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Exploitation of Redfish, *Sebastes marinus* (L.), in the Gulf of Maine-Georges Bank Region, with Particular Reference to the 1971 Year-Class

R. K. Mayo
National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole, Massachusetts 02543, USA

Abstract

The redfish fishery of the Gulf of Maine-Georges Bank region is reviewed and an assessment of the current status of the stock is presented. Annual nominal catches of approximately 13,000 to 14,000 metric tons in 1977 and 1978 were considerably below the peak annual yield of about 60,000 tons but close to the estimated maximum sustainable yield (MSY) as determined by general production model analyses. However, the level of effort expended during the most recent years was 2 to 3 times higher than the level corresponding to the estimated MSY. Standardized effort calculations indicate that real effort has substantially increased since the mid-1960's due in part to a major shift in the size composition of the redfish fleet toward larger, more efficient vessels.

Estimated von Bertalanffy growth parameters are utilized in a yield-per-recruit analysis. For an instantaneous natural mortality rate (M) of 0.10, maximum yield per recruit is achieved at an instantaneous fishing mortality (F) in excess of 1.00 at recruiting ages of 9-10 years. For M of 0.05, the maximum yield per recruit occurs at slightly lower F levels but at considerably higher recruiting ages. The $F_{0.1}$ levels, however, are generally in the range of 0.10-0.20 under both assumptions of M.

Recruitment to the redfish fishery in this region has been extremely variable over the last two decades, and the fishery is becoming increasingly dependent on one or two dominant year-classes. Between 1964 and 1978, only the 1971 year-class appeared in the population in significant quantities. This year-class began to account for a considerable portion of the catches in 1976 and 1977 and became fully recruited to the fishery in 1978 at an age when these fish were just beginning to mature.

Introduction

The redfish, *Sebastes marinus* Linnaeus, population in the Gulf of Maine (NAFO Subarea 5) has been commercially exploited since the mid-1930's when freezing techniques were developed to market the catch. Nominal catches increased from about 500 metric tons in 1934 to a maximum of nearly 60,000 tons in 1941. The initial rapid increase in catch was followed by a long period of decline and subsequent relative stability with catches varying from 7,000 to 20,000 tons annually. This decline in catch from the Gulf of Maine coincided, in the mid-1940's, with a rapid expansion of fishing activity to more distant grounds on the Scotian Shelf and in the Gulf of St. Lawrence (Subarea 4) and on the Grand Bank (Subarea 3). This period of expansion culminated in a peak USA redfish catch from all areas of 127,000 tons in 1951. Since then, however, the fishery has declined as the fleets relied on fishing grounds closer to their home ports. In 1978, the total USA redfish catch was just over 16,000 tons, of which 14,000 tons were taken in the Gulf of Maine-Georges Bank region. A general review of the USA redfish fishery may be found in Kelly *et al.* (1972).

The Gulf of Maine redfish fishery was under ICNAF management from 1973 to early 1977. A total allowable catch (TAC) of 30,000 tons in 1973 and 1974 was lowered to 25,000 tons for 1975. However, after an initial assessment (Mayo, MS 1975) indicated a substantially lower surplus yield, the TAC was further reduced to 17,000 tons for 1976. Further analysis (Mayo, MS 1976) indicated that a greater reduction would be required to allow for rebuilding of the stock, and the TAC for 1977 was reduced still further to 9,000 tons. No regulatory measures have been in effect for redfish since early in 1977.

The present study reexamines historical catch and effort data for the Gulf of Maine redfish fishery, and utilizes recent age composition data to calculate growth and mortality rates and to assess the impact of the commercial fishery on the newly-recruited 1971 year-class.

Distribution and taxonomy

At least two species of redfish *Sebastes viviparus* Kroyer and *S. marinus* Linnaeus, are considered to inhabit the North Atlantic (Templeman, 1959; Mead and Sindermann, 1961; Kelly *et al.*, 1961). *S. viviparus*, a smaller, shallow water species, is found only in the eastern North Atlantic from East Greenland to the Norwegian coast, whereas *S. marinus* inhabits deeper water on both sides of the North Atlantic from the North Sea to Greenland and southward to New Jersey (Templeman, 1959; Bigelow and Schroeder, 1953). The Gulf of Maine, however represents the southern limit of any sizeable concentrations of *S. marinus* in the western North Atlantic.

Considerable controversy has surrounded the taxonomic status of *S. marinus*. Two types have been identified, a large-eyed deep-water form possessing a sharp protuberance on the lower jaw (Travin, 1951) termed the *mentella*-type, and the relatively shallow water *marinus*-type having a rounded protuberance on the lower jaw (Templeman, 1959). Travin (1951) ascribed the former to a separate species, *S. mentella*, to distinguish it from *S. marinus*, but Andriiashev (1954) described the *mentella*-type as a subspecies, *S. marinus mentella* Travin. In view of the great temperature-induced geographic variation in *Sebastes* morphometric and meristic characteristics (Templeman and Pitt, 1961), Kelly *et al.* (1961) concluded that it would be difficult to determine whether the different forms of *S. marinus* are genetically or environmentally controlled. The taxonomy is further confused by the existence of intermediate forms at certain sizes (Kotthaus, 1958), but the evidence indicates a clear separation between *S. viviparus* and the types of *S. marinus*. The current taxonomic status of *S. marinus* is undecided and, consequently, most authors refer to the variations as *mentella*-type and *marinus*-type.

In the Northwest Atlantic, the *marinus*-type is generally found in the northernmost regions, and in some cases, at shallower depths as far south as the northern slope of the Grand Bank (Templeman, 1959). In this region, *mentella*-type redfish are found at greater depths, usually in excess of 300 m. On the slopes of the Grand Bank and in areas to the west and south, the *mentella*-type predominates at all depths, forming the basis of commercial fisheries from Georges Bank to the Grand Bank (Mead and Sindermann, 1961). Thus, the name "redfish" in this paper refers to *S. marinus, mentella*-type.

Biology

Redfish are slow-growing, long-lived animals (Kelly and Wolf, 1959; Sandeman, 1969), with ages in excess of 50 years and maximum sizes of 45-50 cm having been noted (Debaie, MS 1964). Consequently, the natural mortality rate is quite low compared with that for faster-growing species.

According to Perlmutter and Clarke (1949), redfish in the Gulf of Maine reach sexual maturity in about 9 years at an average length of 22-23 cm. Redfish are viviparous, retaining their eggs in the ovary after fertilization until yolk sac absorption. Mating is thought to take place in the autumn with larval extrusion occurring in the following spring and summer (Templeman, 1959). Larvae remain pelagic for 4-5 months, after which they move to the bottom at an average length of 50 mm (Kelly and Barker, 1961). Detailed accounts of these and other aspects of redfish biology may be found in Magnusson (1955), Steele (1957), Sorokin (1961) and Trout (1961).

Materials and Methods

Commercial catch and effort data

Catch and effort data for the USA commercial redfish fishery in the Gulf of Maine were obtained from records on file at the Northeast Fisheries Center of the National Marine Fisheries Service, Woods Hole, Mass. Nominal catch statistics of the distant water fleets (mainly USSR) for 1957-78 were taken from statistics published annually by the International Commission for the Northwest Atlantic Fisheries (ICNAF, 1959-79; ICNAF, MS 1979).

Individual trip records of USA vessels involved in the Gulf of Maine fisheries from 1942 to 1978 were examined for trends in catch and effort. For those trips of otter trawlers, operating from the ports of Portland, Rockland and Gloucester, in which redfish comprised 50% or more of the total catch from each trip (directed redfish trips), the catch-per-unit-effort (CPUE) was expressed as the ratio of the total redfish catch to the total days fished. A day fished is defined as 12 hours of actual fishing time with the net on the bottom. A 12-hour day was used because redfish are usually fished only during daylight hours due to their diurnal migratory habits. The total fishing effort in each year was estimated by dividing the total annual catch of redfish by the corresponding annual CPUE of the selected USA fleet.

Standardized CPUE index

The gradual introduction of echo-sounders on fishing vessels during the 1950's and the substantial shift in size composition of the redfish fleet during the late 1960's and early 1970's contributed to changes in fishing efficiency which are apparent in the nominal CPUE indices. To account for the effect of these confounding influences, the catch and effort data were divided into three periods. In the first period (prior to 1952), the actual CPUE indices were not adjusted because there was no apparent shift in vessel size composition and negligible use of echo-sounders. During the second period (1952-63), the gradual introduction of echo-sounders increased the fishing efficiency of the fleet. K. Smith (pers. comm.) estimated that the use of echo-sounders, if introduced at a constant rate, would have led to a 40% increase in real effort over the 12-year period, at the end of which the entire fleet is assumed to have been using echo-sounders (Mayo and Miller, 1976). The expression e^{kt} (Halliday and Doubleday, 1976) was used to adjust the actual CPUE index such that the values decreased by 2.74% each year ($K = 0.0274$), resulting in a decline of 29% in effective CPUE and a corresponding increase in adjusted effort after 12 years. During the third period (1964-78), there was a major change in the size composition of vessels, resulting in a higher proportion of larger vessels catching redfish than previously. To account for this, the CPUE for each of the vessel tonnage groups was calculated for each year in the same way as the nominal index mentioned previously except that data for vessels landing at all ports were used. To approximate the fishing activity of vessels which had traditionally fished in the Gulf of Maine and which fished in all years during this period, the CPUE of vessels of the 50-150 GRT class was chosen as the standard against which the CPUE values of all other tonnage classes were adjusted. A linear regression of annual CPUE values for each tonnage class against the CPUE values for the standard (50-150 GRT) fleet was performed, forcing the intercept through the origin. Analysis of residuals revealed an inordinate number of negative values in the later years for most of the larger vessels, indicating reduced performance of these vessels relative to the standard group, a matter which is currently being investigated. The slope of the line, calculated as $b = \Sigma XY / \Sigma X^2$ (Steel and Torrie, 1960), was used as an expression of the fishing power of each vessel tonnage class relative to the standard. The fishing power coefficients were multiplied by the corresponding fishing effort values for each tonnage class, the adjusted effort values and catches summed, and new CPUE indices calculated and adjusted for the increased efficiency resulting from the use of echo-sounders in the preceding period. The above method, in effect, relates all CPUE values to the period prior to 1952. The adjusted annual CPUE values were then divided into the corresponding redfish catches to estimate annual fishing effort in terms of standard days fished.

Yield estimates

The relationship between catch and effort for the 1952-78 period was examined using the generalized production model (Pella and Tomlinson, 1969). Data for the period prior to 1952 were excluded from the analysis because the fishery during the initial years was based on an accumulated virgin stock of large, old individuals. The weighted average effort method proposed by Fox (1975) was used to approximate equilibrium conditions. Recent age composition results indicate that, with the exception of the 1971 year-class, redfish first appear in the catch in considerable numbers at ages 12-14 and contribute substantially to the fishery at least to age 25. A 12-year averaging period was therefore chosen.

Regressions of standard CPUE on average standard effort were accomplished by the PROFIT method of Fox (1975). The CPUE data were fitted with the parameter m = 1.0 and m = 2.0 to approximate the shapes of the Gompertz exponential (Fox, 1970) and logistic (Schafer, 1954, 1957) population growth curves. The model was also allowed to iterate through successive values of m starting at 1.0 and 2.0 until convergence was achieved. In both cases, the best fit occurred at a value of m between 0.96 and 0.97, indicating that the exponential growth curve more closely approximates the data.

Research vessel surveys

Research vessel surveys have been conducted in the Gulf of Maine-Georges Bank area, at depths ranging from 27 to 365 m, during the autumn since 1963 and during the spring since 1968 (Fig. 1). Survey methodology has been described by Grosslein (1969, MS 1974). Stratified catch-per-tow and length

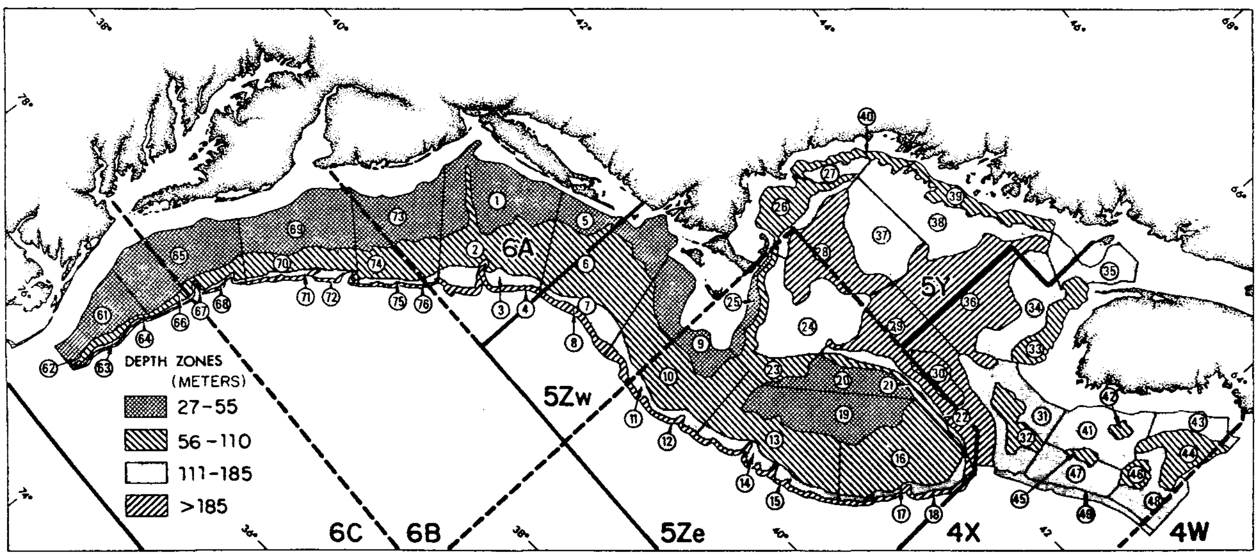

Fig. 1. USA research vessel bottom trawl survey strata in NAFO Subareas 4, 5 and 6.

frequency data were grouped for inshore (<111 m) and offshore (>111 m) strata sets to examine trends in relative abundance and size composition. Age-length keys, constructed from the results of otolith readings of samples from the spring and autumn surveys of 1975, 1976 and 1977, were applied to the length compositions to estimate catch per tow by age-group.

Age composition of catches

Semiannual estimates of the numbers of redfish landed by length (1-cm intervals) were calculated from weighted length frequency samples of the commercial catches. Six age-length keys derived from the spring and autumn research surveys in 1975, 1976 and 1977 were applied to the semiannual length compositions to estimate the numbers-at-age caught in each of the 3 years.

Growth and mortality estimates

Growth parameters for male and female redfish and for the sexes combined were derived from von Bertalanffy growth curves, fitted, using the computer program (BGC-2) developed by Tomlinson and Abramson (1961), to 3,186 individual length-at-age observations from the 1975–77 research vessel surveys.

Instantaneous total mortality coefficients (Z) were estimated from the numbers per tow of the spring surveys, and from the numbers landed per day fished in the commercial fishery for the period 1975–77 by calculating $\log_e$ of the ratio of the CPUE of successive age-groups for each of the year-classes from 1931 to 1972. The commercial and survey catch at age data for all successive year-classes prior to 1963 were also utilized to estimate mortality from catch curves. Slopes were calculated from $\log_e$ abundance of all year-classes between 1931 and 1963, and of the relatively recent year-classes between 1952 and 1963.

Yield isopleth diagrams were constructed from the model of Paulik and Gales (1964), using the estimated growth parameters and assumed natural mortality coefficients (M) of 0.10 and 0.05.

Results and Discussions

Fishery trends

Consistent exploitation of the redfish stocks in the Northwest Atlantic began in the 1930's, the initial effort being limited to the Gulf of Maine and a small amount of effort on the Scotian Shelf. When the Gulf of Maine catch peaked in 1941 and began to decline, more effort was diverted to the Scotian Shelf and the Gulf of St. Lawrence (Subarea 4) and subsequently to the Grand Bank (Subarea 3) (Fig. 2). The initial rapid expansion of the redfish fishery continued to 1951 when the USA harvested 127,000 tons from all areas combined. Since then, the USA catch off Canada (Subarea 3 and 4) has continued to decline while the Gulf of Maine catch has remained relatively stable, fluctuating between 7,000 and 17,000 tons. In 1978, USA vessels caught 16,100 tons of redfish, of which 14,000 tons were taken in the Gulf of Maine-Georges Bank area.

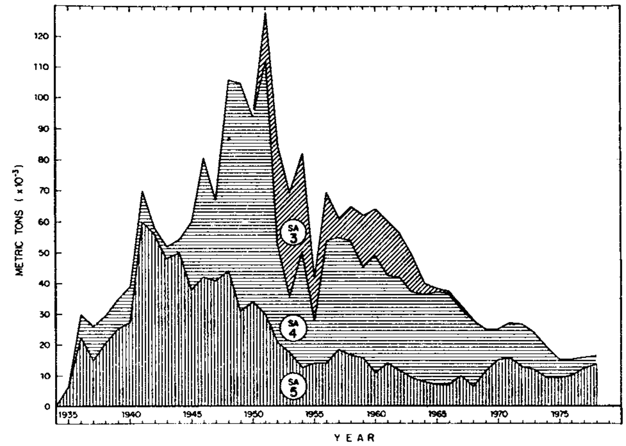

Fig. 2. Trends in USA redfish catches in the Northwest Atlantic, 1934–78.

Historical catch records reveal three distinct periods of exploitation in Subarea 5 (Table 1). The first period, 1935–52, was characterized by a rapid increase and subsequent decline in catch as the large accumulated virgin stock was exploited. The second period, 1952–64, showed a relatively steady decline in both catch and effort and the beginning of exploitation by non-USA vessels, mainly USSR. The third period, 1964–78, is somewhat similar to the first but on a much smaller scale, due chiefly to increased catches of non-USA vessels in the early 1970's. The highest level of non-USA harvest occurred in 1972 when nearly one-third of the total Subarea 5 catch of 19,000 tons was taken by countries other than USA, but this catch declined to less than 100 tons in 1978.

Traditionally, Div. 5Y has accounted for the greatest part of the redfish harvest in Subarea 5, the highest catches being attained in the vicinity of Cashes and Fippinies Ledge and Jeffreys Bank in the central part of the Gulf (Kelly *et al.*, 1972). Div. 5Z has traditionally been of less importance, generally accounting for 10–20% of the USA harvest. However, this area accounted for the major part of the non-USA redfish catch, most of which was taken in the northern part of the Great South Channel. Since there are no barriers between the deep-water areas where redfish are found, the populations in Div. 5Y and 5Z have been treated as a unit stock for assessment.

Almost all of the redfish taken by USA vessels have traditionally been landed in the ports of Portland and Rockland, Maine, and Gloucester, Mass. In recent years, Boston, Mass. had become important with about 1,000 tons landed there annually.

TABLE 1. Nominal redfish catches, actual and standardized catch per unit effort, and calculated standardized USA and total effort for the Gulf of Maine (NAFO Subarea 5) redfish fishery.

	Nominal catches (tons)			USA catch per unit effort (tons/day)		Calculated standard effort (days fished)	
Year	USA	Others	Total	Actual	Standard	USA	Total
1934	519	—	519	—	—	—	—
1935	7,549	—	7,549	—	—	—	—
1936	23,162	—	23,162	—	—	—	—
1937	14,823	—	14,823	—	—	—	—
1938	20.640	—	20,640	—	—	—	—
1939	25,406	—	25,406	—	—	—	—
1940	26,762	—	26,762	—	—	—	—
1941	59,796	—	59,796	—	—	—	—
1942	55,892	—	55,892	6.9	6.9	8,100	8,100
1943	48,348	—	48,348	6.7	6.7	7,216	7,216
1944	50,439	—	50,439	5.4	5.4	9,341	9,341
1945	37,912	—	37,912	4.5	4.5	8,425	8,425
1946	42,423	—	42,423	4.7	4.7	9,026	9,026
1947	40,160	—	40,160	4.9	4.9	8,196	8,196
1948	43,631	—	43,631	5.4	5.4	8,080	8,080
1949	30,743	—	30,743	3.3	3.3	9,316	9,316
1950	34,307	—	34,307	4.1	4.1	8,368	8,368
1951	30,077	—	30,077	4.1	4.1	7,336	7,336
1952	21,377	—	21,377	3.5	3.4[a]	6,287	6,287
1953	16,791	—	16,791	3.8	3.6	4,664	4,664
1954	12,988	—	12,988	3.4	3.1	4,190	4,190
1955	13,914	—	13,914	4.5	4.0	3,478	3,478
1956	14,388	—	14,388	4.4	3.8	3,786	3,786
1957	18,490	—	18,490	4.3	3.6	5,136	5,136
1958	16,043	4	16,047	4.4	3.6	4,456	4,458
1959	15,521	—	15,521	4.3	3.5	4,435	4,435
1960	11,373	2	11,375	3.8	3.0	3,791	3,792
1961	14,040	61	14,101	4.6	3.5	4,011	4,029
1962	12,541	1,593	14,134	5.4	4.0	3,135	3,533
1963	8,871	1,175	10.046	4.1	3.0	2,957	3,349
1964	7,812	501	8,313	4.3	2.9[b]	2,604	2,867
1965	6,986	1,071	8,057	7.0	4.5	1,552	1,790
1966	7,204	1,365	8,569	11.7	6.5	1,092	1,318
1967	10,442	422	10,864	12.4	5.8	1,740	1,873
1968	6,578	199	6,777	14.7	6.4	997	1,059
1969	12,041	414	12,455	11.4	5.2	2,272	2,395
1970	15,534	1,207	16,741	9.0	4.1	3,613	4,083
1971	16,267	3,767	20,034	7.0	3.3	4,784	6,071
1972	13,157	5,938	19,095	5.7	3.0	4,386	6,365
1973	11,954	5,406	17,360	5.3	2.7	4,427	6,930
1974	8,677	1,794	10,471	5.0	2.3	3,615	4,553
1975	9,075	1,497	10,572	4.0	2.0	4,538	5,286
1976	10,131	565	10,696	4.6	2.0	5,066	5,348
1977	13,012	211	13,223	4.9	2.1	6,196	6,297
1978	13,991	92	14,083	4.8	2.0	6,995	7,042

[a] CPUE data for 1952-63 adjusted for increased efficiency due to gradual introduction of echo-sounders.
[b] CPUE data for 1964-78 adjusted additionally for changes in size composition of the USA redfish fleet.

The fishery exhibits a distinct seasonal pattern of exploitation, as illustrated by the monthly trends in catch and effort statistics (Fig. 3). The spring months from March to June have, since 1964, accounted for 48% of the annual redfish catch and 45% of the fishing effort directed to redfish. As would be expected, the CPUE was also highest during this period (Mayo, MS 1975).

By-catches

The redfish fishery has a very small by-catch of other species. For example, over 70% of the redfish landed from the Gulf of Maine during 1964–78 were taken during trips in which redfish comprised over 85% of the total landed weight of all species, but these trips accounted for less than 17% of the total trips in which some redfish were taken. Most of this redfish by-catch was taken in fisheries directed to other species, especially groundfish species. Dicarding of small redfish has been noted in recent years in the shrimp fishery and substantial discards were reported in the early 1970's when a strong year-class of redfish began to appear in the catches.

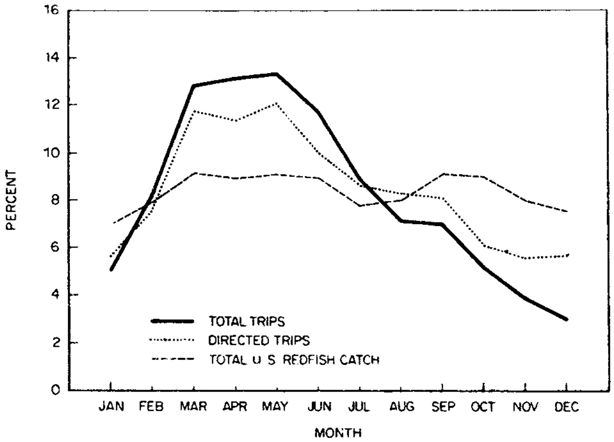

Fig. 3. Monthly distribution of USA redfish catch and effort in Subarea 5, based on data for the 1964-77 period.

Fishing effort

The nominal CPUE data indicate a gradual decline from the early 1940's to the early 1960's, followed by an increase in the late 1960's and a subsequent decline (Table 1). The fishing effort, however remained high during the initial period, declined steadily until the late 1960's and increased during the 1970's. Mayo (MS 1975) indicated that there was a substantial decline in the number of trips directed to redfish fishing in the Gulf of Maine between 1964 and 1968, followed by an increase in the early 1970's due chiefly to increased fishing activity of vessels larger than 150 GRT as the USA fishery in Subarea 4 declined.

From the early 1940's up to about 1964, over 70% of the annual redfish catch was taken by vessels in the 51-150 GRT range (tonnage groups 31-33) (Fig. 4). Starting in 1966 and continuing through later years, vessels of 151-500 GRT (tonnage groups 41-44) accounted for a greater share of the redfish harvest. In 1978, over 67% of the redfish catch in the Gulf of Maine was taken by vessels greater than 150 GRT. This shift in size composition of the fleet has a profound effect on the CPUE index because the larger vessels usually have higher catch rates than the smaller ones (Fig. 5). This difference is due to a number of factors including carrying capacity, more powerful engines capable of pulling larger trawls, and the ability to make longer trips to more productive grounds.

The differences between the nominal and standardized CPUE indices and the resulting calculated effort (Table 1) indicate that the actual effort is greatly underestimated, especially since the late 1960's as a result of the dominance of larger, more efficient vessels in the fishery. However, despite the differences in magnitude, both sets of CPUE data show maximum values during 1966-69, followed by a steady decline to 1975 and stabilization or possibly a slight increase in 1977 and 1978.

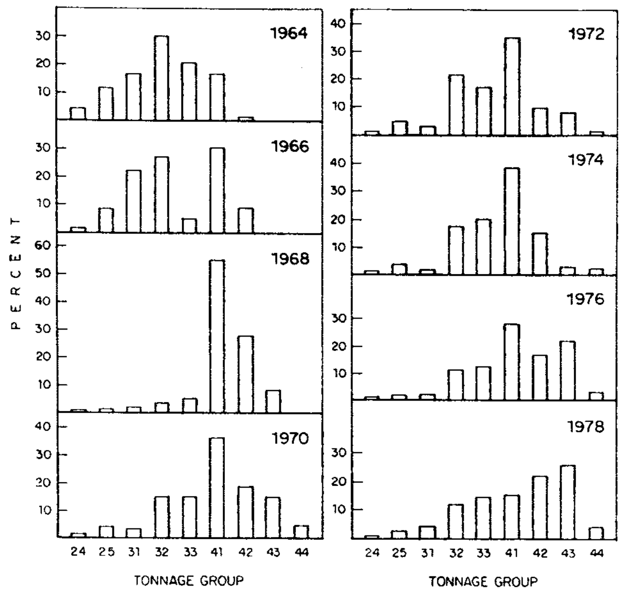

Fig. 4. Percentage distribution of USA nominal catches of redfish in the Gulf of Maine by tonnage groups (24 = 23-33 GRT; 25 = 34-50 GRT; 31 = 51-72 GRT; 32 = 73-104 GRT; 33 = 105-150 GRT; 41 = 151-215 GRT; 42 = 216-310 GRT; 43 = 311-400 GRT; 44 = 401-500 GRT).

The aggregate CPUE for a species such as redfish, whose small-scale geographic distribution is considered to be highly clumped, may not be indicative of overall abundance on a larger scale. During the early period of the fishery, high catch rates were probably maintained by successive exploitation of a number of discrete aggregations. The similarity in magnitude of the standard CPUE values for 1966-69 and 1941-43 at considerably different levels of catch and fishing effort supports this hypothesis. Rather than indicating similar levels of abundance over the whole Gulf of Maine area, the results infer that abundance within certain exploited aggregations may have been at similar levels and that the number of such aggregations under recent exploitation is substantially reduced. Therefore, it may be concluded that the overall abundance of redfish in the Gulf of Maine has probably declined at a much faster rate than indicated by the trends in CPUE, which may remain relatively high due to the progressive searching for and exploitation of redfish aggregations. A decline in CPUE, similar to that which occurred in the 1970's, probably indicates a decline both in the number of aggregations and in the abundance of fish within the aggregations.

Examination of catch and effort trends (Table 1) reveals that high catches in the order 40,000-60,000 tons were sustained only for a short time after the rapid increase in fishing effort during the initial phase of the fishery on the accumulated virgin stock. After this "fishing up" phase, both catch and CPUE declined substantially while fishing effort remained rather high.

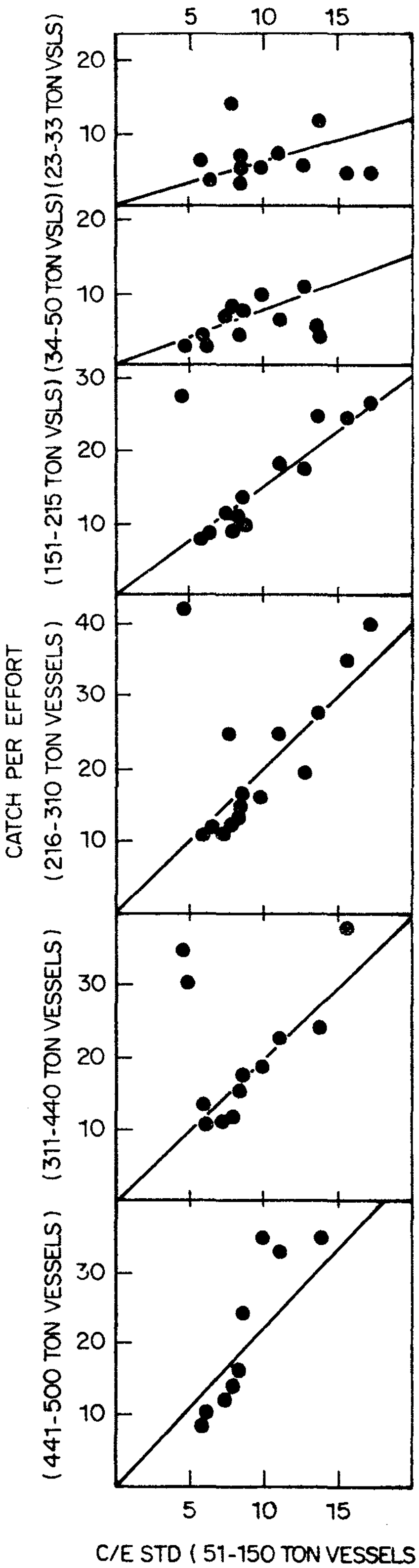

Fig. 5. Regressions of CPUE of various tonnage classes against the CPUE of the standard 51-150 GRT class, for the Gulf of Maine redfish fishery during 1964-77.

A period of relative stability ensued during the 1950's and early 1960's with catches of 10,000-15,000 tons prevailing. The subsequent increase in catch to 20,000 tons in 1971 was achieved through an extraordinary expenditure of effort in a period of declining CPUE. This level of catch could not be sustained at the existing level of redfish abundance and both the catch and CPUE declined to historically low levels. Between 1971 and 1976, the nominal catch declined by about 50% with an accompanying decrease in effort of only 25%. By 1978, when the effort had again reached the level of the early 1970's, the yield was about one-third less.

Research vessel survey trends

Stratified catch per tow indices (Table 2) show that redfish abundance in recent years was substantially below that of the 1960's in both the inshore and offshore areas. This pattern is similar to that exhibited by the commercial CPUE data. Smaller redfish are typically more abundant in the inshore than in the offshore area (Fig. 6).

An increase in size of redfish with increasing depth has been recognized by several authors (Templeman, 1959; Hennemuth and Brown, MS 1964; Gulland, MS 1965; McKone, MS 1979; Chekhova and Konstantinov, MS 1979). Major and Shippen (1970) cited similar evidence for the closely related Pacific Ocean perch (*Sebastes alutus*). Hennemuth and Brown (MS 1964) found statistically significant differences in the size composition of redfish in the Gulf of Maine from 4

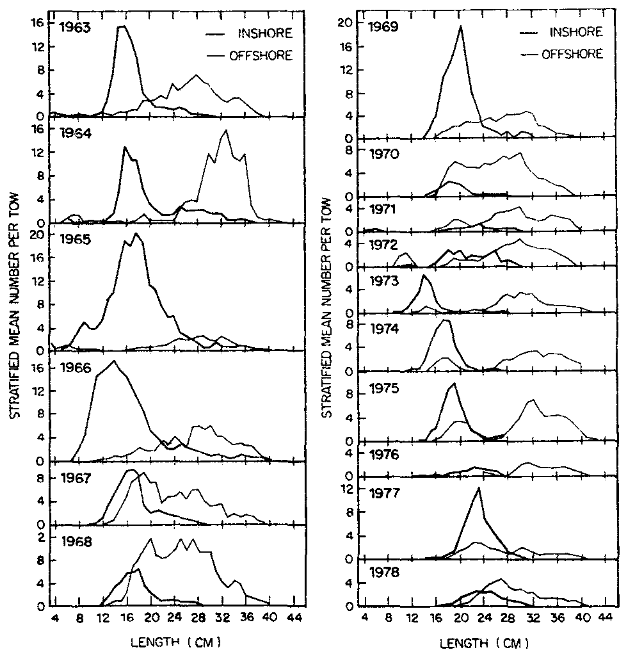

Fig. 6. Length composition of redfish caught in USA bottom trawl autumn surveys in the Gulf of Maine, 1963-78.

TABLE 2. Stratified mean catch per tow of redfish in numbers and weight (kg) from the autumn and spring research trawl surveys in Subarea 5.

	Inshore strata[a]		Offshore strata[b]		Total Subarea 5	
Year	Number	Weight	Number	Weight	Number	Weight
			Autumn Surveys			
1963	86.3	7.6	87.5	27.0	87.3	24.1
1964	81.3	13.5	122.3	61.8	116.3	54.6
1965	189.5	22.3	33.9	11.5	57.0	13.1
1966	172.8	17.0	77.8	31.2	91.9	29.1
1967	62.9	5.3	107.1	27.6	100.5	24.3
1968	41.1	4.7	161.3	46.6	143.4	40.4
1969	105.9	16.0	65.2	24.8	71.2	23.5
1970	18.2	2.8	107.2	38.2	94.0	32.9
1971	20.7	4.7	52.8	26.7	48.0	23.4
1972	36.4	6.6	58.9	27.8	55.6	24.6
1973	26.2	2.1	41.4	19.7	39.2	17.0
1974	44.2	4.7	49.0	27.6	48.3	24.2
1975	45.7	6.0	79.9	45.9	74.8	39.9
1976	11.6	2.5	31.9	17.5	28.9	15.3
1977	54.6	12.3	37.9	18.1	40.4	17.3
1978	20.4	5.5	49.5	23.4	45.2	20.7
			Spring Surveys[c]			
1968	7.9	1.2	51.7	19.8	45.2	17.0
1969	59.0	8.3	44.2	21.7	46.4	19.7
1970	29.7	9.3	59.1	20.6	54.7	18.9
1971	49.9	13.3	176.0	81.7	157.2	71.6
1972	23.8	4.6	114.7	51.3	101.2	44.4
1973	14.4	4.6	49.6	28.9	44.4	25.3
1974	25.7	6.1	35.8	21.1	34.3	18.8
1975	50.9	18.9	37.3	17.4	38.9	17.6
1976	45.9	6.4	65.1	29.6	62.2	26.2
1977	79.1	24.1	15.6	9.4	25.1	11.6
1978	33.7	10.4	22.3	12.5	24.0	12.2

[a] Inshore strata 26, 27, 39 and 40.
[b] Offshore strata 24, 28–30, 36–38.
[c] No adjustment made for difference in fishing power of #36 Yankee trawl used in 1968–72 and #41 Yankee trawl used in 1973–78.

depth zones ranging from 57 to 370 m, with modal length differences as large as 7-8 cm in samples from depths between 57 and 278 m. These results suggest either an extremely large variation in growth rate or a shift in age composition of the population with depth, the latter implying an inshore to offshore movement associated with age. The inshore areas may therefore represent nursery grounds and the length frequencies from these areas may be useful as pre-recruit indicators.

Three separate modal groups of small redfish are evident in the time series of inshore length compositions (Fig. 6), one increasing in size from 1963 to 1965, the second between 1966 and 1969, and the third beginning in 1971. Age-length keys based on data from research surveys in 1975–77 confirm the presence of strong year-classes in 1953, 1963 and 1971, and some moderately strong year-classes in the late 1950's. The year-classes of the late 1950's and that of 1963 were responsible for the large number of 12–22 cm redfish in the research survey catches during 1965–69. Since 1963, only the 1971 year-class has shown evidence of above-average strength.

Commercial length compositions

The average length of redfish in the USA commercial landings from the Gulf of Maine decreased

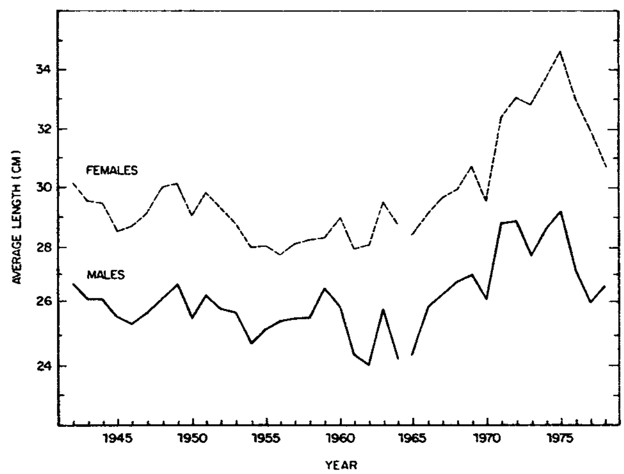

Fig. 7. Trends in average length of redfish in the USA commercial fishery in the Gulf of Maine, 1942–78. (Values for 1942–64 from Brown and Hennemuth (1965)).

in recruitment noted in the length distributions. The 1971 year-class is estimated to have contributed 8.7 million (31%) and 14.3 million (38%) individuals to the total number of redfish landed by USA vessels in 1976 and 1977 respectively. In terms of weight, however, this contribution was considerably less.

Recruitment patterns

According to Beverton and Holt (1957), recruitment fundamentally denotes the entry of fish to the fishing areas where they first become liable to encounters with the gear. Although redfish are caught in most parts of the Gulf of Maine, over 74% of the total catch is taken from the deeper offshore areas, where encounters with fishing gear are more probable. Since the 1971 year-class contributed substantially to the catches from 1976 onwards, the age at first capture in the directed redfish fishery is less than 5 years.

Selection factors for redfish, based on studies with trawls made of manila twine, have been found to vary from 2.1 to 3.0 with most values in the 2.1-2.6 range (Clark, 1963; McCracken, 1963; Templeman, 1963). Furthermore, Treschev and Stepanov (1968) found that selection factors for redfish taken in trawls made of synthetic twine are about 25% higher than for manila. These results indicate that a selection factor of about 2.5 may be a reasonable approximation for redfish taken in synthetic codends. Applying this selection factor to the mesh sizes of codends (64, 102 and 130 mm) commonly used in the fishery in 1976 and 1977 gives 50% retention lengths of 16, 25 and 32 cm. The 64-mm mesh is used almost exclusively by the Portland and Rockland vessels which accounted for over 61% of the USA redfish catch in these 2 years. The larger mesh sizes were used by Gloucester and Boston vessels which caught redfish while fishing for other groundfish species. The estimated 50% retention lengths indicate that the 1971 year-class of redfish was vulnerable to trawls with mesh sizes up to 102 mm during 1976 and 1977.

The extent to which the 1971 year-class was selected in 1977 was estimated by comparing the proportion of age 6 redfish in the spring research survey with that in the commercial catch. This year-class accounted for 44% of all individuals in the survey and 40% in the commercial catch. Furthermore, 46% of all males in the survey were age 6 compared with 51% in the catch. The higher proportion of age 6 males in the catch was probably due to sampling variation inherent in survey catch per tow data rather than to selective fishing practices. In any case, the proximity of both estimates indicate these males were similarly selected by both commercial trawls and the small-meshed research trawl.

Age 6 females accounted for only 25% of the females landed in 1977, although they represented 43% of the Gulf of Maine population of females. In the offshore areas, where 74% of the catch was taken, age 6 females accounted for only 21% of the female population and 14% of the females landed. In the inshore areas, however, these females accounted for 66% of the female population and 48% of the females landed. The percentages of age 6 males indicate similar but less exaggerated differences between the inshore and offshore areas in 1977. These trends and the evidence for increase in size of redfish with depth imply an inshore to offshore movement associated with size and age. Although the survey results show approximately equal representation of age 6 redfish of both sexes in all parts of the Gulf of Maine during the spring of 1977, young males far outnumbered young females in the commercial catches, further indicating that the offshore movement occurs at an earlier age in males than in females. The length composition of commercial catches in 1978 indicates that both males and females of the 1971 year-class were fully recruited to the exploitable stock. If, as Kelly and Barker (1961) suggested, redfish spawning occurs over the deeper basins (>180 m) of the Gulf of Maine, the offshore population of large adults may constitute the spawning stock to which the younger redfish are recruited from the shallower inshore areas.

Davis and Taylor (MS 1957) considered that recruitment of Gulf of Maine redfish to the fishing grounds was complete by age 8. The present study suggests that recruitment of the 1971 year-class was complete for males and females at ages 6 and 7 respectively. Davis and Taylor (MS 1957) also hypothesized that redfish, upon first recruiting to the fishing grounds, spend considerable time in a pelagic state, and that the proportion of time spent on or near the bottom increases with age until age 14. The ascending limbs of the catch curves for ages 7-14 (Fig. 10) tend to support this hypothesis. The high values at

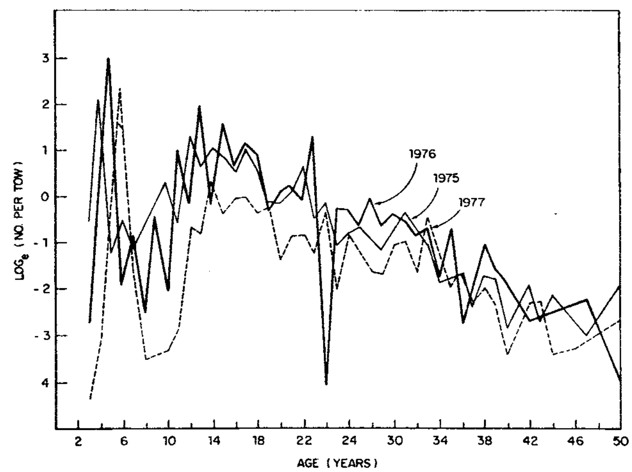

Fig. 10. Catch surves derived from number per tow at age of redfish in the spring bottom trawl surveys in the Gulf of Maine, 1975-77.

ages 4, 5 and 6 in 1975, 1976 and 1977 respectively represent the abundant 1971 year-class. However, it is possible that these younger fish were as available to the research trawl as the older fish and that the low values at ages 5-11 in Fig. 10 were the result of poor year-classes during 1965-70. All available commercial and research data indicate that this was true and that the 1971 year-class in 1978 was fully available to the otter trawl and full recruited to the fishery. Therefore, the only contribution of this year-class to the fishable biomass in the future will be through growth of individual fish.

Growth

In the past, considerable controversy has surrounded the question of redfish growth. Kotthaus (1958) considered that the growth rate of redfish was not very different from that of most fish species. However, several researchers, among them Perlmutter and Clarke (1949), Bratberg (1956), Kelly and Wolf (1959) and Sandeman (1961, 1969), have contributed substantial evidence supporting the hypothesis that redfish are long-lived, slow-growing fish, presently a widely-held tenet of redfish biology.

Perlmutter and Clarke (1949) noted that redfish in the Gulf of Maine and on Browns Bank (Div. 4X) grew at an average rate of 2.5 cm per year up to age 9. Sandeman (1961) reported a slightly higher rate of growth based on length frequencies and otolith age determinations of small redfish from Hermitage Bay, Newfoundland. A similar time series of length frequencies of small redfish from the Gulf of Maine research surveys is evident in Fig. 6 beginning in 1971. The average annual increment in modal length of these fish up to age 7 in 1978 is 3.00 cm, a value slightly less than the annual increment of 3.25 cm exhibited by Sandeman's (1961) series of length frequencies. The mean lengths at age of young redfish, calculated from age-length keys of research samples taken in 1975-77, agree quite closely with these observed modal lengths.

The estimated growth parameters based on the ageing of more than 3,000 redfish from research surveys in 1975-77 (Table 3) are within the range of previously reported results for *mentella*-type redfish from the Grand Bank area and the Gulf of St. Lawrence (Sandeman, 1969) and agree with values calculated from data presented by Kelly and Wolf (1959) for the Gulf of Maine. The calculated growth curves (Fig. 11) indicate similar growth rates for both sexes up to age 6, beyond which females tended to be larger than males at each age. Redfish sampled from the inshore areas exhibited higher L_{∞} and lower K values than those taken from the offshore areas (Table 3), but these differences may be due to the disproportionate numbers of ages 4-6 fish (74% for males and 64% for females) in the inshore samples rather than to real differences in growth. Analysis of the data with each age-group weighted equally indicates no significant differences in the growth parameters for redfish from inshore and offshore areas. Therefore, the von Bertalanffy growth curves for the combined inshore and offshore samples may be considered as representative of redfish growth in the Gulf of Maine.

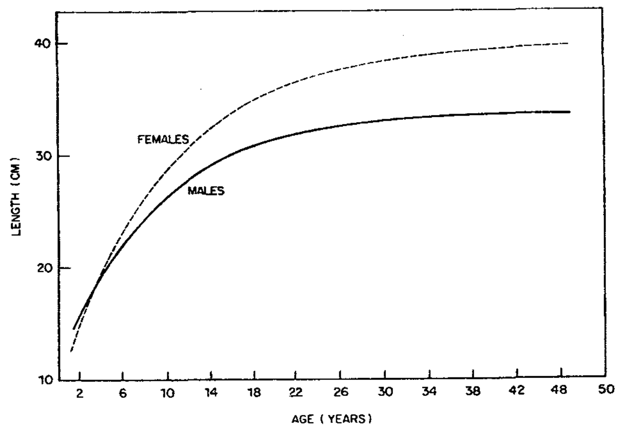

Fig. 11. Von Bertalanffy growth curves for redfish, based on data from the research surveys in the Gulf of Maine, 1975-77.

TABLE 3. Von Bertalanffy growth parameters (± 1 standard error) for redfish sampled from research surveys in the Gulf of Maine, 1975-77, and estimates from the data of Kelly and Wolf (1959).

		L_{∞} (cm)	K	t_0 (yr)	N
Inshore	Male	37.47 ± 1.40	0.0760 ± 0.0113	-5.50 ± 1.04	333
	Female	40.91 ± 1.05	0.0899 ± 0.0098	-3.42 ± 0.65	349
	Combined	39.20 ± 0.81	0.0902 ± 0.0077	-3.49 ± 0.50	697
Offshore	Male	33.45 ± 0.25	0.1203 ± 0.0065	-3.30 ± 0.38	1,077
	Female	39.66 ± 0.24	0.1135 ± 0.0043	-2.07 ± 0.24	1,356
	Combined	37.67 ± 0.25	0.1063 ± 0.0042	-2.92 ± 0.26	2,489
Total	Male	33.82 ± 0.26	0.1133 ± 0.0057	-3.41 ± 0.35	1,410
	Female	39.84 ± 0.25	0.1029 ± 0.0039	-2.27 ± 0.22	1,705
	Combined	37.80 ± 0.24	0.1049 ± 0.0037	-2.88 ± 0.22	3,186
Kelly and Wolf (1959)		41.60 ± 1.30	0.0927 ± 0.0069	-0.19 ± 0.18	

Mortality

Total instantaneous mortality coefficients (Z) of 0.11 and 0.13 were estimated from catch curves based on the research survey data (Fig. 10) and commercial age compositions (Fig. 9) for the 1975-77 period (Table 4). Slightly higher estimates of Z (0.16 for survey, 0.22 for commercial) were obtained when only the indices for age-groups up to age 25 were used in the calculations. Similarly, a catch curve based on length and age data for commercial samples in 1953 (from Kelly and Wolf, 1959) yielded Z = 0.27 for ages 10-18.

Mortality estimates for individual year-classes, based on both the research and the commercial data, were generally higher than those derived from catch curves, a likely event since Z appears to have been increasing throughout the time series. The estimates for individual year-classes (Table 4) are comparable with previous estimates of 0.38-0.52 for Gulf of Maine redfish (Beverton and Hodder, eds. 1962). A recently estimated Z of 0.40 for Scotian Shelf redfish (Mayo and Miller, 1976) is also within this range. The year-class estimates of Z based on research data are subject to extreme variation because of temporal variability inherent in the bottom trawl survey data. However, these values and those based on commercial data (Table 4B) are probably closer to the current level of Z than the values derived from the catch curves (Table 4A).

TABLE 4. Estimates of total instantaneous mortality (Z) for all fully-recruited age-groups and for fully-recruited age-groups to age 25, based on (A) catch curves and (B) average of individual year-classes from research survey and commercial data for Gulf of Maine redfish, 1975-77.

		All ages	Ages $\leq$ 25
A	Survey	0.11	0.16
	Commercial	0.13	0.22
B	Survey	0.30	0.50
	Commercial	0.22	0.38

Given the long life-span of redfish, the average value of Z would be expected to be quite low. The effect of various levels of Z on a hypothetical cohort was simulated by calculating the probability of an individual fish living for 44 years, after entering the fishery at age 6, according to the formula:

$$P = e^{-Zt} = S^t$$

where P is the probability of a fish surviving to age t (44 years) from an initial cohort of 1 million fish, and S is the annual survival rate (Table 5). These calculations imply that, for values of Z greater than 0.3, the probability of survival to age 50 after entering the fishery at age 6 is quite low compared with the relatively large number of ages 40-50 redfish in the population in 1975-77 (Fig. 10). In view of the very slow growth and long life-span of redfish, it is evident that the current level of Z is at or above that which could be sustained throughout a 40-year exploitable life-span of a year-class. In fact, the estimates of Z for the more recent year-classes (0.38-0.50) are probably well above the maximum. The similarity of these estimates of Z to that for the early 1950's [0.27 from the data of Kelly and Wolf (1959)] indicates that, after 2 decades of lower values, the total mortality has now risen to or above the level which existed after the initial period of high exploitation in the late 1940's. The catch and effort data listed in Table 1 seem to support this contention.

TABLE 5. Survival rate (S), probability of survival (P) and number of fish surviving to age 50, from a cohort of 1,000,000 fish entering the fishery at age 6, for various levels of Z.

Z	S	P	Number surviving
0.50	0.606	2.68×10^{-10}	0.0003
0.38	0.684	5.53×10^{-8}	0.06
0.30	0.741	1.87×10^{-6}	2
0.22	0.803	6.42×10^{-5}	64
0.16	0.852	8.70×10^{-4}	870
0.11	0.896	7.97×10^{-3}	7,972

The expected low value of Z required to sustain a redfish fishery implies that the instantaneous natural mortality rate (M) must be extremely low, a logical assumption in view of the long life-spain of this species. This tends to support the previous assumption of Mayo and Miller (1976) that M is about 0.1, in contrast to the proposal by Chekhova *et al.*, (MS 1977) that M for *mentella*-type redfish is 0.25.

Yield per recruit

Yield-per-recruit calculations for Gulf of Maine redfish are based on the parameters listed in Table 6. The yield isopleths (Fig. 12) with M = 0.1 indicate that the maximum yields per recruit of 90 g for males and 117 g for females are achieved at extremely high values of F (>1.0) and at recruiting ages of 9 and 10 years respectively. These ages correspond with the ages at

TABLE 6. Parameters used in the yield-per-recruit calculations for Gulf of Maine redfish.

Parameter	Male	Female
Fishing mortality, F	0.02 - 1.00	0.02 - 1.00
Natural mortality, M	0.05, 0.1	0.05, 0.1
Maximum weight, W_{∞} (g)	502.7	839.7
Growth coefficient, K	0.1133	0.1029
Arbitrary origin of growth curve, t_0 (yr)	-3.4082	-2.2663
Length-weight exponent, b	3.132	3.132
Age at recruitment, t_ρ (yr)	0.5	0.5
Mean selection age, $t_{\rho'}$ (yr)	2.0 - 18.0	2.0 - 18.0
Maximum age, $t\lambda$ (yr)	50.0	50.0

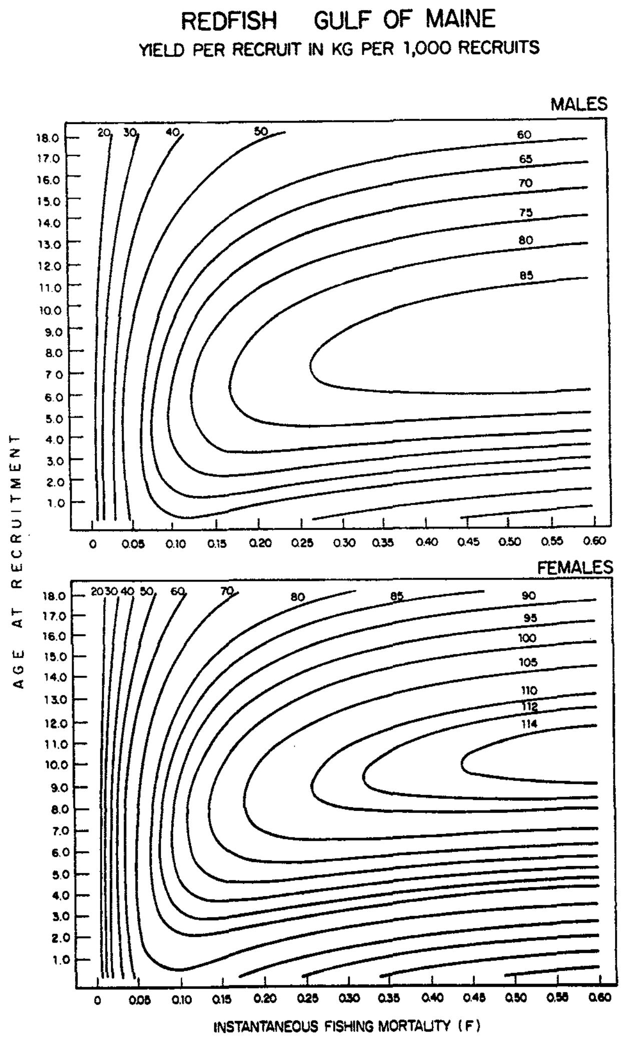

Fig. 12. Yield isopleths for Gulf of Maine redfish, assuming M = 0.1 for both males and females. (Yield-per-recruit values in kg per 1,000 recruits.)

first maturity, as stated by Perlmutter and Clarke (1949).

Transverse sections through the isopleths for M = 0.1 (Fig. 12) and M = 0.05 (not illustrated) at recruiting ages corresponding to the 50% retention lengths of the various mesh sizes used in the fishery result in values of conditional maximum yield per recruit, F_{max} (fishing mortality corresponding to the calculated maximum yield per recruit), and $F_{0.1}$ (see Gulland and Boerema, 1973) listed in Table 7. For M = 0.1, the highest yield per recruit is achieved through using 102 and 114 mm mesh sizes for males and females respectively. It is evident that smaller meshes would result in only moderate yield-per-recruit levels but at relatively low F_{max} values, and the largest mesh size would produce high yields only at high levels of F. Chekhova and Konstantinov (MS 1979) similarly concluded that a 102-mm mesh would maximize yield per recruit for redfish on the Flemish Cap (Div. 3M). However it should be noted that this is based on an assumption of M = 0.25.

For M = 0.05, substantially higher yields per recruit are achieved at lower F_{max} values and higher levels of age at recruitment (Table 7). For males, the maximum yield per recruit is 160 g for F_{max} of 1.0 at a recruiting age of 13 years. For females, the maximum yield per recruit is 230 g for F_{max} greater than 1.0 at a recruiting age of 15 years. The conditional maximum yield-per-recruit values are also higher at all recruiting ages than the corresponding values for M = 0.1. Additionally, the associated F_{max} and $F_{0.1}$ values are considerably less.

Except for the curve representing the lowest age at recruitment, the conditional yield-per-recruit curves for M = 0.1 are all flat-topped with sharply ascending left limbs, indicating minor losses in yield as F is reduced from the F_{max} level. In fact, 90–95% of maximum yield per recruit can be achieved at levels of

TABLE 7. Estimates of maximum yield per recruit, F_{max} and $F_{0.1}$ at two levels of M, corresponding to the mesh sizes commonly used in the Gulf of Maine redfish fishery in 1976 and 1977.

Sex	Mesh size (mm)	Mean age at recruitment (yr)	M = 0.10 Max. Y/R (g)	M = 0.10 F_{max}	M = 0.10 $F_{0.1}$	M = 0.05 Max. Y/R (g)	M = 0.05 F_{max}	M = 0.05 $F_{0.1}$
Male	64	2.1	68.7	0.16	0.18	113.7	0.08	0.05
	76	3.8	76.3	0.22	0.10	124.1	0.10	0.06
	89	5.9	84.0	0.40	0.12	136.4	0.14	0.07
	102	8.8	89.1	1.00+	0.14	149.3	0.24	0.08
	114	13.0	82.0	1.00+	0.18	159.5	0.92	0.10
	130	21.4	48.1	1.00+	0.22	142.3	1.00+	0.13
Female	64	2.7	84.4	0.14	0.07	155.0	0.08	0.05
	76	4.0	92.6	0.16	0.09	166.3	0.08	0.05
	89	5.7	101.5	0.24	0.10	180.4	0.10	0.06
	102	7.6	110.0	0.42	0.12	195.8	0.14	0.07
	114	10.0	115.9	1.00+	0.14	211.6	0.20	0.08
	130	13.3	112.3	1.00+	0.17	225.6	0.44	0.10

F between 0.2 and 0.3 when the age at recruitment is 7 years for males and 9 years for females. However, for M = 0.05, only those curves representing the highest ages at recruitment are flat-topped. At the lower recruiting ages, the F_{max} values are less than 0.3 and the $F_{0.1}$ values generally less than 0.1 (Table 7). Since the age composition results for 1975–77 indicate that substantial numbers of 1971 year-class of redfish were caught at ages 4, 5 and 6 (Fig. 9) and presumably also at age 7, it is evident that the use of small-meshed codends has resulted in a loss of potential yield from this year-class, particularly if M is as low as 0.05.

The tendency of redfish to mesh in the codend and other parts of the trawl was noted by Templeman (1963). However, because this effect is generally confined to redfish in the 95–100% segment of the selection curves, the interpretation of yield per recruit in terms of mesh size is not substantially altered.

Equilibrium yield

Because of the increased need to limit exploitation on various redfish stocks in the Northwest Atlantic, use of the generalized stock production model (Pella and Tomlinson, 1969) for estimating maximum sustainable yield has become a common practice (Pinhorn and Parsons, MS 1974; Parsons and Parsons, 1975; Mayo, MS 1975, MS 1976; Mayo and Miller, 1976; Parsons *et al.*, 1976; McKone and Parsons, MS 1977; Gavaris, MS 1979; Mayo *et al.*, MS 1979; McKone, MS 1979). In the absence of a suitably long time series of age composition data needed for analytical assessment, the general availability of historical catch and effort data for many stocks enables the technique to be applied. However, a number of serious objections has been raised concerning this approach to stock assessment studies, and several methods have been proposed to refine parameter estimation and fitting techniques (Walter, 1975; Schnute, 1977; Rivard and Blesdoe, 1978; Fletcher, 1978a, 1978b). Equilibrium approximation procedures, as described by Gulland (1961) and later refined by Fox (1975), do not appear to be effective when disequilibrium of the stock exists, such as during the initial phase of the Gulf of Maine fishery. Furthermore, for a slow-growing, long-lived species such as redfish, in which long delays between spawning and subsequent recruitment of a year-class to the fishery are common, departures from equilibrium will persist for long periods. Therefore, the catch and effort data pertaining to the initial "fishing up" phase of the fishery have not been used in this analysis.

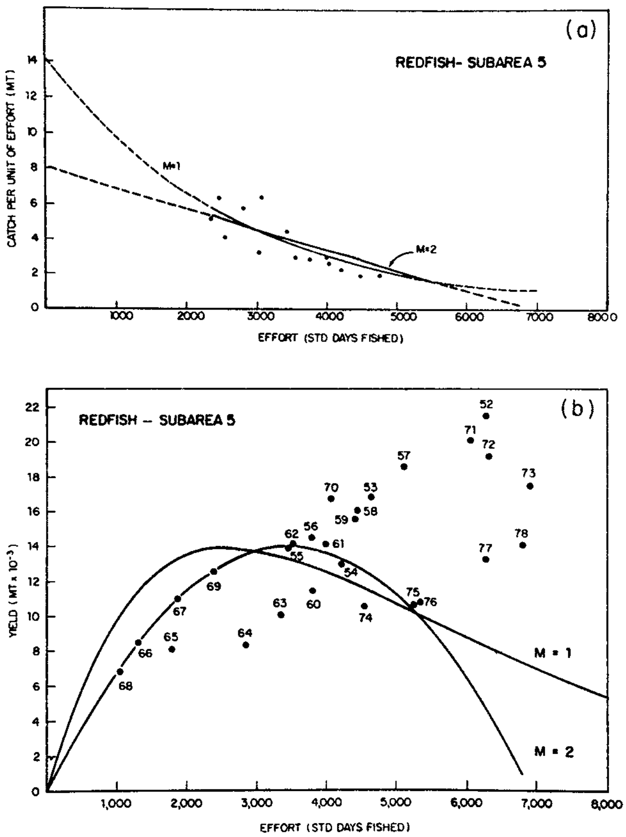

Fig. 13 (A). Regression of CPUE on effort derived from the general production model analysis, for m = 1.0 and 2.0, with effort averaged over 12 years.

(B). Yield curves from the general production model analysis, for m = 1.0 and 2.0, with effort averaged over 12 years.

Another serious deficiency in using the generalized production model is the resultant spurious correlation of CPUE and fishing effort values derived from CPUE indices, especially when averaging techniques are employed (Sissenwine, 1978; Roff and Fairbairn, MS 1979). However, as a technique which allows interpretation of current levels of catch and effort with an historical perspective, the generalized production model retains some degree of utility. Therefore, the standardized CPUE data have been analyzed to evaluate the current effort level in terms of historical patterns (Fig. 13).

The exponential (m = 1.0) and logistic (m = 2.0) models produce similar estimates of maximum sustainable yield (Table 8), but at different levels of effort (f_{MSY}). Both models also indicate that fishing

TABLE 8. Estimates of MSY (tons), f_{MSY} (standard days fished) and U_{opt} (catch per day) from the generalized production model analyses (Fig. 13B).

Parameter	Gompertz m = 1.0	Logistic m = 2.0
Maximum sustainable yield (MSY) (tons)	13,818	14,020
MSY effort (f_{MSY})	2,614	3,460
Optimum CPUE (U_{opt})	5.29	4.05
Residual sum of squares	0.664	0.848
Correlation coefficient	0.77	0.71

effort in recent years, as well as in the late 1950's and early 1970's, has been well above the MSY level. Previous estimates of f_{MSY}, derived from exponential models utilizing unadjusted effort for the 1952–74 period (Mayo, MS 1975, MS 1976), are similar to the present results. Thus, the use of standardized effort in the model does not seriously alter the final estimates of MSY. However, when the standardized effort values for each of the years since 1952 are superimposed on the calculated yield curves (Fig. 13B), the stock is shown to have been severely over-exploited in terms of real effort since 1970. This effect has been obscured by recent increases in fleet efficiency and does not become apparent until this trend is taken into account.

The age composition results indicate that recruitment to the Gulf of Maine fishery has been highly variable over the last 25 years, and, therefore, the assumption of a stable age structure has not been met. In view of the present dependence of the fishery on a single, relatively young year-class, the estimated MSY must be interpreted with caution. However, the effect of environmentally-induced fluctuations and of delays between changes in production and changes in stock size are somewhat diminished by the equilibrium approximation technique.

It is evident that the redfish population has oscillated beyond the near-equilibrium condition which appears to have existed in the late 1960's when the age structure was more balanced, with a number of year-classes from the 1950's and early 1960's supporting the fishery. The increase in catch and effort in the early 1970's and the lack of any substantial year-classes between 1963 and 1971 have produced an unstable population dominated by the single 1971 year-class. Between 1971 and 1976, the nominal catch declined by about 50% with an accompanying decrease in effort of only 25%. By 1978, the effort had again reached the level of the early 1970's, but the yield was only about two-thirds of the level in the early 1970's. The calculated effort of 7,042 standard days fished for 1978 is about 2.7 times higher than the estimated f_{MSY} level derived from the generalized production model, although the actual catch is approximately equal to the MSY.

Walter (1976) concluded that fishing at the estimated MSY level of effort on a non-equilibrium population which has been greatly reduced below the virgin biomass level will only lead to a continued reduction in stock size. Both Doubleday (1976) and Sissenwine (1977) noted that, in the presence of environmentally-induced fluctuations in recruitment, the annual yield from a stock must be considerably less than the estimated long-term average yield (MSY) in order to ensure stability of the population. In fact, Doubleday (1976) suggested that setting the fishing effort at a level which corresponds to an equilibrium biomass of two-thirds of the virgin stock biomass will provide a suitable buffer for maintaining stability without greatly reducing the yield. Walter's (1976) method for determining the maximum yield which will allow for potential recovery of the stock was applied to the results obtained from the exponential model (Fig. 13B), using the catch and standardized effort data for 1975–78. The results indicated that the maximum annual yields at f_{MSY} and two-thirds f_{MSY} are 5,200 and 3,500 tons respectively.

Conclusions

The current annual yield in the Gulf of Maine redfish fishery is approximately one-quarter of that obtained during the initial period of exploitation. Fishing effort, which gradually declined until the late 1960's, has steadily increased during the 1970's, but the CPUE, which increased during the 1960's, has steadily declined.

The generalized production model analyses indicate an MSY of about 14,000 tons at an effort level of about 2,600 days fished, but these results must be interpreted with caution due to non-equilibrium. Although this estimated MSY is similar to the long-term average annual yield achieved between 1953 and 1969, the present CPUE values indicate that the stock biomass is now well below the earlier level, implying that there has been a substantial increase in fishing mortality concomitant with the increase in effort during the 1970's. This has resulted in a reduction in the population below the equilibrium level at which it had apparently stabilized during the 1950's and early 1960's.

Recruitment to this fishery has been extremely poor since 1963, the only strong year-class to appear being that of 1971. Prospects for future recruitment, as indicated by the results of bottom trawl surveys to 1978, also appear to be poor. Therefore, since the 1971 year-class is now fully recruited to the fishery, the only potential increase in fishable biomass during the next several years will be through growth of these relatively young individuals.

The yield-per-recruit results indicate that considerable loss in yield occurs when the age at recruitment is below 7–9 years. Therefore, some loss in potential yield from the 1971 year-class has already resulted from the capture of these fish in 1976 and 1977, and possibly in 1978.

All of the evidence indicates that the Gulf of Maine redfish population will soon be dominated by the single 1971 year-class and that the fishery will become increasingly dependent on this year-class. Consequently, the stock will continue to decline if fishing effort is maintained at the present high level.

Acknowledgements

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