-1991; Subarea 3 = Grand Bank, Subarea 4 = Scotian Shelf and Gulf of St. Lawrence, Subarea 5 = Gulf of Maine and Georges Bank

al. (1979). The resulting calculated fishing effort values were derived by dividing total annual landings by the directed CPUE index. Directed CPUE has declined steadily from more than 10 t per day fished during the late 1960s to less than 2 t per day fished since 1984 (Table 1, Figure 2a). The 70 to 80% decline is consistent with the 60 to 70% declines in exploitable biomass estimated by previous VPAs (Mayo *et al.* 1983; NEFC 1986). Total fishing effort, after peaking during the late 1970s (coincident with the highest estimates of fishing mortality [NEFC 1986]), appeared to stabilize during the mid-1980s before declining precipitously through 1989.

Historically, 80 to 90% of the total redfish catch and 20 to 40% of the total number of trips on which redfish were taken were accounted for in the directed CPUE calculation (50% redfish trips) (Table 2). These percentages declined sharply between 1979 and 1982, and are now at levels that preclude any definitive interpretation of the CPUE and effort trends (Figure 2b). Despite these limitations, it is clear that commercial CPUE remains extremely low relative to earlier periods.

Commercial length sampling for redfish has generally been sufficient with one sample being taken for every 100 to 200 t landed (Table 3). The apparent sampling intensity has improved in recent years as landings have declined at a faster rate than the reduction in sampling. However, sampling must be maintained at relatively high levels in order to reflect the age structure of the population. Age samples have been routinely collected since the 1960s but production ageing has ceased since 1985.

In 1978 the landings still reflected a fairly broad size (and age) structure in the population



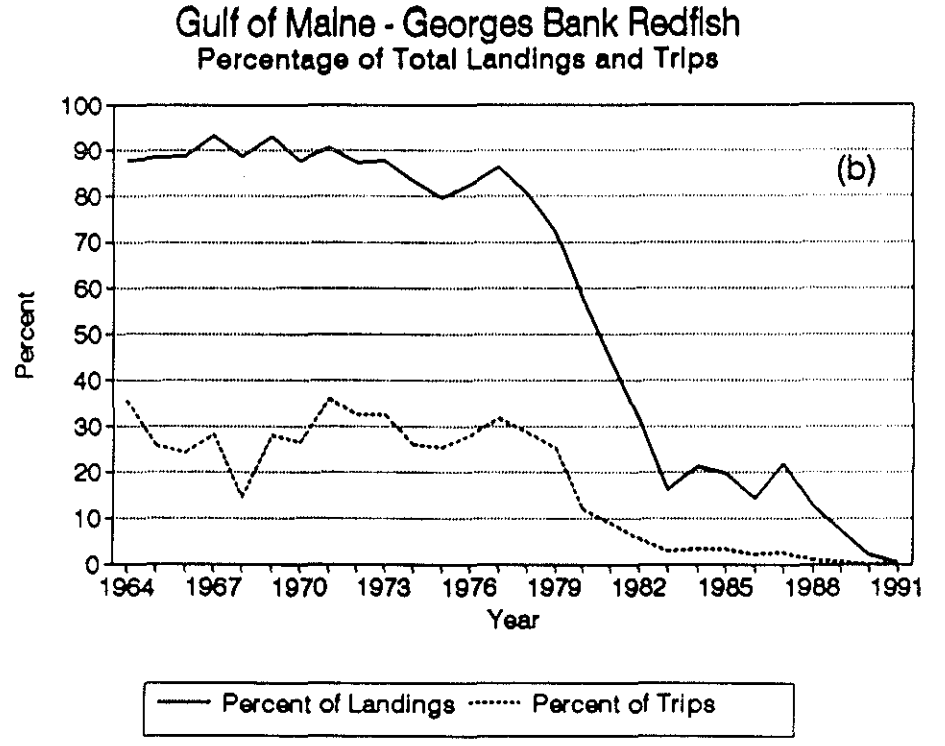


Figure 2. (a) Trends in U.S. commercial catch per unit effort (CPUE) and estimated total effort for Gulf of Maine - Georges Bank redfish, 1942-1989, and (b) percentage of total redfish trips and landings in which redfish composed 50% or more of the total trip landings, 1964-1991.

Table 2. Domestic landings of redfish (metric tons, live) and number of fishing trips on which redfish were caught for total and directed (50% redfish) fishing activity

	Landings (metric tons)			Number of Trips		
Year	Total Landings	50% Trip Landings	Percent of Total	Total Trips	50% Trips	Percent of Total
1964	7843.1	6893.7	87.9	1693	603	35.6
1965	6977.6	6175.7	88.5	1435	370	25.8
1966	7184.0	6366.6	88.6	1122	272	24.2
1967	10348.7	9643.8	93.2	963	274	28.5
1968	6574.8	5828.2	88.6	847	123	14.5
1969	11994.8	11157.0	93.0	1074	301	28.0
1970	15514.2	13639.1	87.9	1691	448	26.5
1971	16235.0	14704.6	90.6	1585	574	36.2
1972	13146.0	11485.9	87.4	1499	490	32.7
1973	11925.4	10463.5	87.7	1662	542	32.6
1974	8644.1	7223.5	83.6	1604	418	26.1
1975	9036.9	7196.7	79.6	1784	453	25.4
1976	10074.3	8308.9	82.5	1675	471	28.1
1977	12950.5	11205.6	86.5	1901	606	31.9
1978	13889.5	11189.7	80.6	2183	625	28.6
1979	14627.9	10570.1	72.3	3313	832	25.1
1980	9747.7	5620.5	57.7	3577	425	11.9
1981	7859.8	3497.6	44.5	3724	332	8.9
1982	6621.1	2082.4	31.5	3513	194	5.5
1983	5120.2	818.7	16.0	3687	106	2.9
1984	4620.7	983.4	21.3	3981	134	3.4
1985	4087.3	806.5	19.7	4551	153	3.4
1986	2844.9	407.7	14.3	4272	89	2.1
1987	1786.2	388.7	21.8	3728	88	2.4
1988	986.1	124.8	12.7	3176	30	0.9
1989	578.3	42.6	7.4	2636	13	0.5
1990	544.8	11.3	2.1	2665	6	0.2
1991	464.9	1.4	0.3	2929	2	0.1

of both males and females with the 1971 year class accounting for the mode between 20 and 30 cm (Figure 3). With the lack of subsequent recruitment, modes shifted toward larger sizes until fish from the 1978 year class appeared in 1983 and 1984. As landings continued to decrease throughout the 1980s, modal lengths shifted further until in 1991 few fish between 20 and 30 cm could be seen recruiting to the fishery. Shifts in modal lengths can also be seen in annual changes in mean length (Figure 4). Increases in mean length occur during periods of poor recruitment (such as 1965-1976) while sharp decreases generally signify the appearance of a strong year class entering the fishery. The declines that began in 1976 and 1983 indicate recruitment of the 1971 and 1978 year classes entering the fishery at age 5. The overall increasing trend indicates a gradual aging of the available population as recruitment frequency has declined over the past 30 years.

The catch at age matrix based on all available commercial length and age data from 1969 through 1985 is given in Table 4. The sharp discontinuity in the age structure of the population created by poor recruitment since the 1960s can be inferred from the age composition of the catch. The most striking feature is the singular presence of the 1971 year class progressing through the fishery since 1974 with almost negligible recruitment evident for five to six years before or after.

RELATIVE ABUNDANCE AND RECRUITMENT

Bottom trawl surveys have been conducted by the Northeast Fisheries Science Center (NEFSC) in the Gulf of Maine - Georges Bank region since the autumn of 1963 and the spring of 1968 (Azarovitz 1981). Abundance (stratified mean number per tow) and biomass (stratified mean weight per tow) indices have been calculated for inshore (strata 26, 27, 39, and 40) and offshore (strata 24, 28-30, 36-38) strata sets in order to

Table 3. Commercial length and age sampling summary for Gulf of Maine - Georges Bank Redfish, 1969-1991

Year	Landings (tons)	Number of Samples	Tons per Sample	Number of Length Measurements	Number of Ages Collected	Number of Ages Available
1969	12455	32	389	3,200	????	616
1970	16741	23	728	2,300	600	461
1971	20034	75	267	7,796	963	963
1972	19095	50	382	5,085	????	1,066
1973	17360	62	280	6,246	1,120	1,027
1974	10471	79	133	7,945	2,170	1,011
1975	10572	69	153	6,871	2,912	1,147
1976	10696	80	134	8,094	3,700	1,028
1977	13223	83	159	8,495	3,688	863
1978	14083	54	261	5,493	2,352	1,012
1979	14755	87	170	8,975	3,866	1,122
1980	10183	48	212	4,858	2,210	1,110
1981	7915	37	214	3,718	1,718	851
1982	6903	40	173	4,216	1,734	849
1983	5328	50	107	5,100	2,416	995
1984	4793	46	104	4,744	2,275	1,018
1985	4282	56	76	5,755	2,962	1,464
1986	2929	60	49	6,063	3,102	N/A
1987	1894	45	42	4,633	2,290	N/A
1988	1177	25	47	2,487	1,258	N/A
1989	637	19	34	1,921	958	N/A
1990	601	13	46	1,338	692	N/A
1991*	500	11	45	1,136	?225	N/A

* **Preliminary**

detect recruitment trends from Western Gulf of Maine coastal nursery areas as described by Mayo *et al.* (1990). An overall index has also been computed based on a combined (strata 24, 26-30, 36-40) strata set. Recruitment indices have been derived from the inshore data by computing the summed stratified mean number per tow within prescribed length ranges corresponding to ages 1-3 as determined by inspection of historical length frequency data.

Relative abundance of redfish has declined sharply in both survey series, from peak levels of around 100 fish per tow in the late 1960s and early 1970s to generally fewer than 10 fish per tow during the mid-1980s (Tables 5 and 6). The decline in biomass has been of the same order (Figures 5a and 5b). Both series suggest a slight increase in abundance and biomass in 1992, but the overall levels continue to remain well below historic observations. As with commercial mean lengths, sharp declines in mean length of redfish in the surveys indicate the emergence of a relatively strong year class (Figures 6a and 6b). This is most evident in the autumn series of inshore data (Figure 6b), which has provided the most consistent recruitment patterns over time. The sharp declines that occur immediately after 1971, 1978, and 1984 reflect the initial appearance and subsequent increased influence of these year classes in the bottom trawl survey indices.

The 1964 year class appeared very strong at ages 1 and 2, and the 1961 through 1965 year classes were strong at age 2 (Table 7). The 1971 year class also appeared to be very strong at age 0, but was not as evident at ages 1 and 2 as were year classes from the early 1960s. Viewed in this perspective, the 1978 year class and those that have appeared since the mid-1980s are relatively weak compared to those which recruited in the earlier years.

Length composition data from spring and autumn surveys (Figure 7) illustrate the changes in relative abundance and size structure of the population that resulted from the decline in recruitment over time. The redfish population was composed of a relatively broad range of sizes in the 1960s resulting from consistent recruitment of year classes from the 1950s and early 1960s. By the 1970s, however, abundance of large fish had declined substantially and only the 1971 year class remained a dominant feature in the demographics of the population. The consistency of the survey indices had begun to erode by the beginning of the 1980s and, throughout the decade, only sporadic indications of the 1978 and subsequent year classes were evident. In 1992,

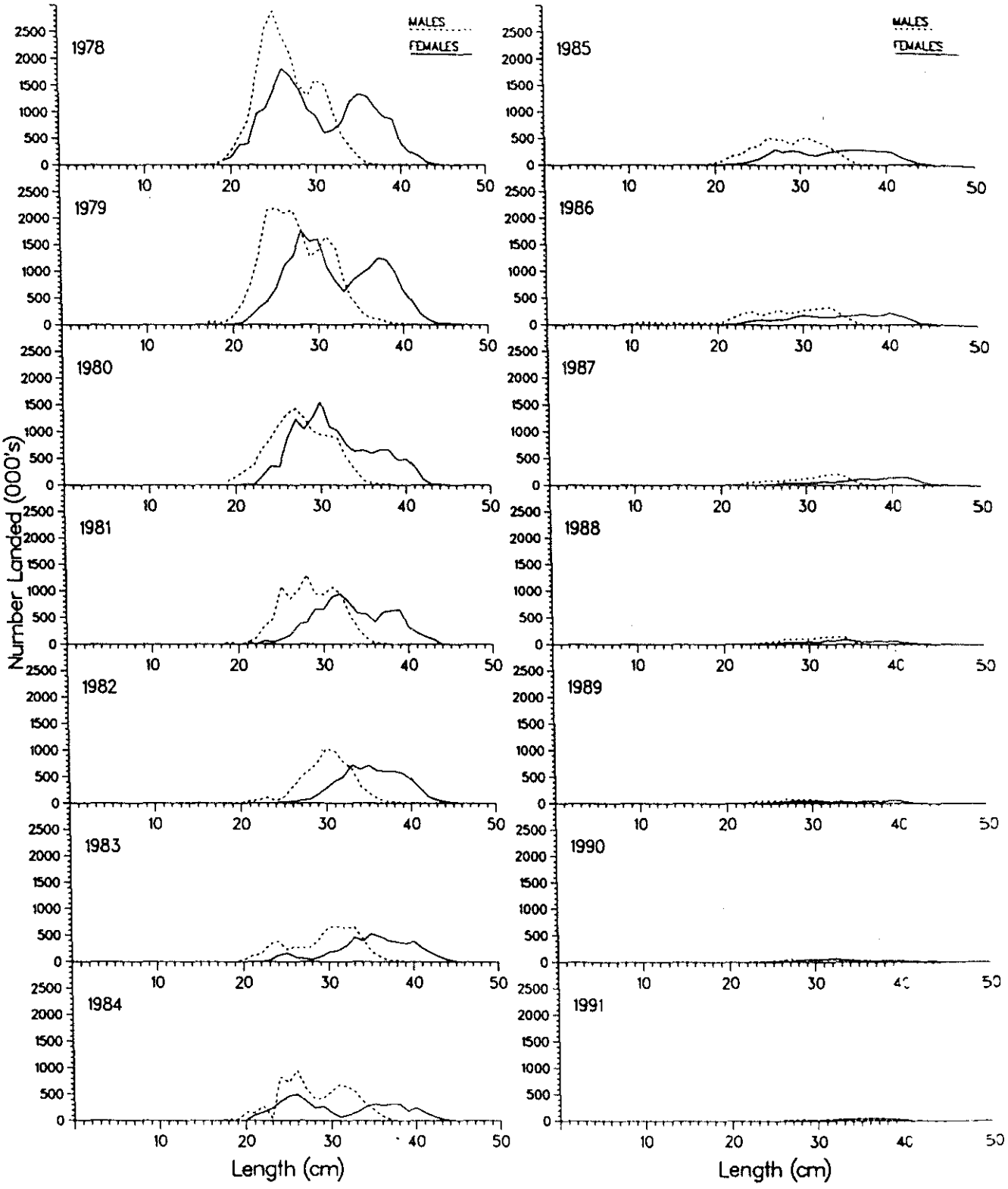


Figure 3. Length composition of U.S. commercial landings of Gulf of Maine - Georges Bank redfish, 1978-1991.

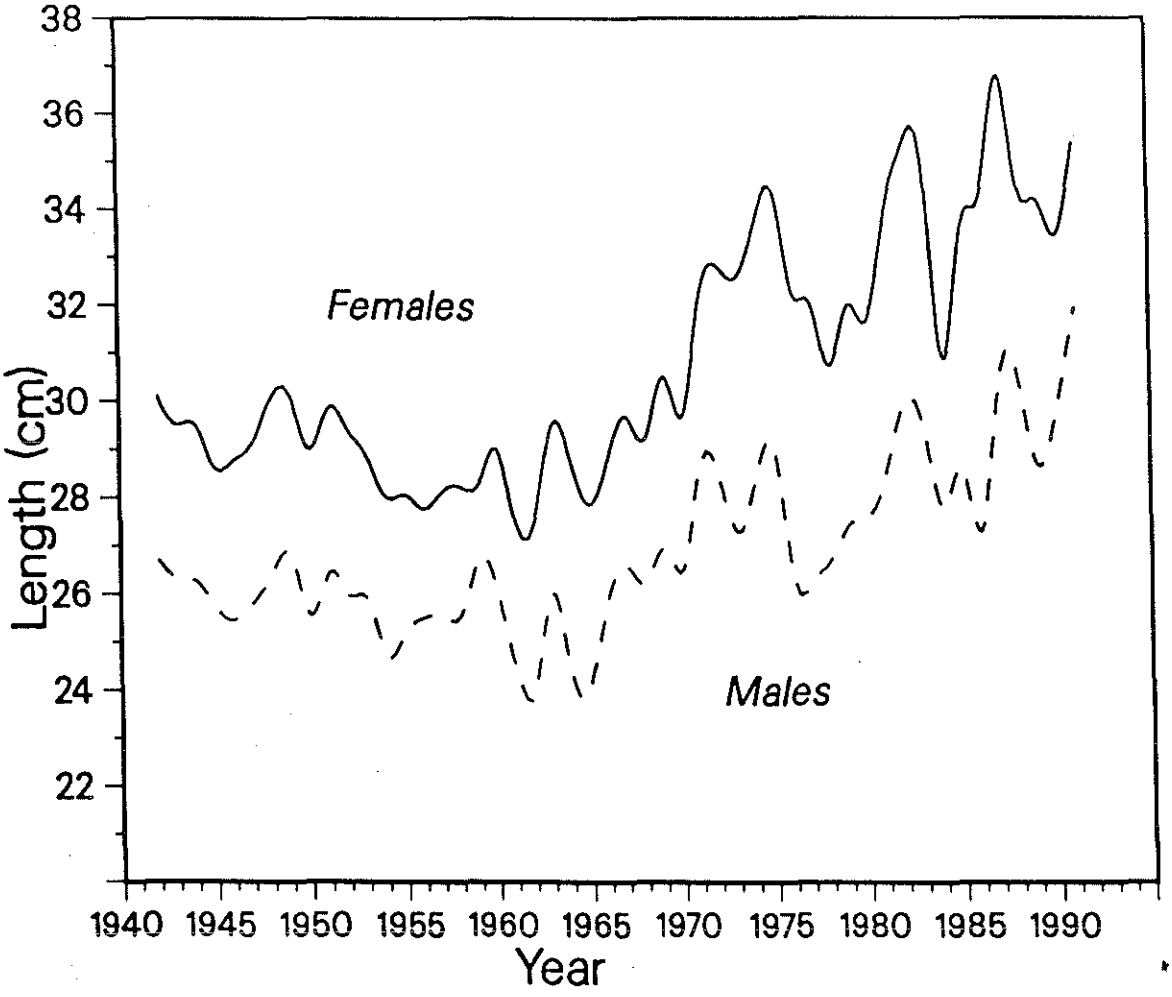


Figure 4. Trends in mean length of female and male redfish landed in the Gulf of Maine-Georges Bank U.S. fishery, 1942-1991. (1942-1964 data from: Brown and Hennemuth 1965).

however, substantial numbers of redfish between 20 and 26 cm appeared as likely 5-to 6-year-old fish from 1986 or 1987 year classes.

GROWTH AND MATURATION

Redfish are relatively long-lived, slow growing fish with an extremely low natural mortality rate compared to most highly exploited species. Growth studies have indicated maximum ages ranging from 50 to 60 years at lengths of 45 to 50 cm (Mayo *et al.* 1990) (Figure 8). Perlmutter and Clark (1949) provided early evidence that immature redfish in the Gulf of Maine exhibited extremely slow growth and that maturation was delayed until about age 9. Kelly and Wolf (1959) further demonstrated the extremely slow growth of adult redfish up to age 20. More recently, Mayo *et al.* (1981) provided further validation of the slow growth rates for redfish up to age 7 based on length mode progression and edge formation analysis. Consequently, an instantaneous natural mortality rate of 0.05 has been employed in virtual population and yield and SSB per recruit analyses, consistent with the longevity of this species. Moreover, growth and maturation appear to be linked. The most recent estimates of redfish maturation suggest a median age of about 5.5 years (Mayo *et al.* 1990; O'Brien *et al.* In Press) (Figure 9).

YIELD AND SSB PER RECRUIT

Yield and spawning stock biomass (SSB) per recruit were calculated according to the methods described by Thompson and Bell (1934) and Gabriel *et al.* (1989). Partial recruitment was taken from the most recently published VPA

Table 4. Total catch at age and mean weights at age for Gulf of Maine-Georges Bank redfish, 1969-1985

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26+
Number landed (000s)																										
69	-	-	-	22	421	439	1008	6065	2513	6717	2660	3975	3287	2221	2820	1348	751	526	606	426	451	345	469	38	100	847
70	-	-	-	-	146	4055	4048	1060	9692	3221	8351	2734	4702	2672	2302	3489	1778	1640	393	662	368	529	572	488	64	1743
71	-	-	-	-	-	72	1941	4430	1536	7907	2767	6504	3088	4267	3680	2895	2206	2765	1347	1163	560	1048	559	282	138	2439
72	-	-	-	-	-	-	933	3296	7401	1712	7580	2782	2884	1994	3531	2449	1205	1276	2245	734	1011	1172	718	538	1280	2874
73	-	-	-	-	-	-	235	2463	7938	8391	2201	7337	2078	3100	2376	2024	1799	1380	864	933	411	590	426	295	289	1977
74	-	-	308	105	-	17	8	174	1886	4724	2945	2435	1709	1115	1302	935	1454	910	640	661	589	730	271	285	250	1755
75	-	-	4	695	72	11	-	30	124	1944	4360	2154	1932	1442	1009	1344	1360	1235	945	1116	608	887	492	294	298	1282
76	-	-	-	196	8961	439	-	-	21	48	467	2706	3375	1702	1725	1388	1233	1166	1424	608	769	681	323	672	94	2011
77	-	-	-	-	234	16747	311	-	-	-	81	2127	1262	4012	1823	2747	1466	1190	1064	461	706	541	117	571	1013	2157
78	-	-	-	-	-	271	24569	215	-	34	33	182	1689	1484	2948	1748	1310	866	899	1283	895	734	500	192	530	2220
79	-	-	-	-	25	205	849	23729	152	117	48	168	541	1228	1972	1299	1580	983	845	1008	798	594	532	538	427	2506
80	-	-	-	-	-	132	175	1110	16900	208	44	46	217	491	830	1221	860	664	564	452	473	370	349	294	265	1308
81	-	-	23	-	77	40	57	47	223	12380	84	22	-	44	317	364	1274	506	534	396	318	381	306	326	350	1540
82	-	-	3	271	123	60	92	30	-	15	7268	56	32	21	128	185	582	452	840	324	501	484	301	134	104	2270
83	-	-	-	11	1687	159	46	43	86	49	141	4959	58	106	64	42	85	319	270	551	169	224	314	195	131	1817
84	-	-	46	11	51	6674	-	20	40	-	35	15	3571	-	44	49	34	92	210	166	324	215	144	157	162	1807
85	-	-	27	146	33	31	3818	-	28	11	13	40	12	3202	-	25	11	101	116	260	230	187	197	142	107	1489
Mean weight (kg)																										
69	.010	.020	.052	.113	.115	.142	.169	.195	.219	.260	.320	.339	.366	.404	.425	.473	.495	.457	.589	.497	.515	.594	.589	.705	.708	.591
70	.010	.020	.052	.092	.172	.168	.170	.189	.221	.236	.290	.339	.356	.367	.340	.418	.427	.438	.523	.579	.505	.450	.464	.476	.345	.541
71	.010	.020	.052	.092	.135	.172	.242	.244	.265	.304	.333	.369	.399	.437	.445	.468	.435	.449	.541	.553	.514	.544	.581	.481	.473	.540
72	.010	.020	.052	.092	.135	.171	.197	.240	.257	.289	.334	.367	.399	.427	.451	.472	.490	.515	.509	.562	.581	.565	.604	.489	.560	.668
73	.010	.020	.052	.092	.135	.171	.162	.213	.257	.281	.343	.341	.384	.402	.482	.454	.500	.492	.523	.525	.529	.641	.633	.568	.653	.620
74	.010	.020	.064	.080	.135	.195	.150	.233	.270	.326	.331	.378	.399	.427	.449	.442	.503	.527	.540	.565	.525	.578	.585	.641	.633	.642
75	.010	.020	.039	.098	.161	.221	.195	.383	.349	.317	.342	.394	.399	.420	.460	.469	.533	.527	.522	.550	.600	.547	.595	.607	.663	.662
76	.010	.020	.052	.076	.135	.199	.195	.245	.345	.278	.296	.347	.395	.389	.405	.427	.511	.469	.542	.517	.518	.552	.645	.577	.628	.630
77	.010	.020	.052	.092	.090	.173	.288	.245	.277	.297	.350	.413	.412	.408	.433	.454	.462	.534	.537	.610	.466	.595	.611	.544	.552	.605
78	.010	.020	.052	.092	.135	.135	.209	.300	.277	.311	.383	.468	.402	.433	.423	.458	.551	.504	.526	.547	.523	.537	.633	.551	.606	.641
79	.010	.020	.052	.092	.135	.200	.191	.251	.304	.295	.248	.402	.508	.472	.474	.564	.526	.543	.551	.617	.664	.597	.567	.605	.567	.647
80	.010	.020	.052	.092	.135	.108	.175	.188	.283	.371	.421	.362	.424	.454	.506	.478	.499	.518	.554	.595	.647	.664	.629	.599	.681	.695
81	.010	.020	.080	.092	.117	.150	.143	.195	.247	.318	.374	.466	.404	.532	.592	.543	.528	.499	.537	.550	.594	.617	.560	.633	.552	.650
82	.010	.020	.052	.142	.203	.256	.242	.252	.277	.383	.395	.491	.563	.383	.544	.475	.540	.504	.564	.583	.592	.563	.621	.499	.535	.699
83	.010	.020	.052	.107	.172	.198	.249	.329	.252	.368	.396	.425	.381	.471	.504	.595	.494	.579	.639	.580	.614	.647	.622	.630	.589	.682
84	.010	.020	.110	.092	.206	.197	.195	.311	.252	.297	.333	.377	.403	.420	.497	.630	.569	.529	.519	.499	.610	.547	.568	.600	.517	.619
85	.010	.020	.092	.146	.154	.177	.239	.245	.279	.345	.421	.362	.595	.443	.441	.591	.494	.545	.599	.552	.603	.635	.605	.699	.624	.692

Table 5. Spring NEFSC bottom trawl survey stratified mean catch per tow indices, mean weights and mean lengths of redfish in the Gulf of Maine-Georges Bank region

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

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

(NEFC 1986) which reflects the recruitment of the 1971 year class. Natural mortality was assumed to be 0.05. Mean weights at age for the yield per recruit calculations were taken as the 1969-1984 mean of the commercial mean weights at age (Table 4). Growth and maturation data for SSB/R analysis were taken from the female data presented by Mayo *et al.* (1990) and O'Brien *et al.* (In Press).

Estimates of $F_{0.1}$ (0.06) and F_{max} (0.13) (Table 8, Figure 10) are similar to those reported by Mayo (1980) using the Beverton-Holt approach with the same value of M (0.05) for 89mm mesh (males) and 102 mm mesh (females). The F at 20% of Maximum Spawning Potential was estimated as 0.12, slightly below the estimate of F_{max}. However, considering the life history characteristics of redfish, the 20% MSP level is likely to be unrealistically low and the corresponding F reference point unrealistically high to allow the stock to replace itself on a sustained basis.

CONCLUSIONS

Landings have remained at historic low levels (< 1,000 t) since 1989 after declining from an average 14,000 t during 1977-1979. Commercial CPUE in recent years has declined by more than 80% from levels observed during the 1960s, and exploitable (age 5+) biomass estimates from VPA have declined by 75% between 1969 and 1984. Fully recruited (age 9+) instantaneous fishing mortality (F) ranged from 0.18 to 0.26 between 1969 and 1983, but has likely declined in recent years as landings have declined sharply from mid-1980s levels.

Relative abundance and biomass indices from NEFSC bottom trawl surveys have declined by over 90% between the mid- to late 1960s and late 1980s. As a consequence of extremely poor recruitment since the mid-1960s, the age structure of the population has narrowed considerably to only one or two significant year classes.

Table 6. Autumn NEFSC bottom trawl survey stratified mean catch per tow indices, mean weights, and mean lengths of redfish in the Gulf of Maine-Georges Bank region

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

[1] Strata Set: 26, 27, 39, 40
[2] Strata Set: 24, 28-30, 36-38
[3] Strata Set: 24, 26-30, 36-40
*** Preliminary**

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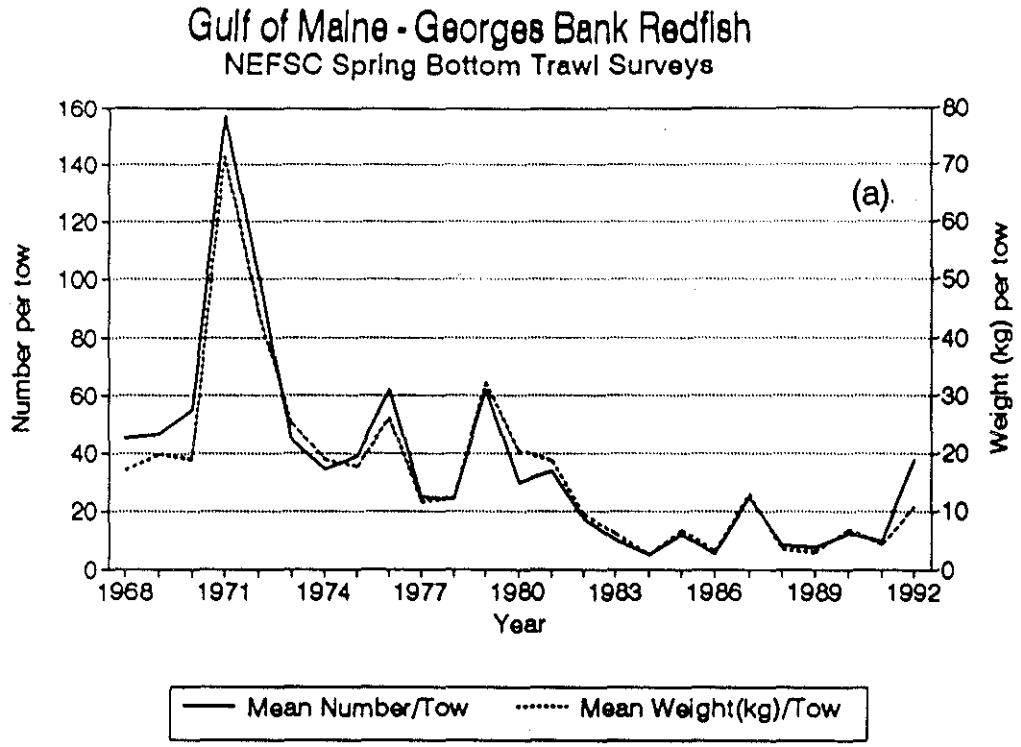


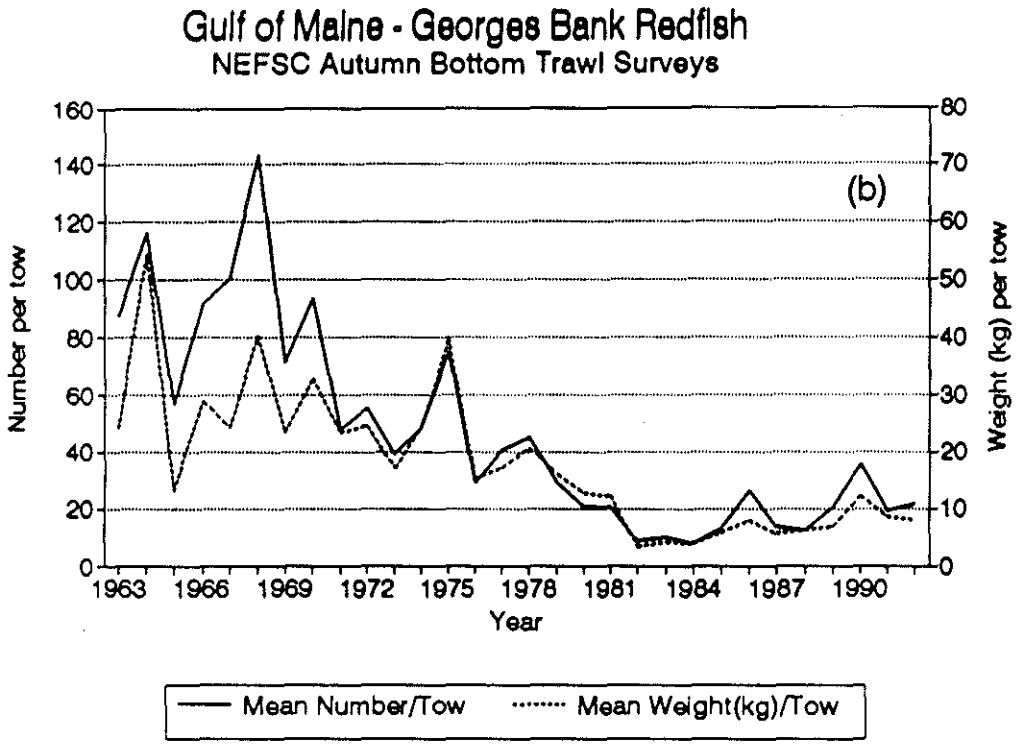
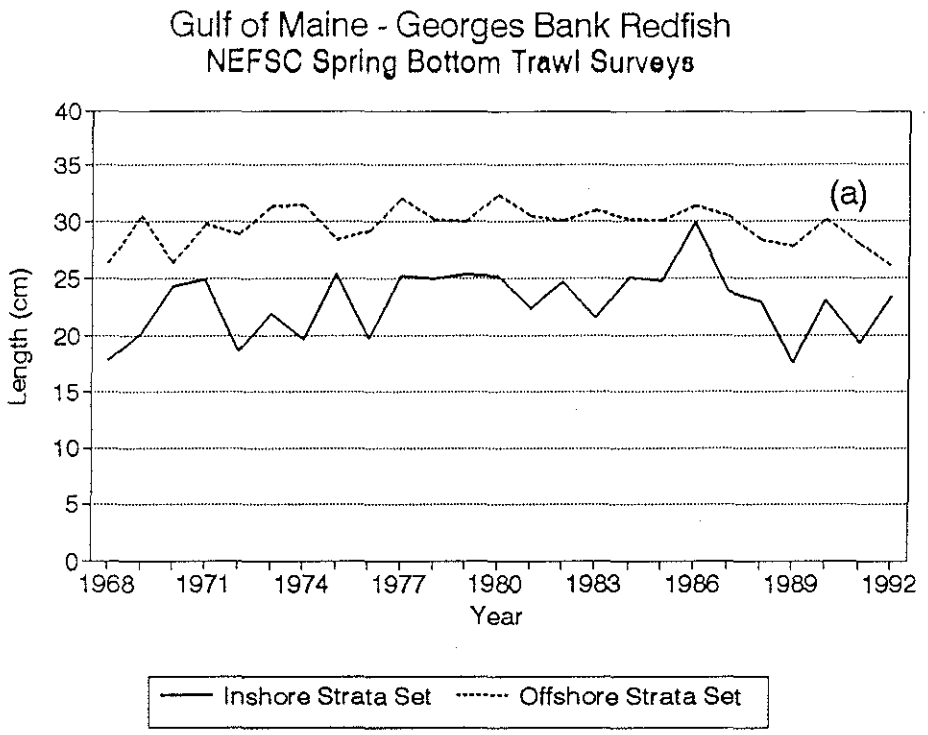


Figure 5. Trends in abundance (mean number per tow) and biomass (mean weight [kg]) per tow of Gulf of Maine-Georges Bank redfish based on (a) NEFSC spring and (b) NEFSC autumn bottom trawl surveys (strata 24, 26-30, 36-40), 1963-1992.



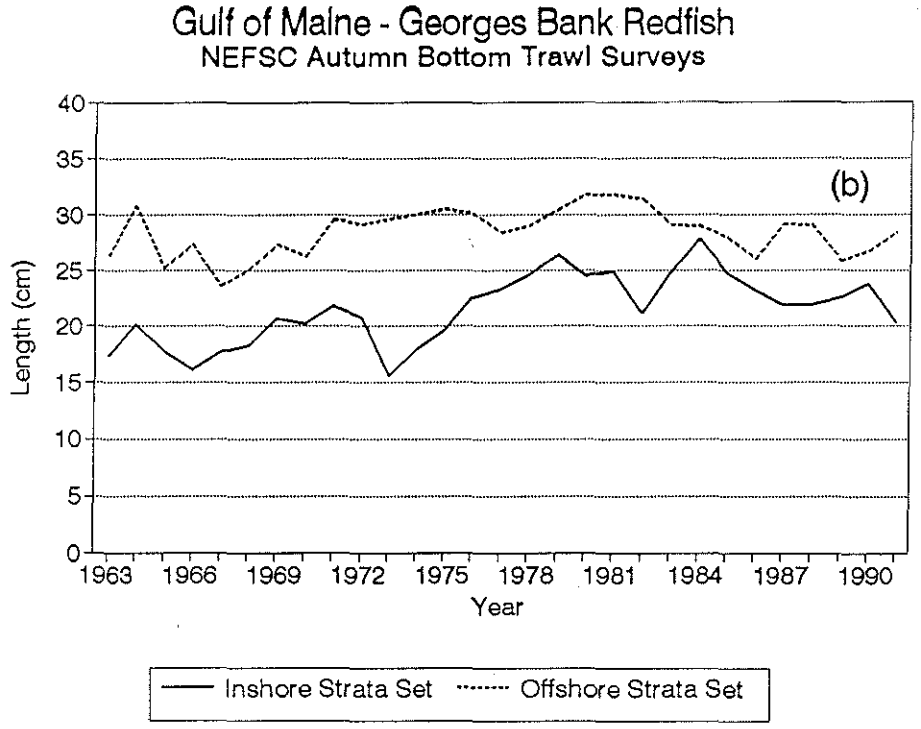


Figure 6. Trends in mean length of Gulf of Maine-Georges Bank redfish based on (a) NEFSC spring and (b) NEFSC autumn bottom trawl surveys for inshore (strata 26, 27, 39, and 40) and offshore (strata 24, 28-30, 36-38) strata sets.

Table 7. Prerecruit indices for Gulf of Maine redfish derived from NEFSC autumn surveys conducted in western Gulf of Maine inshore strata (26, 27, 39, and 40)

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

[1] **4-7 cm = young-of-the-year fish**
[2] **8-12 cm = 1 year old fish**
[3] **13-16 cm = 2 year old fish**

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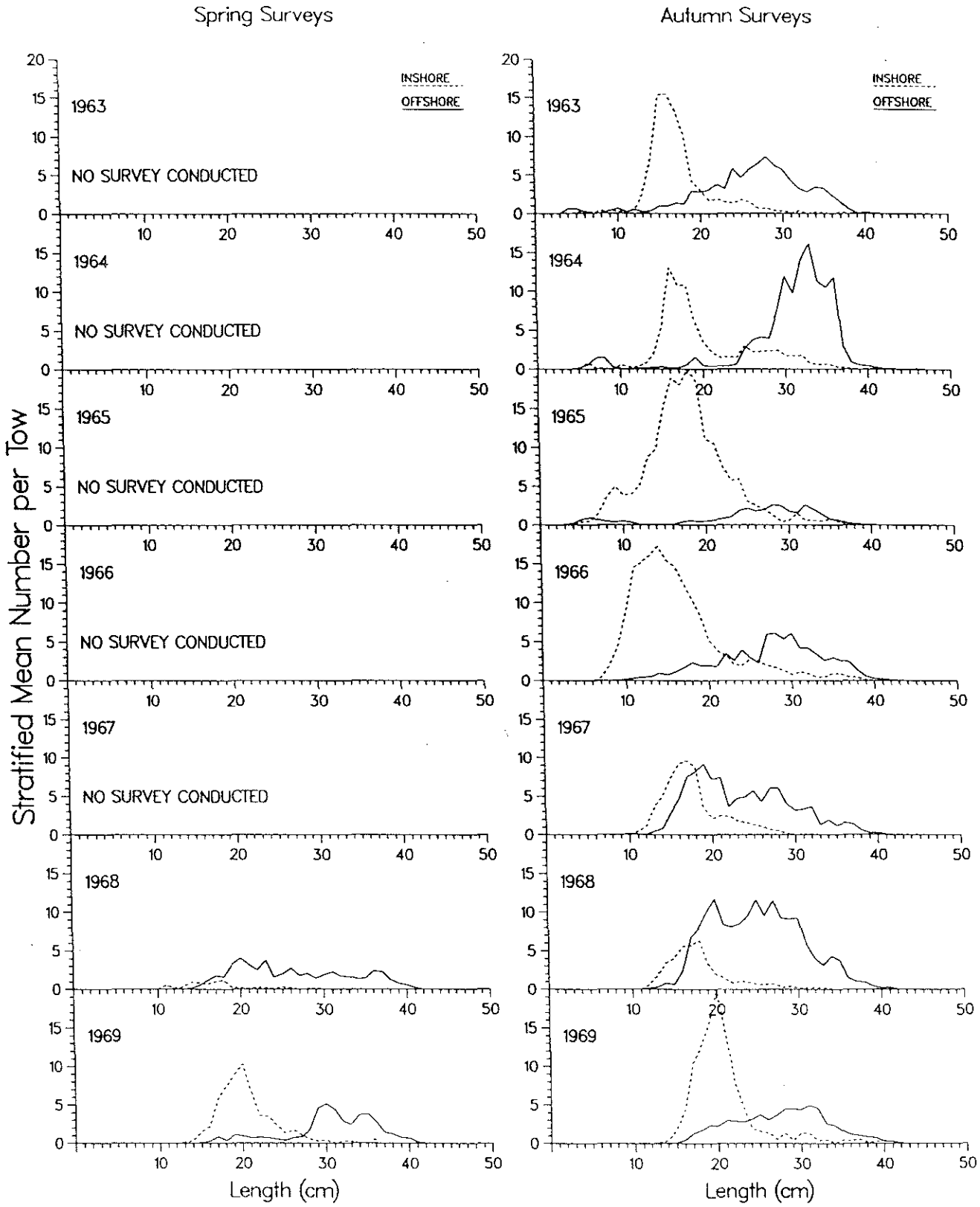
Figure 7. Length composition of Gulf of Maine-Georges Bank redfish based on NEFSC spring and autumn bottom trawl surveys for inshore (strata 26, 27, 39, and 40) and offshore (strata 24, 28-30, 36-38) strata sets, 1963-1992.



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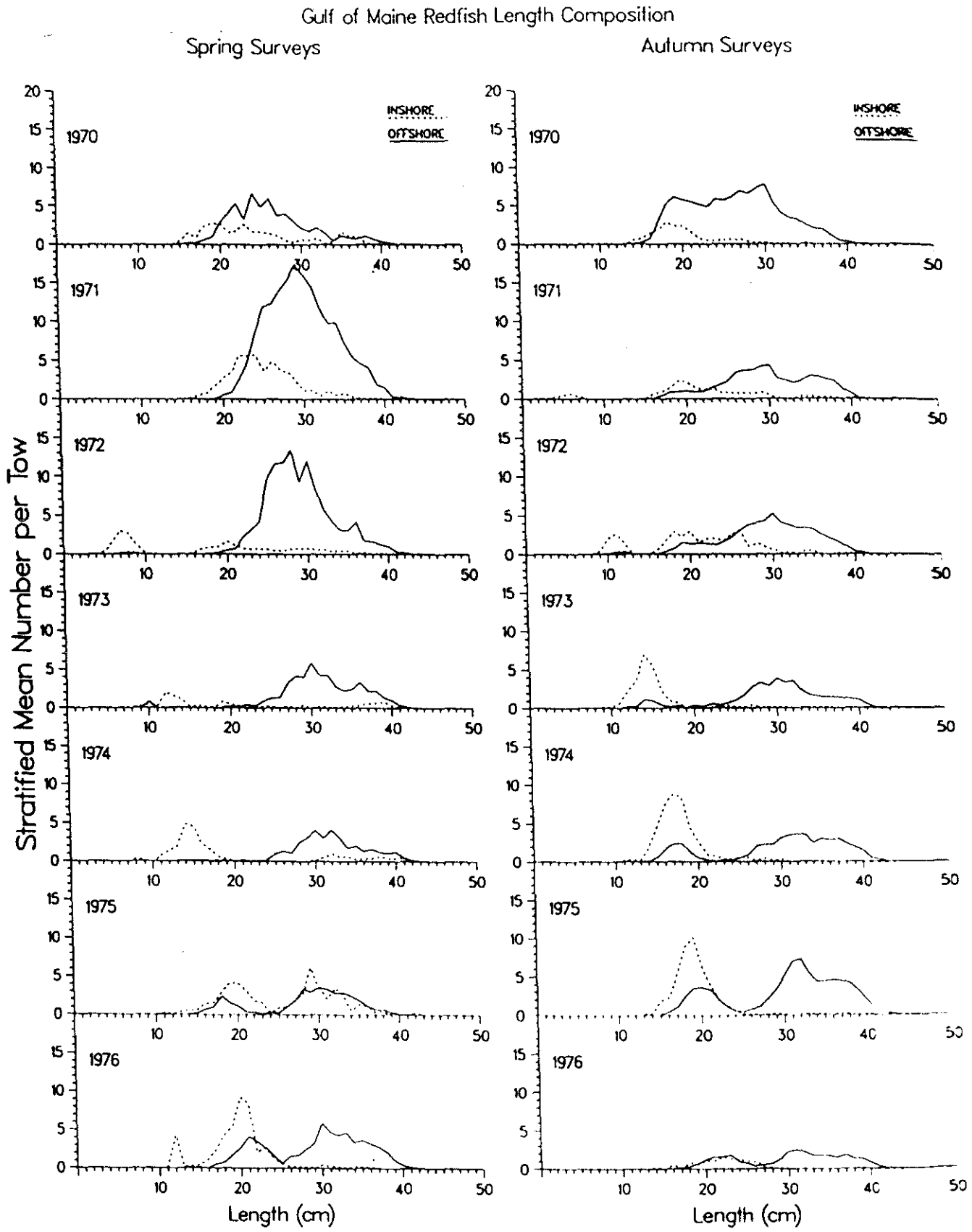

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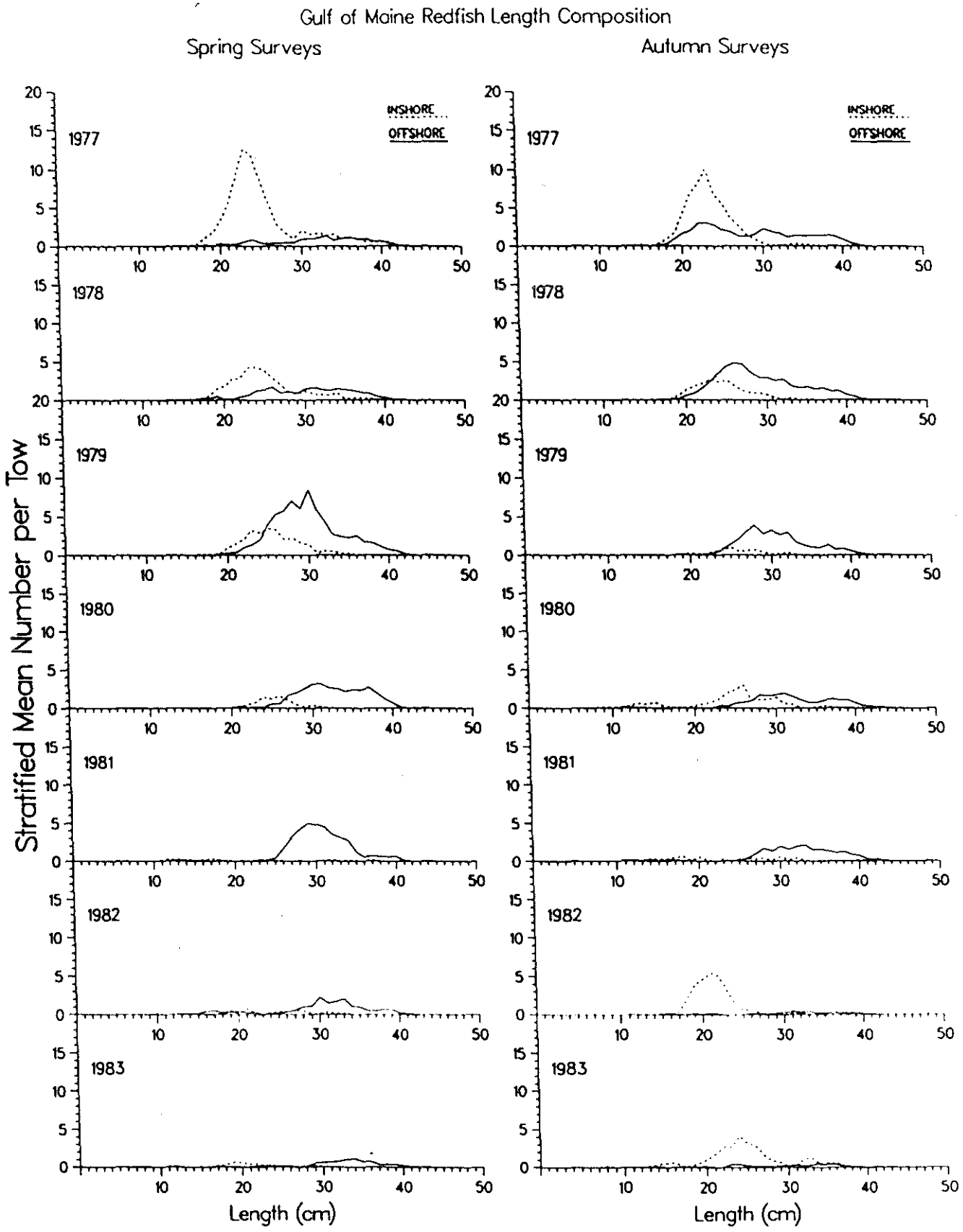


Figure 7. Continued.

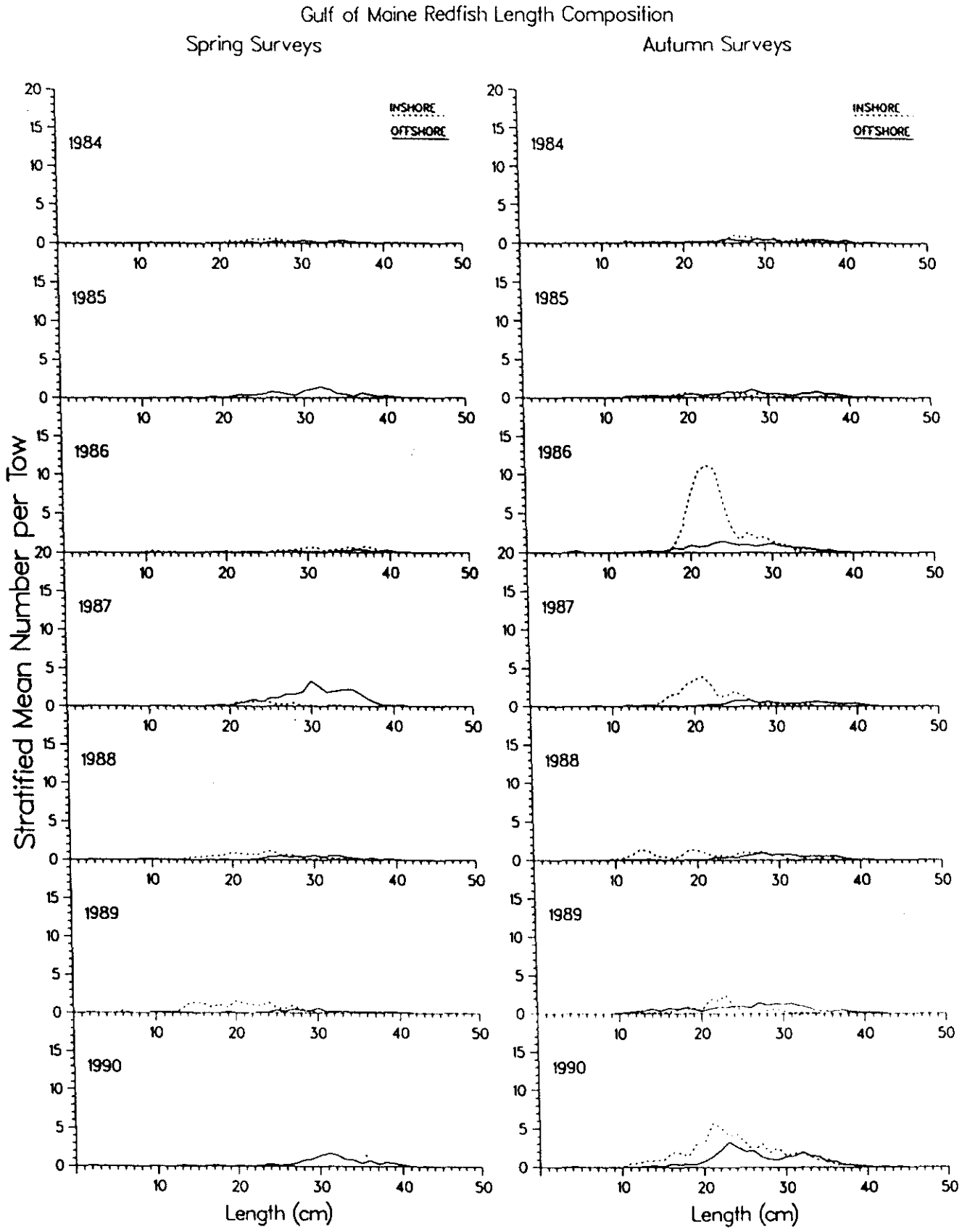
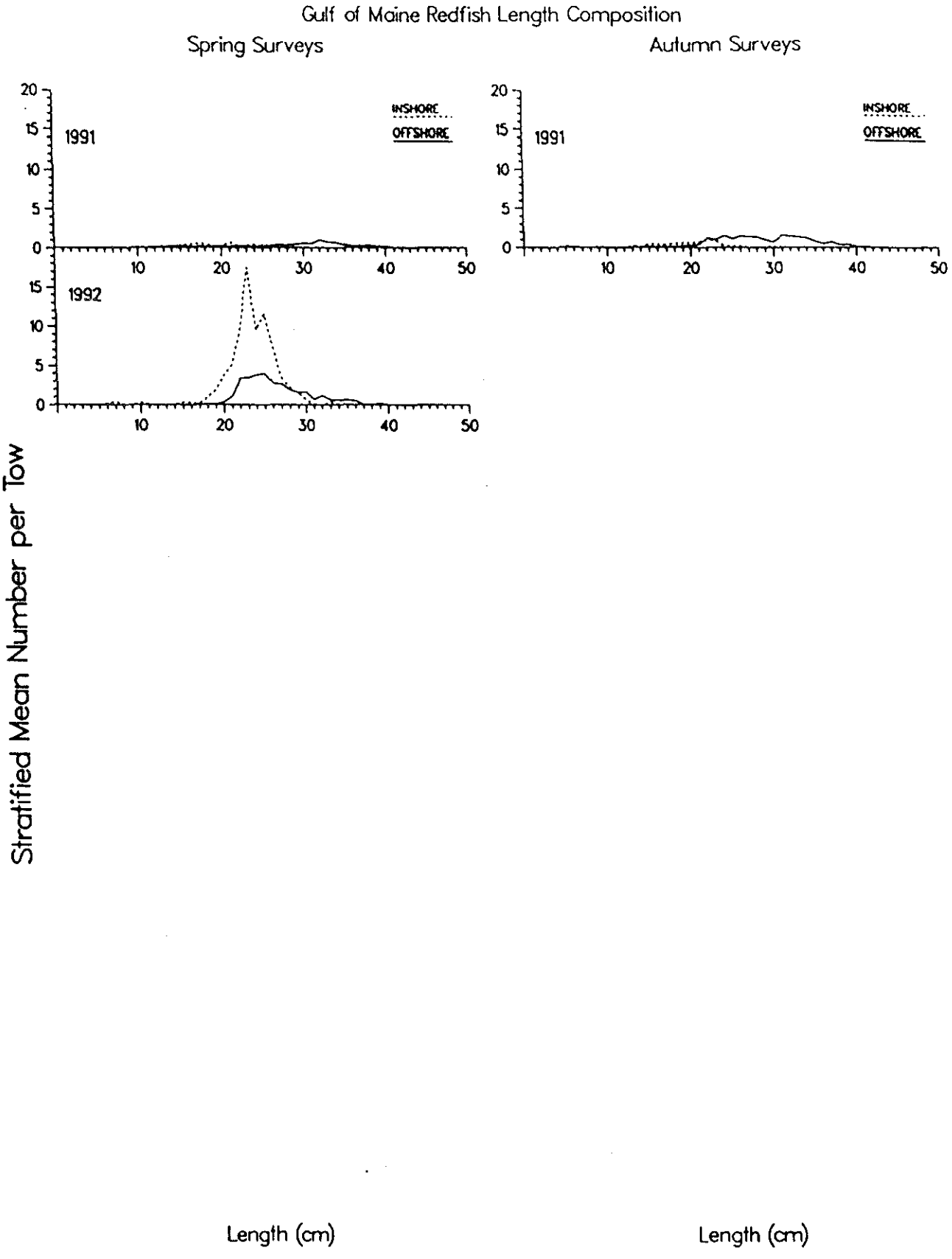


Figure 7. Continued.



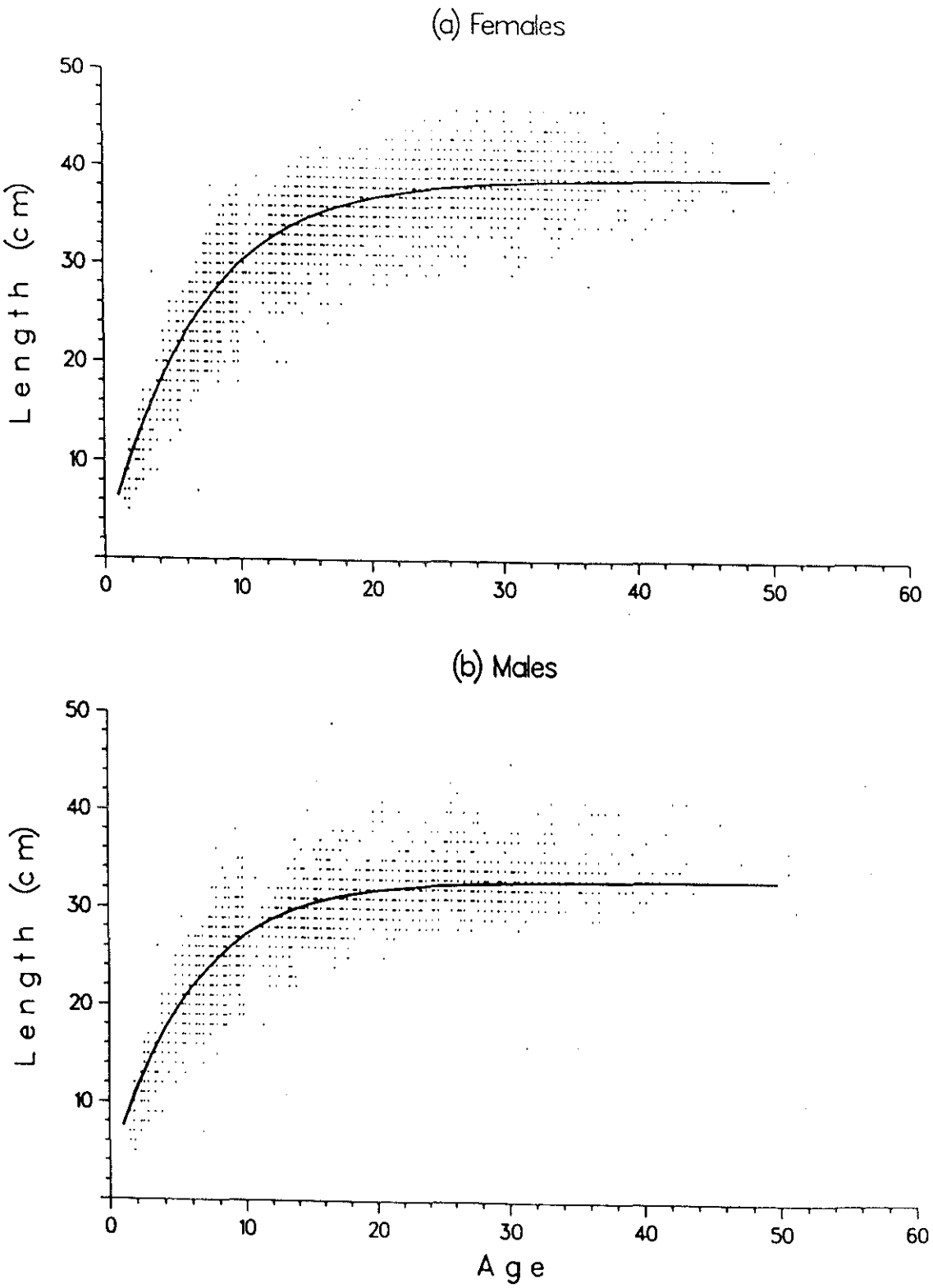


Figure 8. Fitted von-Bertalanffy growth curves and observed length at age of female and male redfish from the Gulf of Maine-Georges Bank region. Data from aged fish collected during spring, summer, and autumn NEFSC bottom trawl surveys conducted between 1975 and 1980 (From: Mayo *et al.* 1990).

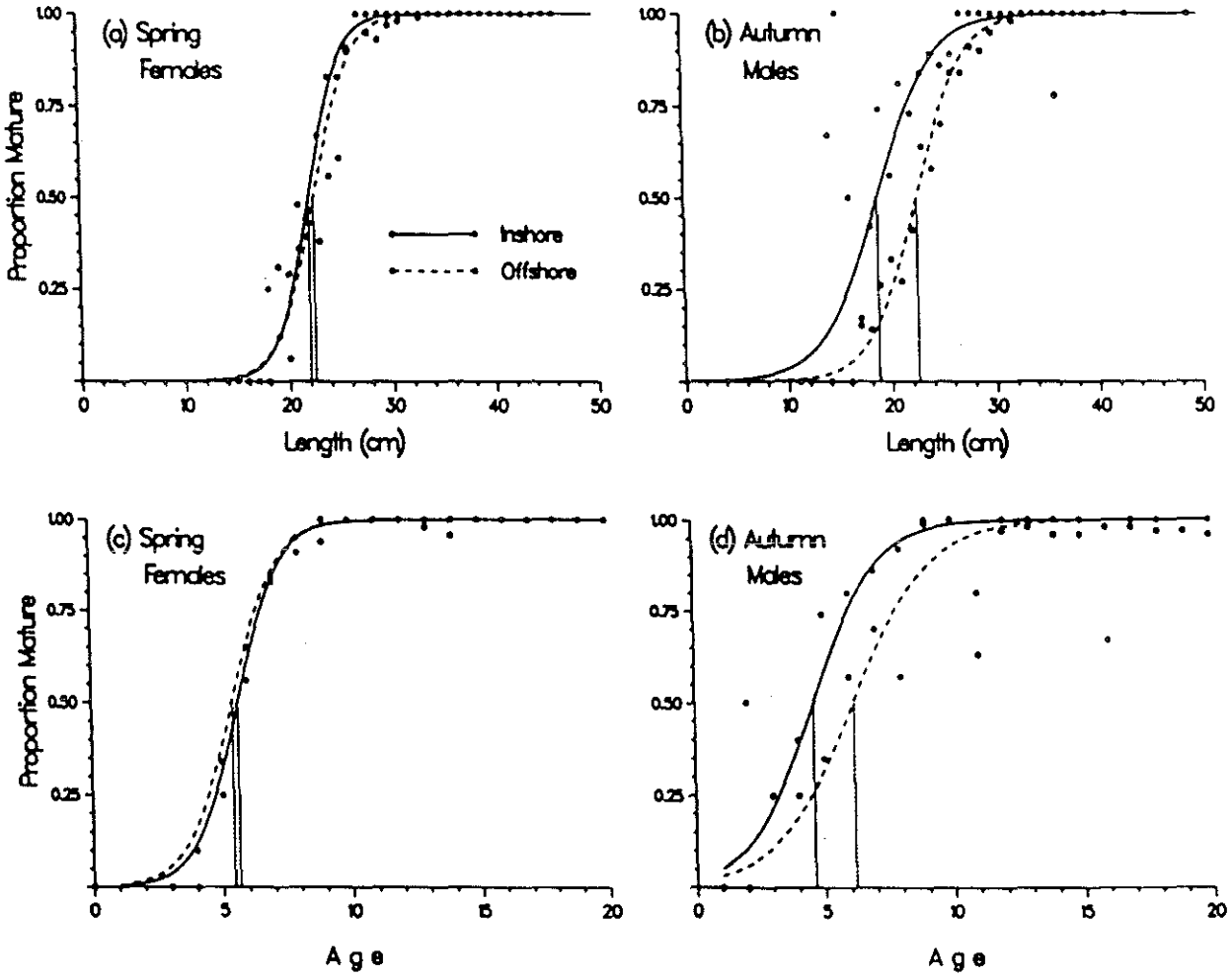


Figure 9. Fitted logistic maturation ogives and observed proportions mature at length and age for female and male redfish from the Gulf of Maine-Georges Bank region. Data from fish collected during spring and autumn NEFSC bottom trawl surveys conducted between 1975 and 1980 (From: Mayo *et al.* 1990).

Table 8. Yield and SSB per recruit analysis for Gulf of Maine redfish

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
Run Date: 23-11-1992; Time: 12:51:50.48
REDFISH UPDATED AVE WTS, MAT VECTOR (MAYO ET AL. 1990), 1971 YC FPAT

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

Age-Specific Input Data for Yield per Recruit Analysis

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

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

Slope of the yield/recruit curve at F=0.00: ->7.4657
F level at slope=1/10 of the above slope ($F_{0.1}$): -->.060
Yield/recruit corresponding to $F_{0.1}$: -->.1639
F level to produce maximum yield/recruit (F_{max}): -->132
Yield/recruit corresponding to F_{max}: -->.1819
F level at 20 % of maximum spawning potential ($F_{20\%}$): -->116
SSB/recruit corresponding to F_{20}: ---->1.7605

Table 8. Continued.

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

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	20.5042	9.2038	15.7030	8.8055	100.00
	.025	.25729	.11261	15.3600	5.6199	10.5714	5.2426	59.54
	.050	.38630	.15495	12.7813	3.9256	8.0049	3.5651	40.49
$F_{0.1}$	.060	.42199	.16394	12.0681	3.4774	7.2965	3.1229	35.47
	.075	.46399	.17253	11.2289	2.9656	6.4643	2.6189	29.74
	.100	.51602	.17961	10.1898	2.3604	5.4367	2.0253	23.00
$F_{20\%}$	.116	.54048	.18132	9.7014	2.0893	4.9553	1.7605	19.99
	.125	.55337	.18176	9.4441	1.9506	4.7023	1.6253	18.46
F_{max}	.132	.56220	.18186	9.2679	1.8572	4.5292	1.5345	17.43
	.150	.58155	.18148	8.8819	1.6582	4.1510	1.3415	15.23
	.175	.60361	.17999	8.4421	1.4412	3.7218	1.1319	12.85
	.200	.62138	.17791	8.0880	1.2750	3.3781	.9723	11.04
	.225	.63602	.17558	7.7963	1.1443	3.0965	.8475	9.63
	.250	.64833	.17318	7.5514	1.0394	2.8616	.7479	8.49
	.275	.65882	.17081	7.3427	.9536	2.6625	.6670	7.57
	.300	.66790	.16851	7.1623	.8823	2.4916	.6002	6.82
	.325	.67583	.16632	7.0047	.8223	2.3433	.5443	6.18
	.350	.68284	.16425	6.8655	.7712	2.2133	.4969	5.64
	.375	.68909	.16230	6.7417	.7272	2.0983	.4565	5.18
	.400	.69469	.16046	6.6306	.6889	1.9959	.4215	4.79
	.425	.69976	.15874	6.5303	.6554	1.9041	.3911	4.44
	.450	.70436	.15712	6.4391	.6258	1.8214	.3645	4.14
	.475	.70857	.15560	6.3559	.5995	1.7463	.3409	3.87
	.500	.71244	.15417	6.2794	.5759	1.6779	.3200	3.63
	.550	.71932	.15155	6.1436	.5356	1.5578	.2846	3.23
	.600	.72526	.14922	6.0264	.5023	1.4557	.2558	2.90
	.650	.73047	.14714	5.9238	.4744	1.3677	.2319	2.63
	.700	.73509	.14526	5.8331	.4506	1.2911	.2119	2.41
	.750	.73921	.14356	5.7520	.4301	1.2237	.1949	2.21
	.800	.74294	.14201	5.6789	.4121	1.1639	.1803	2.05
	.850	.74632	.14060	5.6126	.3964	1.1105	.1676	1.90
	.900	.74941	.13930	5.5521	.3824	1.0624	.1565	1.78
	.950	.75226	.13809	5.4964	.3698	1.0189	.1467	1.67
	1.000	.75488	.13698	5.4451	.3585	.9793	.1380	1.57

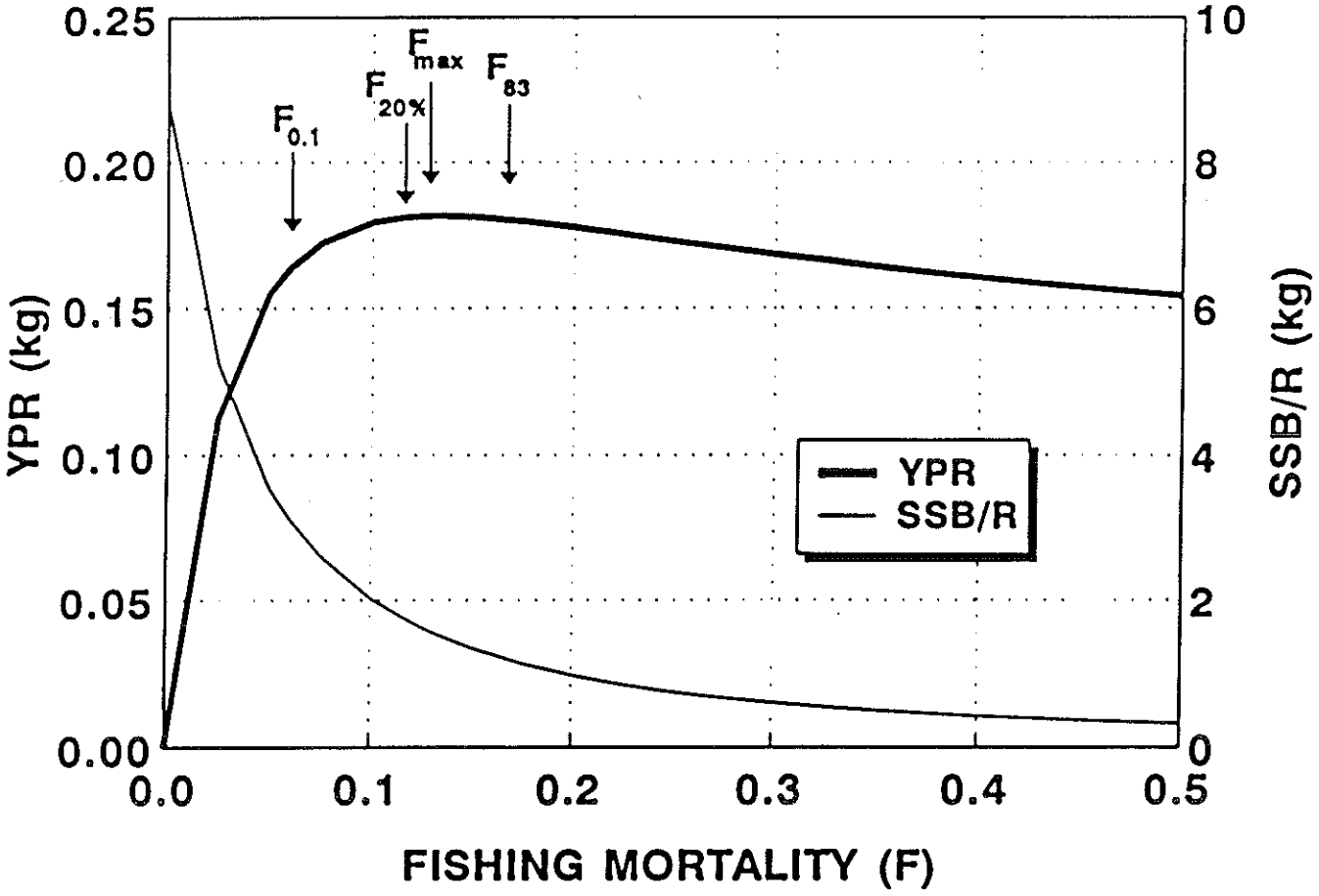


Figure 10. Yield and spawning stock biomass (SSB) per recruit curves for Gulf of Maine - Georges Bank redfish and estimates of $F_{0.1}$, $F_{20\%}$, F_{max}, and F in 1983.