An Assessment of the Gulf of Maine Redfish, *Sebastes marinus* (L.), Stock in 1978

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Laboratory Reference No. 79-20
May 1979

INTRODUCTION

Redfish, <u>Sebastes marinus</u> Linnaeus, in the Gulf of Maine (ICNAF Subarea 5) have been commercially exploited since the mid-1930's when freezing techniques were developed to market the catch. Landings increased from 519 metric tons (MT) in 1934 to a maximum of 59,796 MT 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 MT annually.

This decline in Gulf of Maine landings coincided, in the mid-1940's, with a rapid expansion of fishing activity to the more distant grounds off Nova Scotia, in the Gulf of St. Lawrence, and on the Grand Banks. This period of expansion culminated in a peak USA redfish catch from all areas combined of 126,954 MT in 1951. Since then, however, the fishery has been contracting as the fleets continue to rely on fishing grounds closer to their home ports. In 1978, out of a total USA redfish catch of 16,131 MT, 13,984 MT were taken from 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 between 1973 and 1977. A total allowable catch (TAC) of 30,000 MT in effect for 1973 and 1974 was lowered to 25,000 MT in 1975. However, after an initial assessment (Mayo 1975) indicated a substantially lower surplus yield, the TAC was again decreased to 17,000 MT in 1976. Further analysis (Mayo 1976) suggested that a greater reduction would be required to allow for rebuilding of the stock and the 1977 TAC was set at 9,000 MT. However, since early 1977, no redfish regulatory measures have been in effect.

The present study re-examines historical catch and effort data for the Gulf of Maine redfish fishery in terms of standard vessel classes. In addition, recent age data are used to calculate growth and mortality rates and to assess the impact of the commercial fishery on the newly recruited 1971 year class.

BIOLOGY AND DISTRIBUTION

Distribution

At least two species of redfish, *Sebastes viviparous* Krøyer, and *S. marinus* Linnaeus, are believed to inhabit the North Atlantic (Templeman 1959; Mead and Sindermann 1961; Kelly et al., 1961). *S. viviparous*, a smaller, shallow water species, is found only in the eastern North Atlantic from East Greenland to the Norwegian coast, while *S. marinus* inhabits deeper water on both sides of the North Atlantic from the North Sea to Greenland and south 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.

Taxonomy

Considerable controversy surrounds the taxonomic status of *S. marinus*. Two types have been identified, a large-eyed deep water form possessing a sharp lower jaw protuberance (Travin 1951) termed the *mentella* type and the relatively shallow water *marinus* type having a rounded protuberance (Templeman 1959). Travin ascribed the former to a separate species, *S. mentella*, to distinguish it from *S. marinus*, while Andriiashev (1954) described the *mentella* form as a subspecies, *S. marinus mentella* Travin. Given 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 1961). However, the evidence of Kotthaus does suggest a clear separation between S. viviparous and the various types of S. marinus. The current taxonomic status of S. marinus is undecided and, consequently, most authors refer to the variations as S. marinus, mentella type and S. marinus, marinus type.

In the Northwest Atlantic, the marinus type has been found generally in the northernmost regions and, in some cases, in the shallower water as far south as the northern slope of the Grand Banks (Templeman 1959). In this region, the mentella redfish are found in deeper water usually in excess of 300 meters. On most of the Grand Banks, and in waters to the west and south, the mentella type predominates at all depths forming the basis of the commercial fisheries from Georges Bank to the Grand Banks (Mead and Sindermann 1961). Thus, the common name redfish in this paper refers to S. marinus, mentella type.

Biology

Redfish are relatively slow growing, long-lived animals (Kelly and Wolf 1959; Sandeman 1969); hence the natural mortality rate is quite low. Ages in excess of 50 years (Calvin - Debaie 1964) and maximum sizes of 45-50 cm have been noted.

According to Perlmutter and Clarke (1949), redfish in the Gulf of Maine reach sexual maturity in about nine years, at an average length of 22 to 23 cm. Redfish are viviparous, retaining eggs in the ovary after fertilization until yolk sac absorption. Mating is thought to take place in the autumn with subsequent larval extrusion occurring the following spring and summer (Templeman 1959). Larvae remain pelagic for about 4.5 months, after which they move to the bottom at an average length of 50 mm (Kelly and Barker 1961). Detailed treatment of these and other aspects of redfish biology may be found in Sorokin (1961), Steele (1957), Magnusson (1955), and Trout (1961).

COMMERCIAL FISHERY

Fishery Trends

As stated previously, redfish stocks in the Northwest Atlantic began to be exploited consistently in the mid-1930's. The initial harvest was limited to the Gulf of Maine with a small amount of effort devoted to the Nova Scotian Banks. When the Gulf of Maine catch peaked and began to decline in 1941, more effort was diverted to the Nova Scotian Shelf, the Gulf of St. Lawrence, and the Grand Banks (Figure 1). This period of rapid initial expansion continued until 1951 when the USA harvested 126,954 MT of redfish from all areas combined. Since then, the USA catch off Canada has continued to decline while the Gulf of Maine catch has remained relatively stable. In 1978 the USA harvested 16,131 MT of redfish of which 13,984 MT were taken from the Gulf of Maine - Georges Bank area.

Although the USA fishery within this region has been relatively steady in recent years, the total historical catch records reveal three distinct periods of exploitation (Table 1, Figure 2). The first period, from 1935 to 1952, was characterized by a rapid increase and subsequent decline in catch as the large accumulated virgin stock was exploited. The second period, from 1952 to 1966, showed a relatively steady decline in USA catch and effort and the beginning of exploitation by distant water fleets. The third, most recent period is similar to the first, but on a smaller scale, as the catch exhibited a modest increase and decline chiefly in response to increased distant water fleet catches in the early 1970's (Table 1). The highest level of foreign harvest occurred in 1972 when 5,938 MT out of a Subarea 5 total of 19,095 MT were taken by countries other than USA. The foreign catch has since decreased to 204 MT in 1977.

Traditionally, ICNAF Division 5Y has accounted for the greatest share of the Subarea 5 harvest (Table 2). The highest catches have been attained in the vicinity of Cashes and Fippinies Ledge and Jeffreys Bank located in the central basin of the Gulf (Kelly et al. 1972). Division 5Z has traditionally been of less importance, generally accounting for 10 to 20 percent of the USA harvest. However, this area has accounted for the major share of the distant water fleet catch (Table 2). Most of the 5Z redfish are caught in the northern part of the Great South Channel. In assessing the Gulf of Maine fishery, we have treated the 5Y and 5Z data as one unit.

The ports of Portland and Rockland, Maine, and Gloucester, Massachusetts, have traditionally accounted for almost all of the redfish landings. In recent years, the importance of Boston, Massachusetts, as a redfish port has increased with current landings averaging about 1,000 MT annually.

This fishery exhibits a distinct seasonal exploitation pattern as illustrated by the 1964-1977 monthly catch and effort summary presented in Figure 3. It is evident that the spring months from March to June are of greatest importance. Since 1964, these four months have accounted for 48 percent of the redfish catch and 45 percent of the directed redfish trips; that is, those trips in which redfish comprise over 50 percent of the total landed weight. As would be expected, the catch per unit of effort (CPUE) is also highest during this period (Mayo 1975).

By-catch

The redfish fishery generally accounts for very little by-catch of other species. For example, between 1964 and 1978, over 70 percent of the redfish taken from the Gulf of Maine was landed on trips in which redfish comprised over 85 percent of the total landed weight. However, these trips accounted for less than 17 percent of the total trips in which redfish were taken.

A rather small proportion of the redfish landings is taken in the other fisheries. Most of this redfish by-catch is presumably taken by vessels engaged in groundfish activities. Discarding of small redfish has also been noted in recent years in the Gulf of Maine northern shrimp fishery, but the amount has not been determined. Substantial discards were reported during the early 1970's when a relatively strong year class of redfish began to appear.

Effort

Between 1964 and 1968, the number of directed redfish trips in the Gulf exhibited a substantial decline. Since then, however, this number has once again risen to former levels chiefly as a result of increased fishing activity by larger vessels greater than 150 gross registered tons (GRT) (Mayo 1975). From the early 1940's through the mid-1960's over 70 percent of the redfish landings from the Gulf of Maine was taken by vessels in the 50-150 GRT range. Since then smaller vessels have decreased fishing activity and new, larger ones have become dominant to the point where, in 1978 over 67 percent of the Gulf of Maine catch was landed by vessels greater than 150 GRT. Figure 4 illustrates the shift in the proportion of redfish landed by various sized vessels. In 1964, as in previous years, the majority of the catch was taken by vessels in tonnage groups 31-33 (50-150 GRT). Starting in 1966, and continuing through the later years, vessels in tonnage groups 41-43 (150-500 GRT) began accounting for a greater share of the redfish harvest. This shift in the size composition of the fleet has had a profound effect on the overall CPUE index since the larger vessels usually have higher catch rates than the smaller ones (Mayo 1975). This difference may be due to a number of factors including greater hold capacity, more powerful engines capable of pulling larger trawls, and the ability to make longer trips to more productive grounds. The following section deals with methods designed to account for the change in the overall fleet fishing power.

Commercial CPUE Index

Individual trip records from the Gulf of Maine fishery from 1942 to 1977 were examined for trends in catch and effort. The unadjusted CPUE index, based on all directed redfish trips using otter trawls from the ports of Portland, Rockland, and Gloucester, is expressed as the ratio of total redfish landings to total days fished for these selected trips. A day fished is defined as 24 hours of actual fishing time with the net on the bottom. However, since redfish are fished only during daylight hours due to their diurnal migratory habits, the effort figures were doubled before being divided into the landings to approximate a 12-hour fishing day. The annual total directed effort was estimated by dividing the total annual catch by the corresponding USA CPUE value for each year (Table 3).

The CPUE data reveal a gradual decline from the early 1940's to the early 1960's, followed by a sharp rise and subsequent decline (Table 3, Figure 2). Nominal effort remained high during the initial period, dropped steadily until the late 1960's, and finally rose during the early 1970's.

The apparent fluctuations in CPUE are due to a number of causes in addition to probable changes in redfish abundance. The shift in size composition of the redfish fleet, and the introduction of electronic echo sounding gear in the 1950's has affected the fleet's ability to capture redfish. To account for the effect of both of the above confounding influences, we have divided the catch and effort data set into three segments (Table 3). In the first segment, prior to 1952, the raw CPUE index was not adjusted since there was no shift in vessel size composition and negligible use of echo sounding gear. During the second segment, from 1952 to 1963, we adjusted for the increase in fleet efficiency caused by the gradual introduction of the echo sounding gear. It was estimated (K. Smith, personal comm.) that the echo sounding gear would increase overall fleet efficiency by a factor of about 40 percent. Conversion of the entire fleet was assumed to be complete by 1963 and, due to increased efficiency, a 40 percent increase in real effort to have gradually taken place during the 12-year period (May and Miller 1976). The expression e^{kt} (Halliday and Doubleday 1976) was used to adjust the CPUE index in each year such that the adjusted CPUE decreased by a constant percentage every year for each of the 12 years, yielding a corresponding increase in real adjusted effort. A k of 0.0274 (a 2.74 percent decrease per year) resulted in an adjusted decline of 39 percent in effective CPUE after 12 years. This adjustment was then applied to the CPUE index for each year since 1964 in addition to the following adjustment for the shift in vessel size composition.

As stated previously, during the third segment, from 1964 to present, a major change in vessel size composition occurred, resulting in a higher proportion of large vessels landing redfish than had previously existed. To account for this, the CPUE of each of the vessel tonnage groups (Table 4) was calculated for each year. These indices were calculated in the same manner as the previous index except that all ports were used and the days fished were not doubled. To approximate vessels which had traditionally fished in the Gulf of Maine, we chose vessels in tonnage groups 31-33 (50-150 GRT) as the standard against which all other tonnage groups were adjusted. This group has also appeared in all years throughout this segment. A linear regression using annual values of the CPUE of each tonnage group against the combined 31-33 tonnage group index was performed forcing the intercept through the origin (Table 4, Figure 5). Analysis of residuals reveals 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. The CPUE data in Table 4 show declining catch rates for most vessel categories in the more recent years. The effect of this time trend on relative catchability of these vessels is currently under investigation. The slope of the line, calculated as $b = \Sigma XY/\Sigma X^2$ (Steel and Torrie 1960), is used as an expression of the fishing power of each vessel tonnage group in terms of the standard. The fishing power coefficients were multiplied by the corresponding effort of each tonnage group for each year, the adjusted effort and catch were summed, and a new CPUE index was calculated and adjusted for the effect of the echo sounding gear. The methods described above, in effect, relate all CPUE indices to the period prior to 1952. The adjusted indices, listed in Table 3 in the column labelled STD US CPUE, were divided into the total catch to estimate total standard days fished.

Figure 2 graphically portrays the differences between the raw and adjusted CPUE indices and the resulting calculated effort. These results suggest that actual effort is severely underestimated, especially in recent years, when raw CPUE indices are used. The rather large increase in apparent CPUE in the late 1960's is shown to be generally a result of dominance of the large, more efficient vessels in the fishery. The implications of using adjusted CPUE data in the production models will be discussed in a later section.

Despite differences in magnitude, recent trends revealed by the raw and adjusted CPUE data are similar. Both sets of indices show maximum values during the period 1966-1969 followed by a steady decline through 1975. By 1976 this trend appears to have ceased, and a slight increase is noted in 1977 and 1978.

The use of 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 the 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 standardized CPUE values exhibited in the 1966-1969 period to those during the 1941-1943 period at considerably different levels of catch and effort supports this hypothesis. Rather than indicating similar levels of abundance over the whole Gulf of Maine, these results suggest that abundance within certain exploited aggregations may have been at similar levels, and that the number of such pockets under recent exploitation is substantially reduced.

It may be concluded that overall redfish abundance in the Gulf may decrease while fleet CPUE remains high through identification and exploitation of the remaining productive pockets of fish. A decline in the CPUE index, however, similar to that which occurred in the 1970's, probably indicates both a decrease in the number of aggregations and a decline in the abundance of fish within these pockets.

SIZE COMPOSITION

Research Survey Trends

Research vessel survey data for the Gulf of Maine from 1963 to 1978 were grouped by inshore (<111 m) and offshore (>111 m) strata sets to examine trends in abundance and size composition. Stratified catch per tow indices (Table 5) show current abundance levels to be substantially below that which existed in the mid-to-late 1960's in both the inshore and offshore areas. However, a slight increasing trend is evident in the most recent years. This pattern is similar to that exhibited by the commercial CPUE data. Relatively high abundance of smaller redfish (12-22 cm) is typical of the inshore strata, while offshore areas are dominated by fish in the 28-36 cm range (Figure 6). For example, the spring 1977 survey indicates that over 80 percent of the redfish in the inshore strata were less than 28 cm. In the offshore strata, however, only 24 percent were less than this size.

An increase in size of redfish with increasing depth has been recognized by several authors (Hennemuth and Brown 1964; Gulland 1965; McKone 1979; Chekhova and Konstantinov 1979). Major and Shippen (1970) cited similar evidence for the closely related Pacific Ocean perch, *Sebastes alutus*. Hennemuth and Brown (1964) found statistically significant differences in 25th, 50th, and 75th centile lengths of redfish from four depth zones ranging from 57 to 370 m. In the Gulf of Maine, they found modal length differences as large as 7 to 8 cm between 57 and 278 m. These results suggest either an extremely large variation in growth rates or a shift in age composition of the population with depth. If the latter is true, an inshore to offshore movement associated with age is implied. The inshore areas may, therefore, represent nursery grounds, and the length frequency distributions from these areas may be useful as pre-recruit indicators.

Three separate modal groups of small redfish are evident in the inshore length composition time series (Figure 6), one increasing in size from 1963 to 1965, a second between 1966 and 1969, and a third beginning in 1971. Age/length keys from 1975 through 1977 research cruises confirm the presence of relatively strong year classes in 1953, 1963, and 1971, and a number of moderately strong year classes in the late 1950's. The year classes from the late 1950's and 1963 are responsible for the large number of 12-22 cm redfish present in the survey data in the mid-to-late 1960's. Since 1963, only the 1971 year class has shown evidence of above-average strength.

Commercial Length Frequencies

The average length of redfish in the USA commercial landings from the Gulf of Maine decreased sharply in 1976 and 1977 (Figure 7), reversing a trend which began in the mid-1960's (Mayo 1975). The fact that little or no decrease in average size occurred during the early period of initial expansion and stabilization of the fishery (1937-1964) supports the hypothesis of successive exploitation of a series of smaller stock units within each of the major fishing areas (ICNAF 1962). A series of sharp declines, evident in Figure 7, probably indicate periods of above-average recruitment; the two most distinct periods are 1960-1964 and 1976-1977.

Changes in average length, however, will not always identify recruitment patterns, especially in the case of redfish where a large number of fully recruited year classes may be present in the landings. Commercial length frequency plots from 1965-1978 (Figure 8) and those from 1958-1964 (Brown and Hennemuth 1965) depict these patterns more precisely. Despite the large number of year classes, the plots tend to display only one or two dominant modes due to the slow growth of the species. However, new recruits can be seen as a secondary mode of smaller fish varying between 18 and 22 cm. The years in which strong recruitment occurred in this fishery are 1960-1962, 1965-1968, and 1976-1977. The most distinct mode in both the survey and commercial data is that formed by the 1971 year class. The progression of this mode affords an excellent opportunity to study recruitment patterns and to validate early growth estimates. These patterns are explored in greater detail in the following sections.

CATCH COMPOSITION

Numbers at Age

Numbers at age in the commercial catch from 1975 through 1977 (Table 6) were calculated using commercial length frequency data and research survey age/length keys. Six age/length keys, one from the spring and autumn cruise in each of the three years, were applied to semi-annual estimates of numbers landed by length. All ages greater than 25 were combined with age 25, and the resulting summary with sexes combined is presented in Figure 9. Three dominant year classes, 1953, 1963, and 1971, prevail in each of the years for which the age composition was calculated. These year classes account for the increases in recruitment noted in the previous section. In 1976 and 1977, the 1971 year class contributed 8,736,200 and 14,276,700 fish, respectively, or 31 and 38 percent of the total annual number landed. In terms of total weight, however, this contribution was considerably less.

Recruitment Patterns

According to Beverton and Holt (1957), recruitment, in its more fundamental sense, denotes the entry of fish to the exploited area where they first become liable to encounters with the gear. Although the redfish fishery is conducted throughout the Gulf of Maine, over 74 percent of the catch is taken from the deeper offshore areas. It is here that encounters with fishing gear are more probable. It has already been noted that the 1971 year class contributed substantially to the catch beginning in 1976; therefore, the age at first capture in the directed redfish fishery is less than 5 years. By this time, many of the individuals of this year class had grown to a size where they could be captured by the commercial gear.

Manila mesh selection studies published by a number of authors (Clark 1963; McCracken 1963; Templeman 1963) have indicated that selection factors for redfish vary from 2.1 to 3.0 with most in the order of 2.1 to 2.6. Further, Treschev and Stepanov (1968) have found that selection factors for synthetic twine are about 25 percent higher than for manila. These results suggest that a selection factor of about 2.5 may be a reasonable approximation for synthetic cod end meshes.

In 1976 and 1977, the dominant cod end mesh sizes used in the redfish fishery were 64, 102, and 130 mm. Assuming a selection factor of 2.5, the 50 percent retention lengths for these meshes are 16, 25, and 32 cm. The 64 mm mesh is used almost extensively by the Portland and Rockland vessels which accounted for over 61% of the redfish catch during these two years. The larger meshes were used by the Gloucester and Boston vessels which caught redfish presumably during groundfish fishing activities. The calculated 50% retention lengths suggest that 1971 year-class redfish, in 1976 and 1977, were selected by mesh sizes up to 102 mm. Thus, it can be assumed that this year class was vulnerable to a considerable amount of the commercial gear in both years.

The extent to which the 1971 year class was selected in 1977 was determined by comparing the proportion of age 6 redfish in the spring survey with that in the commercial landings. In 1977 this year class accounted for 44% of all individuals in the survey and 40% in the landings. Further, 46% of all males in the survey were age 6 compared to 51% in the catch. The higher proportion of these males in the catch is probably due to the precision of sampling rather than selective fishing practices. Despite this, the proximity of both estimates is evidence that males at this age were equally selected by both commercial nets and the small mesh survey gear.

The age 6 females, however, represented 43% of the overall 1977 female Gulf of Maine population but accounted for only 25% of the female landings. 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 for age 6 males show similar, but less exaggerated differences between the inshore and offshore areas in 1977.

These trends and the increase in size with depth suggest an inshore to offshore movement associated with size and age. Although survey results show approximately equal representation of 6-year old fish of both sexes over the whole Gulf of Maine during the spring of 1977, young males far outnumbered young females in the commercial landings, further suggesting that these males had moved offshore, mixing with the larger adults. The age 6 females, however, appear to have lagged behind the males in initiating this offshore movement. The 1978 commercial length composition results suggest that both males and females of the 1971 year class were fully recruited. If, as Kelly and Barker (1961) suggest, redfish spawning occurs over the deeper basins (>183 m) of the Gulf, the offshore population of large adults may constitute the spawning stock to which younger redfish are recruited from the shallower inshore areas.

Davis and Taylor (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 males and females was complete by ages 6 and 7, respectively. Davis and Taylor also hypothesized that, as redfish first recruit to the fishing grounds, they spend considerable time in a pelagic state, and that the proportion of time spent on the bottom increases with age until age 14. The ascending limb of the catch curves (Figure 10) based on 1975-1977 spring bottom trawl surveys would tend to support this hypothesis except for the presence of the 1971 year class seen here as age 4, 5, and 6 fish. An alternate explanation is that these younger fish are as available to bottom gear as the older fish and that the ascending limb of the catch curve is caused by extremely poor year classes in the middle and late 1960's. All available commercial and survey data suggest that this is the case. Under this hypothesis, the 1971 year class in 1978 is considered fully available to bottom gear and fully 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 AND MORTALITY

Growth Rates

In the past, considerable controversy has surrounded the question of redfish growth rates. Although it has been suggested that redfish do not differ from most other species in their rate of growth (Kotthaus 1958), a number of authors have contributed substantial evidence supporting the hypothesis that redfish are extremely long-lived, slow growing fish (Perlmutter and Clarke 1949; Bratberg 1956; Kelly and Wolf 1959; Sandeman 1961, 1969). Today, this assumption is a widely held tenet of redfish biology.

Perlmutter and Clarke (1949) noted that growth of young redfish proceeded at an average rate of 2.5 cm per annulus up to age 9 both in the Gulf of Maine and on Browns Bank, while Sandeman (1961) reported a slightly higher rate of growth based on length frequencies and examination of otoliths of small redfish samples off Newfoundland. A similar time series of small length frequencies based on Gulf of Maine research cruises is presented in Figure 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 3.25 cm annual increment exhibited by Sandeman's series. The mean lengths at age of young redfish, calculated from the research cruise age/length keys from 1975 through 1977, agree quite closely with these observed modal lengths.

Estimation of adult growth parameters was accomplished by fitting 3,186 individual length at age observations to the von Bertalanffy growth equation for males and females separately, and for the sexes combined. All calculations were performed by the computer program, BGC-2 (Tomlinson and Abramson 1961). The estimated growth parameters (Table 7) are within the range of previously reported results for _mentella_ type redfish from the Grand Banks and Gulf of St. Lawrence (Sandeman 1969), as well as the values calculated from the data presented by Kelly and Wolf (1959) for the Gulf of Maine.

The calculated lengths at age (Figure 11) suggest similar growth rates for both sexes up to age 6; after this, females tend to be larger than males at each age. Redfish sampled from the inshore strata exhibit higher L_∞ and lower K values than those taken from the offshore areas (Table 7). These differences, however, are probably caused by the disproportionate number of 4, 5, and 6-year old fish (74 percent for males, 64 percent for females) in the inshore samples, rather than real differences in growth. When the samples are analyzed with equal weights given to each age group, the inshore and offshore parameter estimates do not show significant differences. Although preliminary, these results do not indicate any substantial differences in growth between the inshore and offshore areas and, hence, the von Bertalanffy estimates based on the combined inshore and offshore samples may be considered as representative of redfish growth in the Gulf of Maine.

Mortality

Instantaneous total mortality coefficients (Z) were estimated from 1975-1977 spring research survey numbers per tow (Table 8) for each of the year classes between 1931 and 1972 (Table 9). The average Z of all year classes from 1933 to 1963 is 0.30. For the more recent year classes (1951-1963), the average Z is 0.50.

The difference between these two estimates is indicative of the increase in the amount of effort expended during the late 1960's and early 1970's, since the fishery at this time was based primarily on year classes from 1953, the late 1950's and 1963. Also since the catches were considerably less than those attained during the 1940's and early 1950's, a substantial decline in population size is implied.

It should also be noted that extremely high Z values were estimated for the relatively poor 1966-1969 year classes. The low estimate of Z for the 1971 year class occurred because these fish were not fully recruited to bottom gear until 1976. The estimated Z for this year class from 1976 to 1977, however, is 0.64. These results suggest that relatively high mortality rates in the order of 0.50 were applied to those year classes which supported the fishery during the recent period of increased exploitation.

Mortality estimates were also determined from catch curves derived from survey numbers per tow (Figure 10) and from the estimated number of fish landed in the commercial fishery by age for the years 1975 through 1977 (Table 6). Slopes were calculated by regressing $\log_e$ number vs. age starting with the 1963 year class, since the year classes from 1964 through 1970 were poorly represented in both survey and commercial catches and the 1971 year class was not fully recruited until 1977. The survey and commercial data yield similar Z values of 0.11 and 0.13, respectively, when all ages are analyzed. Slightly higher estimates of Z (0.16, survey; 0.22, commercial) were obtained when only younger (<25 years) fish were included in the calculations. Similarly, a catch curve based on 1953 commercial length frequencies and a 1953 age/length key presented by Kelly and Wolf (1959) yielded a Z of 0.27 for ages 10 through 18. These estimates are substantially lower than those based on individual year classes, an expected result since Z has been increasing throughout the time series.

The Z values based on the individual year classes, especially those from 1951-1963, are, therefore, more indicative of the current level of mortality in the Gulf of Maine redfish stock. These are comparable to previous estimates which ranged from 0.38 to 0.52 (ICNAF, 1961). A recently estimated Z of 0.40 (Mayo and Miller 1976) for Scotian Shelf redfish is also within this range.

Given the long lifespan of redfish, the average value of Z would be expected to be quite low. To put the preceding estimates of Z in perspective, the probability of an individual fish living for 44 years, after entering the fishery at age 6, was calculated according to the formula:

$$p = (e^{-Zt}) = S^t.$$

where:

p = the probability,

t = 44 years

S = annual survival rate

Z = instantaneous mortality rate

The number of fish surviving to age 50 from an initial cohort of one million fish entering the fishery at age 6 was also calculated (Table 10). From these comparisons, it is evident that Z values in excess of 0.22-0.30 could not be sustained throughout the fish's 44 year exploitable lifespan. It is also clear that the current level of Z (0.50) is well above that which could be sustained by a year class for an extended period. It may be concluded from the number of older fish in the population that, since the early 1970's, when the nominal catch exceeded 20,000 MT annually, the instantaneous fishing mortality rate (F) has been considerably above the expected long-term average.

The relatively low expected average Z values imply that the instantaneous natural mortality rate (M) must be extremely low for redfish, a logical assumption given the long lifespan of this species. This tends to support previous assumptions of M equal to 0.1 (Mayo and Miller 1976), in contrast to the proposal by Chekhova et al. (1977) that M for mentella type redfish is 0.25.

Yield Per Recruit

Yield isopleth diagrams (Figure 12) were constructed using the Paulik and Gales (1964) model based on the preceding growth rate estimates and an assumption of natural mortality equal to 0.1. A list of all parameters used in the yield per recruit calculations can be found in Table 11. Maximum yield per recruit of 90 gms for males and 117 gms for females is achieved at extremely high values of F (>1.0) beyond that illustrated in Figure 12, at an age at recruitment of 9 and 10 years, respectively. This also corresponds with the age at first maturity as stated by Perlmutter and Clarke (1949).

Transverse sections were taken through the isopleths at selected age at recruitment values which correspond to the 50 percent retention lengths of the various mesh sizes utilized in the fishery. The resulting conditional maximum yield per recruit, F_{max}, and $F_{0.1}$ values are listed in Table 12. The highest yield per recruit is achieved using the 102 and 114 mm mesh sizes for males and females, respectively. Chekhova and Konstantinov (1979) similarly concluded that a 102-mm mesh would maximize yield per recruit in the Flemish Cap redfish stock. It is also evident that the smallest meshes will permit only modest yield per recruit levels, although at relatively low F_{max} values. Similarly, the largest meshes produce high yields only at high levels of F.

The tendency of redfish to mesh in the cod end and wings has been noted (Templeman 1963). However, since this effect is generally confined to redfish which are in the 95 to 100 percent segment of the selection curves, the interpretation of yield per recruit in terms of mesh size is not substantially altered.

Except for the lowest age at recruitment levels, the conditional yield per recruit curves are flat-topped with sharply ascending lower limbs, indicating minor losses in yield when F is reduced from the F_{max} level. In fact, 90 to 95 percent of maximum yield per recruit can be achieved at levels of F between 0.2 and 0.3 when the age at recruitment is 7 years for males and 9 years for females. Similarly, the $F_{0.1}$ values presented in Table 12, are all less than or equal to 0.2, even for the highest age at entry.

Since the age composition results indicate that substantial numbers of 1971 year-class redfish have been caught at ages 5, 6, and 7, it is evident that the use of small mesh gear has resulted in a loss of potential yield from this year class.

Equilibrium Yield Models

The relationship between catch and effort for the years 1952 through 1978 was examined using the Generalized Production Model of Pella and Tomlinson (1969). Data 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. Since the catch and effort data represent transitional states, the weighted average effort method proposed by Fox (1975) was employed to approximate equilibrium conditions. The recent age composition results suggest that redfish contribute substantially to the catch at least to age 25 and, excluding the 1971 year class, they first appear in considerable numbers at ages 12 to 14. Therefore, a 12-year averaging period was chosen.

Regressions of standardized CPUE (Table 3) on average effort (Figure 13a) were accomplished according to the PRODFIT method of Fox (1975). The CPUE data were fitted with the parameter, m fixed at 1.0 and 2.0 to approximate the shapes of the Gompertz exponential (Fox 1970) and logistic (Schaeffer 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.

The logistic and exponential models produce similar estimates of maximum sustainable yield, but at considerably different levels of optimum effort (Table 13). Both models also reveal that effort in recent years, as well as during the late 1950's and early 1970's, has been well above the MSY level.

Previous estimates of optimum effort derived from exponential models utilizing unadjusted effort for the 1952-1974 time period (Mayo 1975, 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 points for each of the years since 1952 are superimposed on the calculated yield curve (Figure 13b), the fishery 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.

Although we recognize that regressions of CPUE on effort derived from CPUE indices may lead to spurious correlations (Sissenwine 1978), especially when averaging techniques are applied, lack of another suitable approach for estimating total directed redfish effort necessitated the use of this method. The age composition results indicate that recruitment to the Gulf of Maine fishery has been highly variable over the last 25 years; thus, 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 should be interpreted with caution. The effect of environmentally induced fluctuations and delays between changes in production and changes in stock size have been somewhat diminished, however, by the equilibrium approximation technique.

It is now evident that the population has oscillated beyond the near-equilibrium conditions which seemed to exist 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 has 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 percent. By 1978, the effort had once again reached the level of the early 1970's, but the yield was only at about two-thirds of the early 1970's peak. The 1978 calculated effort of 6,821 standard days fished is about 2.6 times higher than the estimated f_{msy} level derived from the production model, although the catch is approximately equal to the estimated MSY.

Walter (1976) concluded that fishing at the estimated MSY effort level in a nonequilibrium population that has been severely reduced below the virgin biomass level will only lead to continued reductions in stock size. It has been further noted (Doubleday 1976; Sissenwine 1977) that, in the presence of environmentally induced fluctuations in recruitment, the annual yields must be considerably less than the estimated long-term average yield (MSY) in order to insure stability of the population. Doubleday (1976) suggested that setting fishing effort at a level which corresponds to an equilibrium biomass of two-thirds the virgin stock biomass will provide a suitable buffer for maintaining stability without severely reducing 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 yield model (Figure 13b) using the most recent catch and effort points (1975 through 1978). At f_{msy}, the maximum annual yield is approximately 5,200 MT and at two-thirds f_{msy}, the yield is 3,500 MT.

CONCLUSIONS

Recent annual landings from the Gulf of Maine - Georges Bank region, after reaching a peak in the early 1970's, declined to approximately 10,000 MT and have subsequently risen to about 14,000 MT in 1978. Commercial CPUE and bottom trawl survey catch per tow indices have been steadily declining since the late 1960's. Equilibrium yield models indicate that MSY is in the order of 14,000 MT; but, given the current low population abundance, catches should be held substantially below the MSY level.

Recruitment to this fishery since the early 1960's has been extremely poor. Since 1963, the only strong year class to enter the fishery is the 1971 cohort. Prospects for good future recruitment, as indicated by bottom trawl survey results through 1978, also appear to be poor. Therefore, since the 1971 year class is now fully recruited to the fishery, the only near term increase in fishable biomass will be through growth of these relatively young individuals.

The estimated mortality rate on the 1971 year class as well as on those which have supported the fishery since the late 1960's, is considerably higher than the expected long-term average.

All of the evidence suggests that the Gulf of Maine redfish population will soon be dominated by the single 1971 year class, and that the fishery is becoming increasingly dependent on this year class. Given these conditions, it is evident that the current effort and mortality rate will result in further stock declines.

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Table 1. Nominal catch of redfish by country from ICNAF Subarea 5 (metric tons, live).

Year	Canada	USSR	Poland	Other non-US	Total non-US	USA	Subarea 5 Total
1934						519	519
1935						7549	7549
1936						23162	23162
1937						14823	14823
1938						20640	20640
1939						25406	25406
1940						26762	26762
1941						59796	59796
1942						55892	55892
1943						48348	48348
1944						50439	50439
1945						37912	37912
1946						42423	42423
1947						40160	40160
1948						43631	43631
1949						30743	30743
1950						34307	34307
1951						30077	30077
1952						21377	21377
1953						16791	16791
1954						12988	12988
1955						13914	13914
1956						14388	14388
1957						18490	18490
1958	4				4	16043	16047
1959						15521	15521
1960	2				2	11373	11375
1961	50	11			61	14040	14101
1962	3	1590			1593	12541	14134
1963	89	1086			1175	8871	10046
1964	56	445			501	7812	8313
1965	68	968	25	10	1071	6986	8057
1966	420	939	6		1365	7204	8569
1967	194		215	13	422	10442	10864
1968	197			2	199	6578	6777
1969	260	15	56	83	414	12041	12455
1970	338		30	839	1207	15534	16741
1971	269	3394	84	20	3767	16267	20034
1972	124	5639	1	174	5938	13157	19095
1973	35	5240	28	103	5406	11954	17360
1974	59	1705	2	28	1794	8677	10471
1975	59	1368	1	69	1497	9075	10572
1976	186	379			565	10131	10696
1977	204				204	13005	13209
1978					-	13984	13984

Table 2. Nominal catch of redfish from ICNAF divisions 5Y and 5Z (metric tons, live).

	5Y			5Z			Subarea 5
Year	U.S.	Other	Total	U.S.	Other	Total	Total
1954	11561	-	11561	1427	-	1427	12988
1955	11132	-	11132	2782	-	2782	13914
1956	10678	-	10678	3710	-	3710	14388
1957	14471	-	14471	4019	-	4019	18490
1958	13900	4	13904	2143	-	2143	16047
1959	12438	-	12438	3083	-	3083	15521
1960	9321	2	9323	2052	61	2052	11375
1961	12457	-	12457	1583	1593	1644	14101
1962	10196	-	10196	2345	1131	3938	14134
1963	6785	44	6829	2086	499	3217	10046
1964	6137	2	6139	1675	1020	2174	8313
1965	5045	51	5096	1941	1073	2961	8057
1966	4719	292	5011	2485	347	3558	8569
1967	6746	75	6821	3696	177	4043	10864
1968	4062	22	4084	2516	386	2693	6777
1969	9640	28	9668	2401	1048	2787	12455
1970	13551	159	13710	1983	3466	3031	16741
1971	12541	121	12662	3726	5844	7192	20034
1972	7150	94	7244	6007	5395	11851	19095
1973	7001	11	7012	4953	1751	10348	17360
1974	5457	43	5500	3220	1487	4971	10471
1975	5961	-	5971	3114	563	4601	10572
1976	7989	2	7991	2142	204	2705	10696
1977	9848	-	9848	3157	-	3361	13209
1978	11352	-	11352	2632		2632	13984

Table 3. US and total redfish catch, CPUE (metric tons, live) and effort (days fished) for ICNAF Subarea 5.

Year	US Catch	US CPUE	STD US CPUE	Calculated STD US Effort	Total Catch	Calculated Total STD Effort
1942	55892	6.9	6.9	8100	55892	8100
1943	48348	6.7	6.7	7216	48348	7216
1944	50439	5.4	5.4	9341	50439	9341
1945	37912	4.5	4.5	8425	37912	8425
1946	42423	4.7	4.7	9026	42423	9026
1947	40160	4.9	4.9	8196	40160	8196
1948	43631	5.4	5.4	8080	43631	8080
1949	30743	3.3	3.3	9316	30743	9316
1950	34307	4.1	4.1	8368	34307	8368
1951	30077	4.1	4.1	7336	30077	7336
1952	21377	3.5	3.4*	6287	21377	6287
1953	16791	3.8	3.6	4664	16791	4664
1954	12988	3.4	3.1	4190	12988	4190
1955	13914	4.5	4.0	3478	13914	3478
1956	14388	4.4	3.8	3786	14388	3786
1957	18490	4.3	3.6	5136	18490	5136
1958	16043	4.4	3.6	4456	16047	4458
1959	15521	4.3	3.5	4435	15521	4435
1960	11373	3.8	3.0	3791	11375	3792
1961	14040	4.6	3.5	4011	14101	4029
1962	12541	5.4	4.0	3135	14134	3533
1963	8871	4.1	3.0	2957	10046	3349
1964	7812	4.3	2.9**	2604	8313	2867
1965	6986	7.0	4.5	1552	8057	1790
1966	7204	11.7	6.5	1092	8569	1318
1967	10442	12.4	5.8	1740	10864	1873
1968	6578	14.7	6.4	997	6777	1059
1969	12041	11.4	5.2	2272	12455	2395
1970	15534	9.0	4.1	3613	16741	4083
1971	16267	7.0	3.3	4784	20034	6071
1972	13157	5.7	3.0	4386	19095	6365
1973	11954	5.3	2.7	4427	17360	6930
1974	8677	5.0	2.3	3615	10471	4553
1975	9075	4.0	2.0	4538	10572	5286
1976	10131	4.6	2.0	5066	10696	5348
1977	13005	4.9	2.1	5911	13209	6290
1978	13984	4.8	2.05	6821	13984	6821

* 1952-1963 catch/effort data were divided by e^{kt} where $k = .0274$ to reflect a 2.74% increase in vessel efficiency per year between these years. Thus, in 1952, $t=1$ and in 1963 $t=12$.

** 1964-1978 catch/effort were standardized against tonnage class 31, 32, and 33 vessels before the e^{kt} adjustment to account for changes in vessel size composition of the U.S. redfish fleet.

Table 4. Redfish catch per day fished (metric tons) by tonnage group for the Gulf of Maine fishery. STD = tonnage groups 31, 32, 33

Year	STD		24	25	41	42	43	44
1964	8.70		6.42	6.48	10.22	14.57	-	-
1965	13.13		5.39	10.56	17.59	19.38	-	-
1966	17.83		3.91	20.70	26.54	39.91	-	-
1967	16.13		4.31	9.53	24.60	35.10	35.10	-
1968	4.63		22.68	2.27	27.62	42.16	34.89	-
1969	14.13		11.60	3.60	24.75	27.47	24.03	34.42
1970	11.37		6.96	5.98	18.33	24.67	22.86	32.95
1971	10.16		5.02	8.60	14.83	15.95	18.72	34.60
1972	8.78		5.02	6.89	12.45	16.43	17.66	24.10
1973	8.55		2.92	3.96	10.83	13.70	15.20	16.16
1974	8.06		13.84	7.90	8.82	12.02	11.54	13.86
1975	5.95		6.06	3.81	8.28	10.96	13.44	8.30
1976	6.31		2.61	2.33	8.43	11.89	10.71	10.46
1977	7.58		-	6.79	9.23	11.45	11.35	12.15
		Σx^2	1570.14	1627.60	1627.60	1627.60	1061.60	779.99
		Σxy	898.03	1181.44	2471.98	3270.18	2180.75	1881.49
		b	0.572	0.726	1.519	2.009	2.054	2.412
		n	13	14	14	14	11	9

Table 5. Stratified mean catch per tow indices for Subarea 5 redfish from autumn research bottom trawl cruises. (wt./tow in kg).

Year	Inshore[1] strata		Offshore[2] strata		Total[3] Subarea 5	
	No./tow	wt./tow	No./tow	wt./tow	No./tow	wt./tow
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

Stratified mean catch per tow indices for Subarea 5 redfish from spring research bottom trawl cruises. (wt./tow in kg).

Year	Inshore strata[1]		Offshore strata[2]		Total Subarea 5[3]	
	No./tow	wt./tow	No./tow	wt./tow	No./tow	wt./tow
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

[1]Strata 26, 27, 39, 40.

[2]Strata 24, 28-30, 36-38.

[3]Strata 24, 26-30, 36-40.

From 1968 to 1972, a #36 Yankee trawl was used for the spring cruises. From 1973 to present, a #41 Yankee trawl was used. No attempt was made to correct for differences in fishing power.

Table 6. Estimated numbers of redfish (100's) landed in the USA commercial fishery in ICNAF Subarea 5 during the period 1975-1977.

	1975		1976		1977	
	Male	Female	Male	Female	Male	Female
2					31	
3	52		84		-	
4	6113	14	2334	678	446	16
5	905	14	65001	22361	6836	2425
6	-	380	381	496	104217	38550
7	523	570	687	454	1894	929
8	-	-	507	-	-	208
9	-	-	679	1471	-	-
10	1290	4286	679	-	-	810
11	2141	1757	7829	6934	-	299
12	13344	12563	2396	993	4877	6261
13	5670	5591	19918	15815	5920	8001
14	6912	9392	546	2322	17953	16231
15	6211	6930	7548	12179	8592	8978
16	4616	7420	7558	5115	10516	11303
17	6799	8942	6167	10066	7822	9083
18	3534	7018	3828	7064	3789	6038
19	2796	2348	846	4635	4151	6404
20	2545	3486	3043	2078	1721	2654
21	3132	2719	1786	3782	2862	4488
22	8427	4149	1040	2085	3292	2919
23	1530	3151	5298	9078	2276	1590
24	2666	3550	-	48	6628	5584
25	1687	1618	533	2703	*20128	*33411
26	1744	1921	1324	1211		
27	1287	2354	1920	4005		
28	371	517	1314	2291		
29	1212	1196	1594	1136		
30	2056	1400	585	2325		
31	1662	2356	349	1383		
32	2235	1573	1005	1236		
33	1054	1863	1684	2081		
34	486	516	-	750		
35	493	476	1182	269		
36	745	522	971	612		
37	-	1133	-	824		
38	207	356	307	297		
39	623	419	757	482		
40	66	338	559	1378		
41	376	22	433	-		
42	-	1355	-	831		
43	74	22		1160		
44				253		
45			421	133		
46		56				
47		276	10			
48						
49						
50+	182	1350		48		
Total	95766	105919	153103	133062	213951	166282

*In 1977 all fish 25 years and older were grouped with age 25.

Table 7. Von Bertalanffy growth parameters (±1 S.E.) estimated from 1975-1977 research cruise data for Gulf of Maine redfish.

	L_∞	K	t_0	N
Gulf of Maine (Total)				
males	33.82 ± 0.26	0.1133 ± 0.0057	-3.4082 ± 0.3477	1410
females	39.84 ± 0.25	0.1029 ± 0.0039	-2.2663 ± 0.2185	1705
combined	37.80 ± 0.24	0.1049 ± 0.0037	-2.8840 ± 0.2217	3186
Gulf of Maine (Inshore)				
males	37.47 ± 1.40	0.0760 ± 0.0113	-5.4969 ± 1.0370	333
females	40.91 ± 1.05	0.0899 ± 0.0098	-3.4211 ± 0.6521	349
combined	39.20 ± 0.81	0.0902 ± 0.0077	-3.4948 ± 0.5009	697
Gulf of Maine (Offshore)				
males	33.45 ± 0.25	0.1203 ± 0.0065	-3.3022 ± 0.3824	1077
females	39.66 ± 0.24	0.1135 ± 0.0043	-2.0692 ± 0.2380	1356
combined	37.67 ± 0.25	0.1063 ± 0.0042	-2.9177 ± 0.2634	2489
Gulf of Maine (Kelly and Wolf 1959)				
combined	41.60 ± 1.30	0.0927 + 0.0069	-0.1896 ± 0.1789	

Table 8. Redfish number per tow at age and natural log from spring 1975-1977 research cruises in the Gulf of Maine (inshore and offshore strata and sexes combined).

Age	1975		1976		1977	
	No/tow	$\log_e$	No/tow	Log_e	No/tow	Log_e
3	0.557	-0.59	0.066	-2.72	0.012	-4.42
4	8.184	2.10	1.275	0.24	0.041	-3.19
5	0.286	-1.25	21.014	3.05	0.834	-0.18
6	0.588	-0.53	0.143	-1.94	11.085	2.41
7	0.313	-1.16	0.435	-0.83	0.220	-1.51
8			0.086	-2.45	0.029	-3.54
9			0.624	-0.47	-	
10	1.335	0.29	0.135	-2.00	0.035	-3.35
11	0.553	-0.59	2.581	0.95	0.057	-2.86
12	3.527	1.26	0.905	-0.10	0.511	-0.67
13	1.744	0.56	6.956	1.94	0.432	-0.84
14	2.697	0.99	0.814	-0.21	1.321	0.28
15	2.275	0.82	4.662	1.54	0.659	-0.42
16	1.625	0.49	1.925	0.65	0.915	-0.09
17	2.699	0.99	3.152	1.15	0.937	-0.07
18	1.785	0.58	2.464	0.90	0.697	-0.36
19	0.842	-0.17	0.675	-0.39	0.770	-0.26
20	0.842	-0.17	1.051	0.05	0.242	-1.42
21	1.051	0.05	1.182	0.17	0.417	-0.87
22	1.865	0.62	0.906	-0.10	0.422	-0.86
23	0.583	-0.54	3.238	1.17	0.283	-1.26
24	0.819	-0.20	0.017	-4.07	0.779	-0.25
25	0.125	-2.08	0.758	-0.28	0.333	-1.10
26	0.427	-0.85	0.731	-0.31	0.433	-0.84
27	0.492	-0.71	0.503	-0.69	0.278	-1.28
28	-		0.913	-0.09	0.192	-1.65
29	0.305	-1.19	0.500	-0.69	0.180	-1.71
30	0.454	-0.79	0.660	-0.42	0.350	-1.05
31	0.692	-0.37	0.574	-0.56	0.364	-1.01
32	0.502	-0.69	0.408	-0.90	0.187	-1.68
33	0.332	-1.10	0.486	-0.72	0.601	-0.51
34	0.156	-1.86	0.163	-1.81	0.287	-1.25
35	-		0.462	-0.77	0.130	-2.04
36	0.177	-1.73	0.060	-2.81	0.185	-1.69
37	0.087	-2.44	0.150	-1.90	0.091	-2.40
38	0.170	-1.77	0.316	-1.15	0.134	-2.01
39	0.164	-1.81	0.193	-1.65	0.096	-2.34
40	0.054	-2.92	0.137	-1.99	0.031	-3.47
41	-		-		0.055	-2.90
42	0.144	-1.94	0.063	-2.76	0.096	-2.34
43	0.065	-2.73			0.097	-2.33
44	0.109	-2.22			0.031	-3.47
45						
46					0.035	-3.35
47	0.046	-3.08	0.100	-2.30		
48						
49						
50+	0.132	-2.02	0.017	-4.07	0.66	-2.72

Table 9. Regression parameters and estimates of total instantaneous mortality, Z(-b), for Gulf of Maine redfish during the period 1975-1977 (calculated from Table 8 data).

Year class	r^2	a	b
1972	0.24	-0.59	0.21
1971	0.10	2.21	0.16
1970	0.14	-1.31	-0.13
1969	0.82	1.38	-1.51
1968*	1.00	0.13	-1.29
1967*	1.00	2.41	-2.88
1966*	1.00	-1.14	-0.86
1965	0.35	1.51	-0.48
1964	0.11	-0.26	-0.13
1963	0.34	2.14	-0.49
1962	0.90	0.96	-0.49
1961	0.42	1.89	-0.54
1960	0.89	1.36	-0.45
1959	0.32	1.28	-0.43
1958	0.80	1.79	-0.63
1957	1.00	1.59	-1.00
1956	0.53	0.37	-0.35
1955	0.43	0.40	-0.35
1954	0.83	0.87	-0.66
1953	0.37	1.38	-0.44
1952	0.02	-1.34	-0.28
1951	0.84	0.20	-0.32
1950	0.20	-2.02	0.40
1949	0.60	-0.26	0.40
1948	0.37	0.16	-0.50
1947*	1.00	-0 33	-0.36
1946	0.05	-1.05	0.09
1945	0.57	-0.12	-0.45
1944	0.06	-0.45	-0.07
1943	0.79	-0.33	-0.28
1942	0.92	-0.71	-0.47
1941	0.02	-1.61	0.09
1940*	1.00	-3.22	0.41
1939	0.98	-1.60	-0.14
1938	0.01	-2.08	0.05
1937	0.70	-0.60	-0.85
1936	0.87	-1.14	-0.55
1935*	1.00	-3.50	0.58
1934*	1.00	-3.19	0.43
1933*	1.00	-0.41	-1.53
1932	-	-	-
1931*	1.00	-1.09	-1.13
1930			

*2 point regressions, all other regressions are 3 point

Table 10. Survival rate (S), probability of survival (P) and number of fish surviving to age 50, out of a cohort of 1,000,000 fish entering the fishery at age 6, for various levels of Z.

Z	S	P	Number/1,000,000
0.50	0.606	2.68×10^{-10}	3×10^{-4}
0.38	0.684	5.53×10^{-8}	6×10^{-2}
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}	7972

Table 11. Parameters used in yield per recruit calculations for Gulf of Maine redfish.

	Males	Females
F	0.02 - 0.60	0.02 - 0.60
tp'	2.0 - 18.0	2.0 - 18.0
b	3.132	3.132
W_∞(kg)	0.5181	0.8916
M	0.1	0.1
K	0.1133	0.1029
t_o	-3.4082	-2.2663
t_p	0.5	0.5
t_λ	50.0	50.0

Table 12. Maximum yield per recruit and F_{max} values corresponding to predominant cod end mesh sizes used in the Gulf of Maine redfish fishery in 1976 and 1977.

Mesh size (mm)	Mean age at recruitment	Maximum Y/Rec (gm)	F_{max}	$F_{0.1}$
		Males		
64	2.1	69.9	.16	.08
76	3.8	77.5	.24	.10
89	5.9	85.1	.42	.12
102	8.8	90.0	1.00+	.14
114	13.0	81.9	1.00+	.18
130	21.4	47.7	1.00+	.20
		Females		
64	2.7	84.4	.14	.07
76	4.0	92.6	.16	.09
89	5.7	101.5	.24	.10
102	7.6	110.0	.42	.12
114	10.0	115.9	1.00+	.14
130	23.3	112.3	1.00+	.17

Table 13. Estimates of Y_{max} (metric tons), f_{opt} (standard days fished), and U_{opt} from the General Production Model with 12-year average effort from 1952 to 1978.

	Gompertz M = 1.0	Logistic M = 2.0
Maximum Sustainable Yield (Y_{max})	13,818	14,020
Optimum Effort(f_{opt})	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

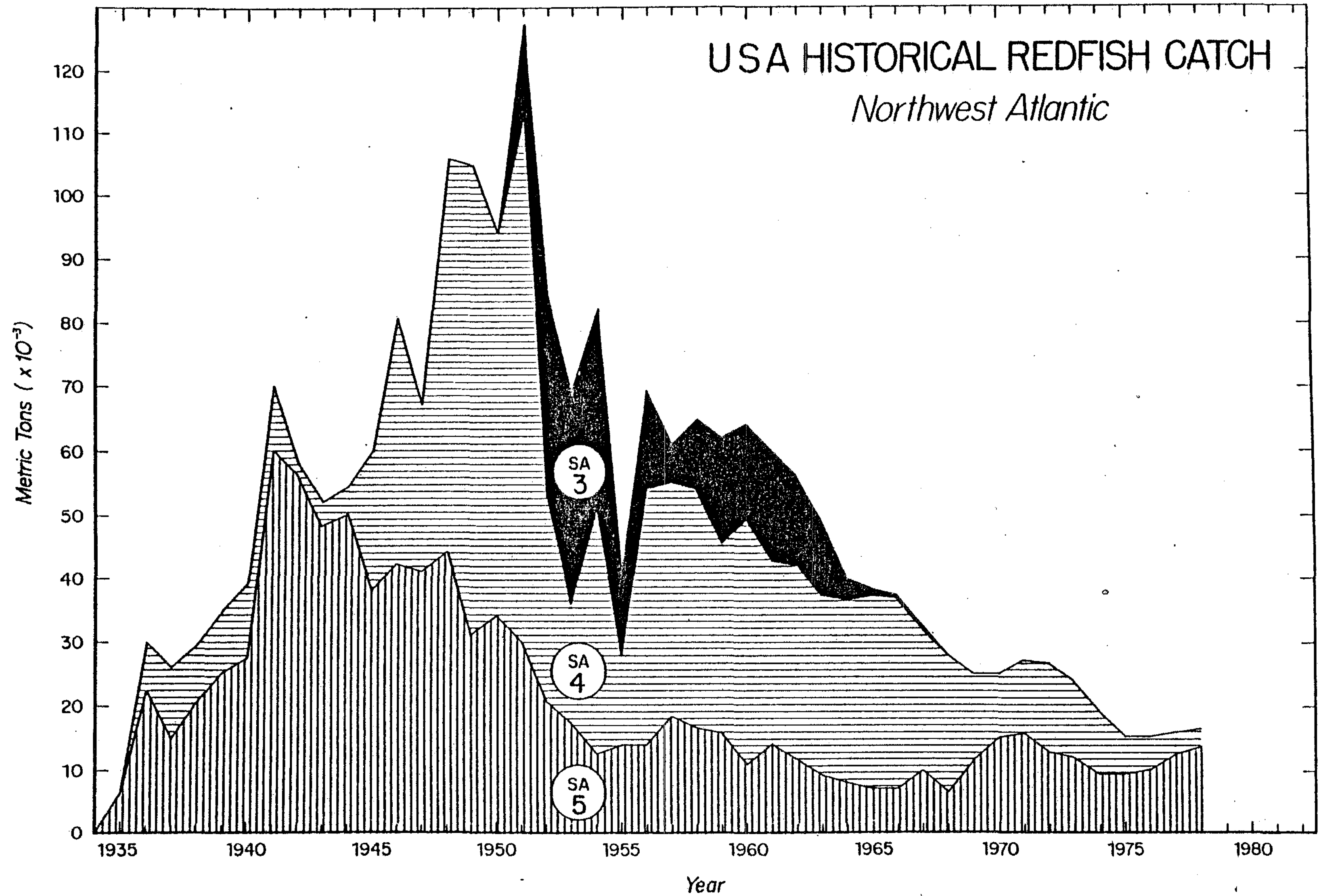


Figure 1. USA nominal redfish catches from ICNAF Subareas 3, 4, and 5.

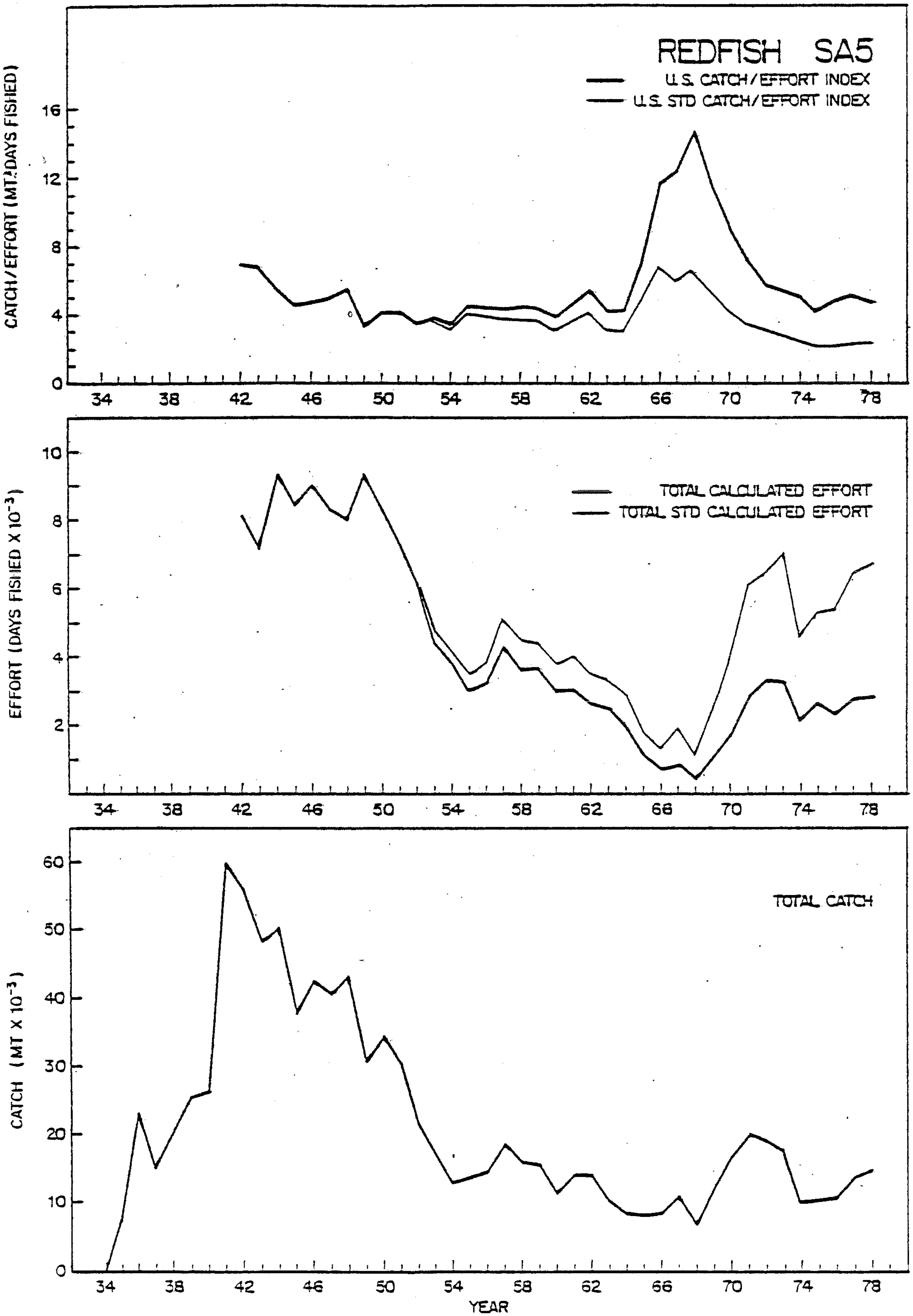


Figure 2. Trends in USA nominal redfish catch, effort and CPUE in the Gulf of Maine.

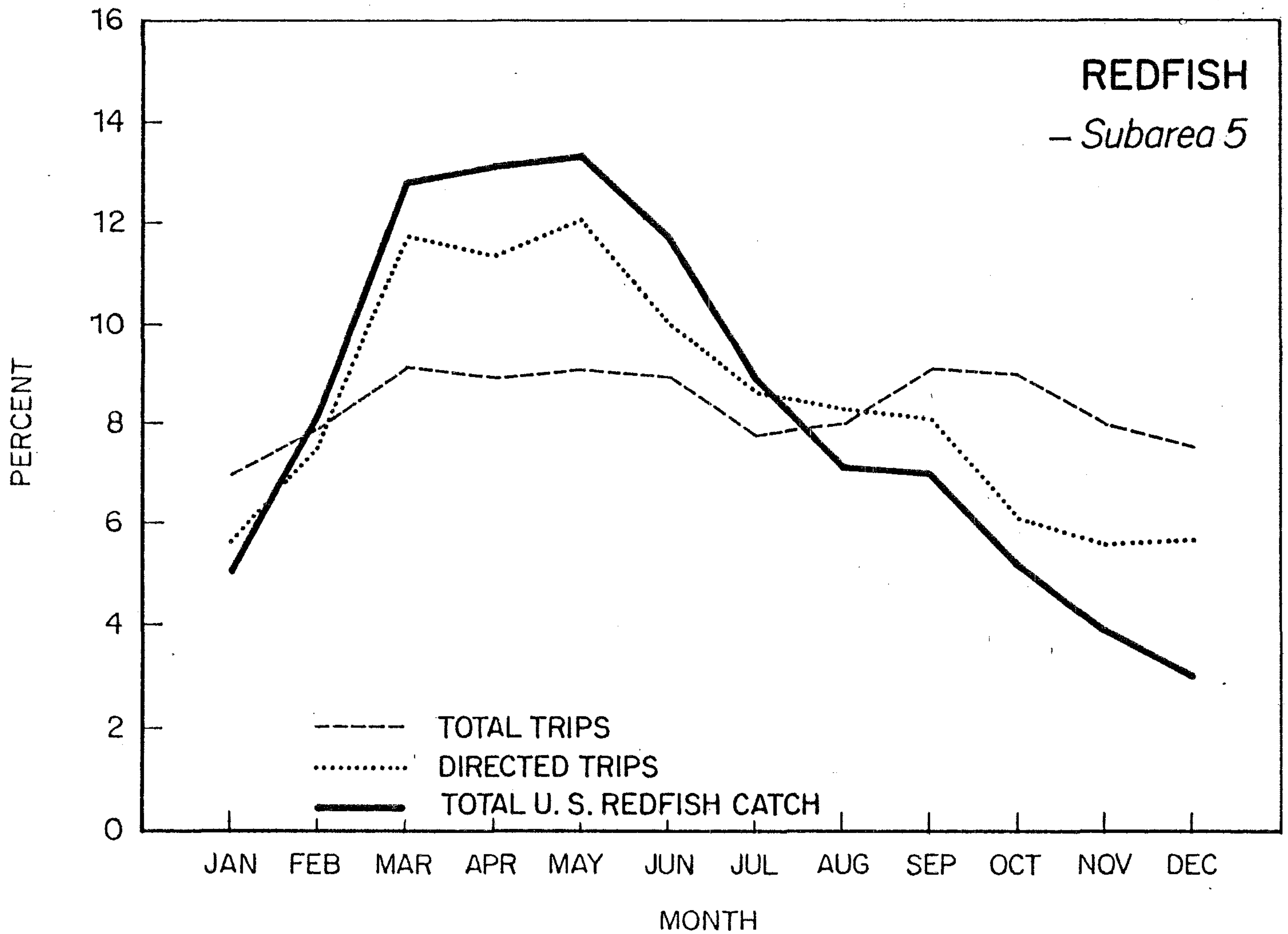


Figure 3. Seasonal distribution of USA redfish catch and effort in the Gulf of Maine from 1964 to 1977.

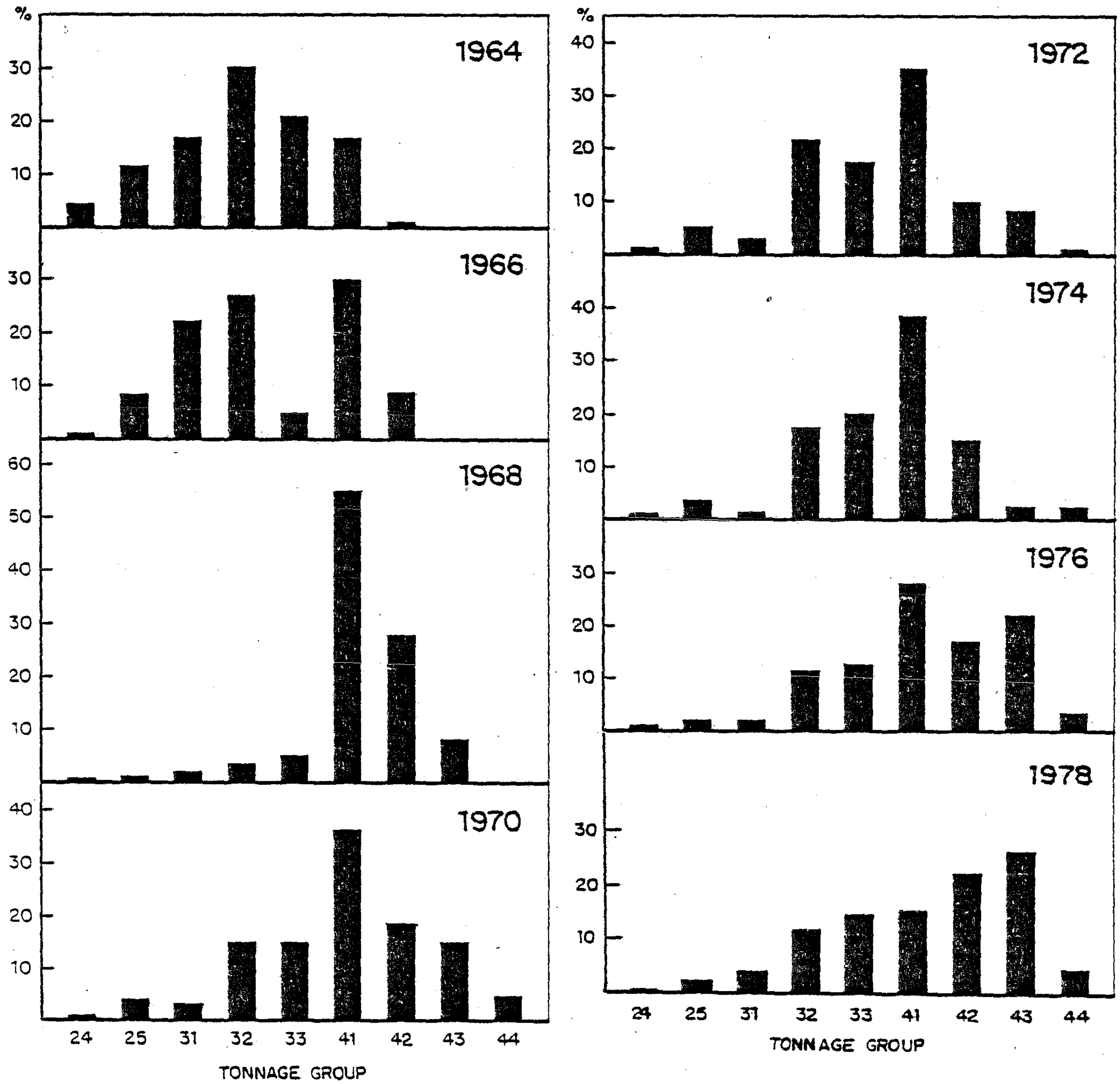


Figure 4. Percentage distribution of USA redfish nominal catch by vessel tonnage from the Gulf of Maine. Tonnage group: 24 = 23-33 GRT; 25 = 34-50 GRT; 31 = 51-72 GRT; 32 = 73-104 GRT; 33 = 105-150 GRT; 41 = 151-215 GRT; 42 = 216-310 GRT; 43 = 311-400 GRT; 44 = 441-500 GRT.

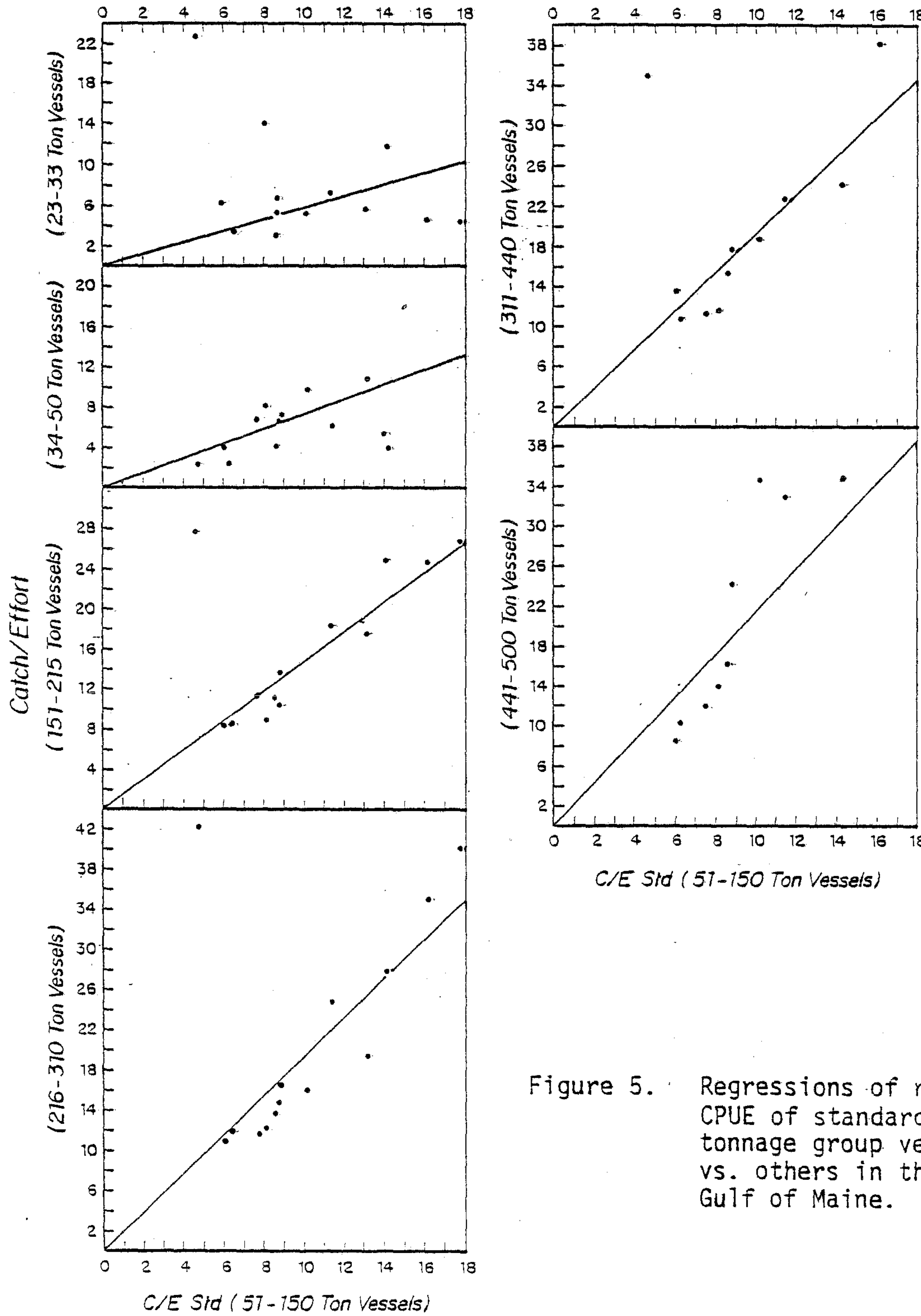


Figure 5. Regressions of redfish CPUE of standard tonnage group vessels vs. others in the Gulf of Maine.

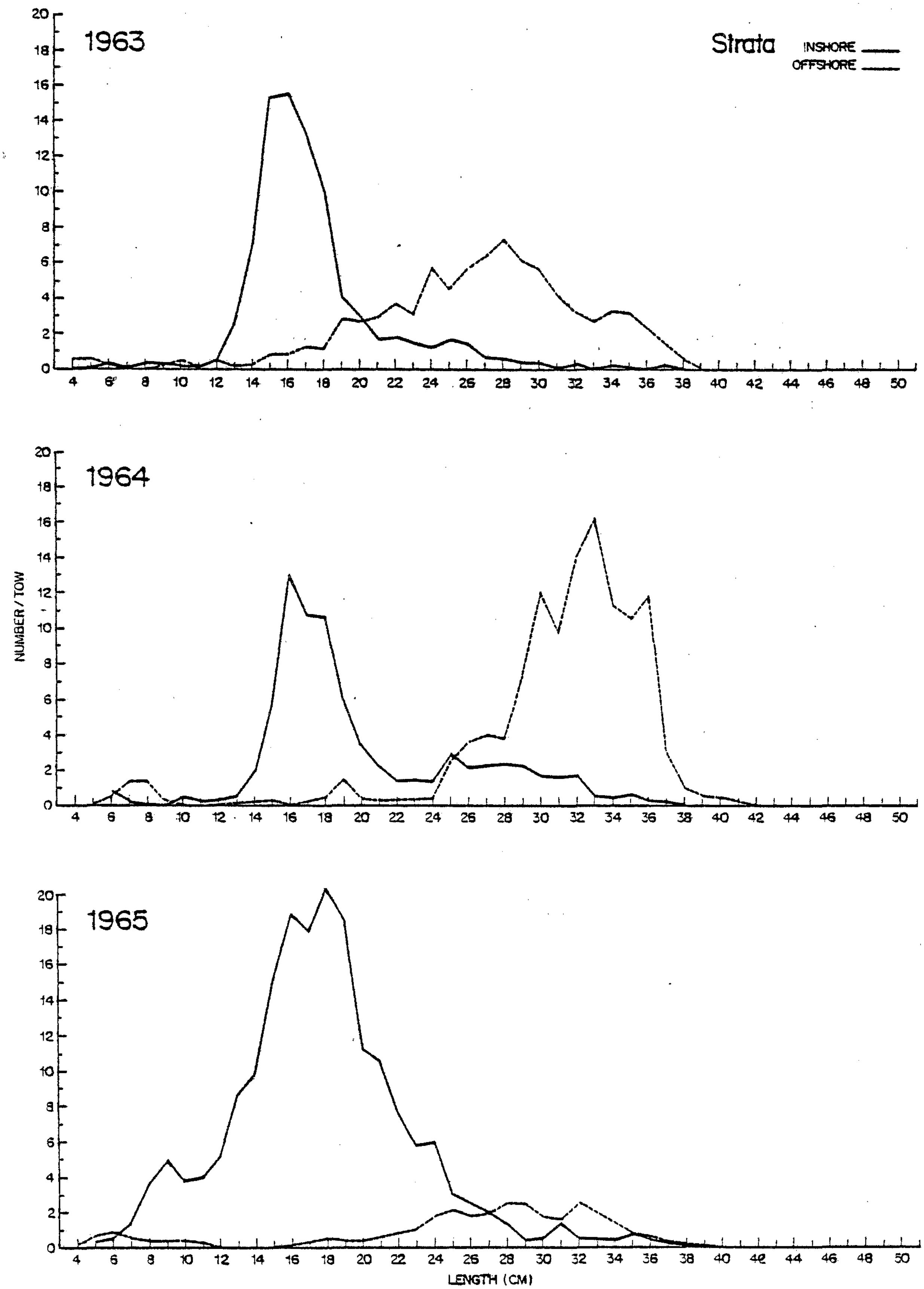
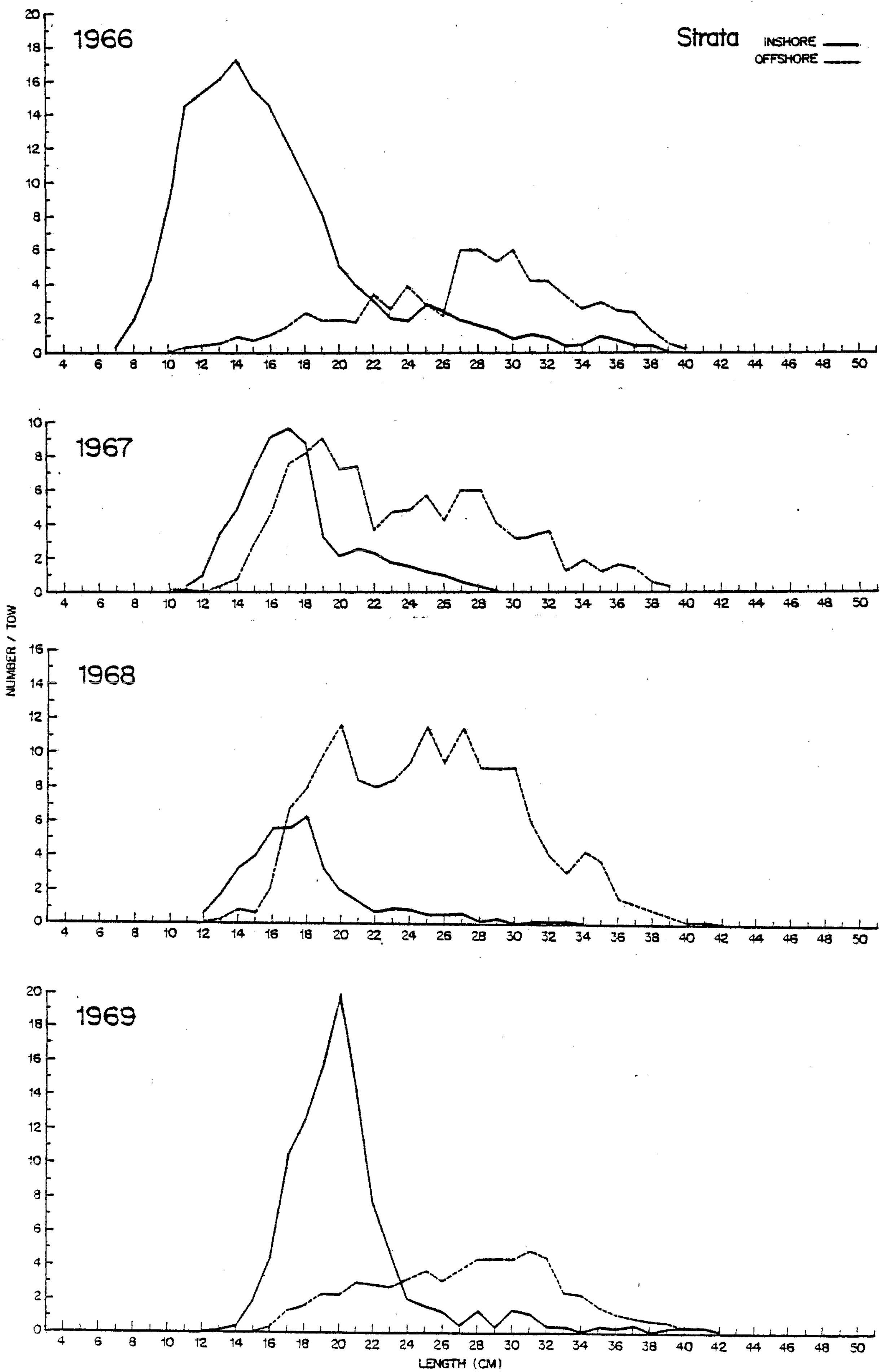
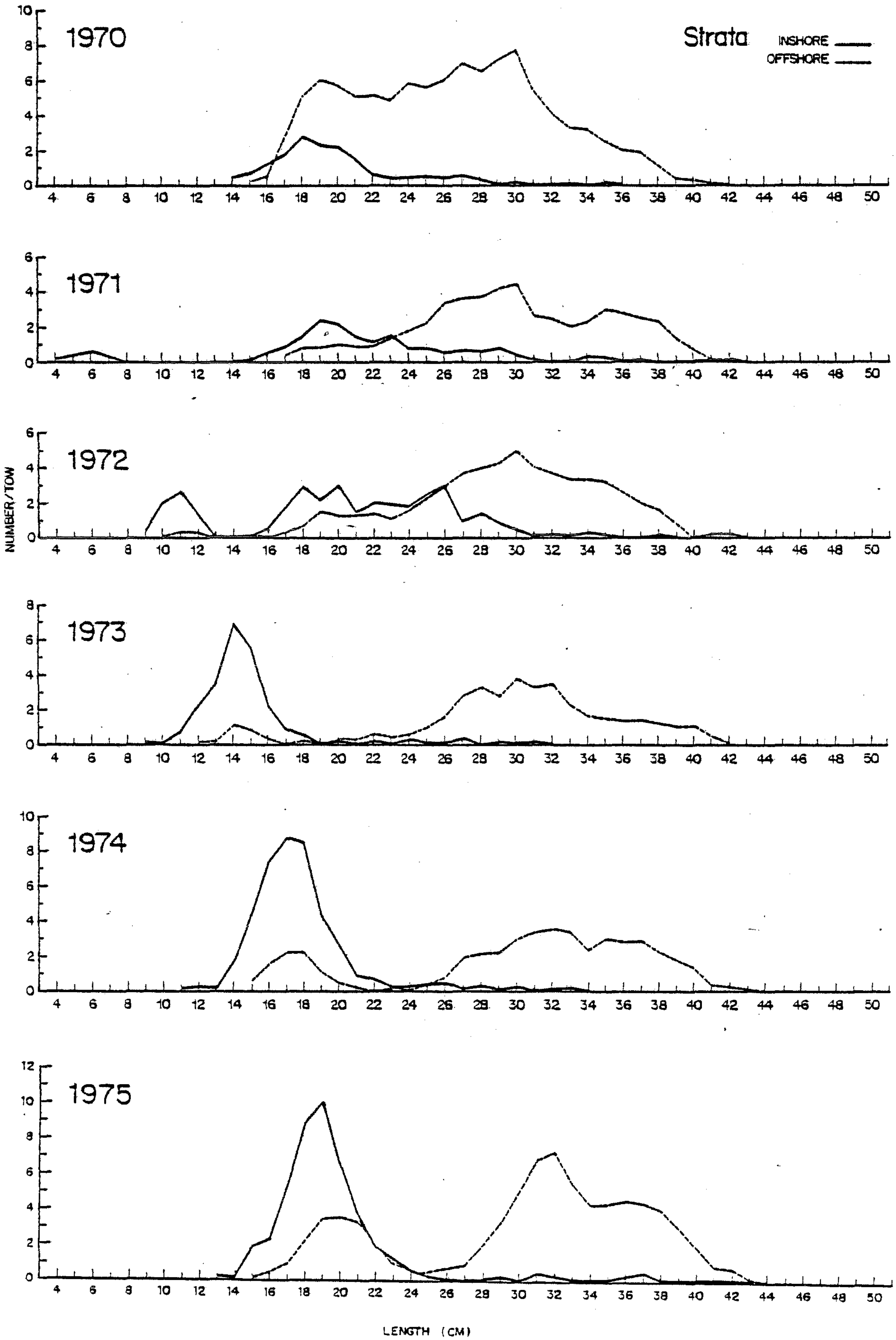


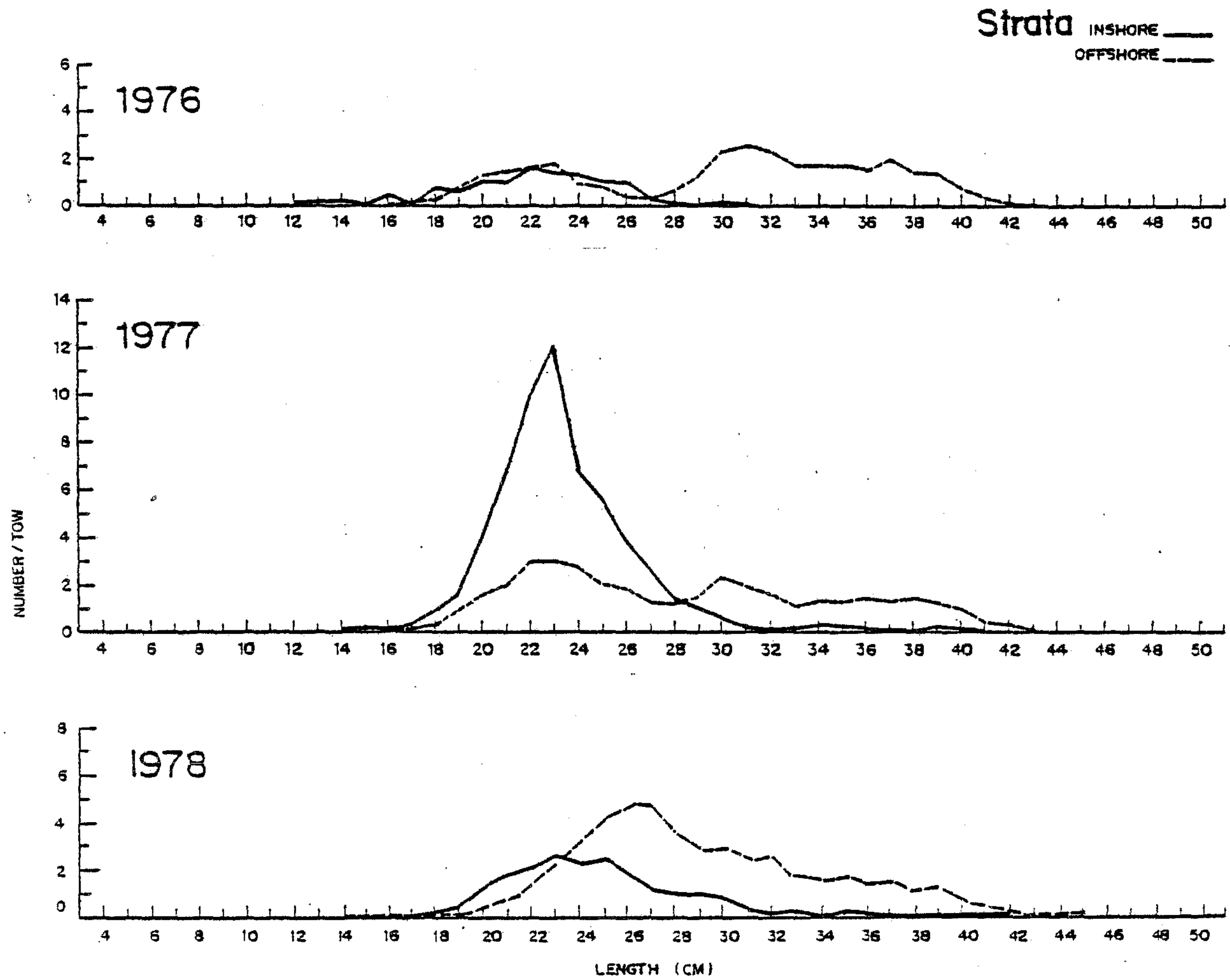
Figure 6. Length frequency distribution of redfish caught in USA autumn bottom trawl surveys in the Gulf of Maine. Inshore = less than 111 m; offshore = greater than 111 m.



1966
Strata
INSHORE
OFFSHORE
1967
1968
1969
NUMBER / TOW
LENGTH (CM)



1970
Strata
INSHORE
OFFSHORE
1971
1972
1973
1974
1975
NUMBER/TOW
LENGTH (CM)



Strata INSHORE
OFFSHORE
1976
1977
1978
NUMBER / TOW
LENGTH (CM)

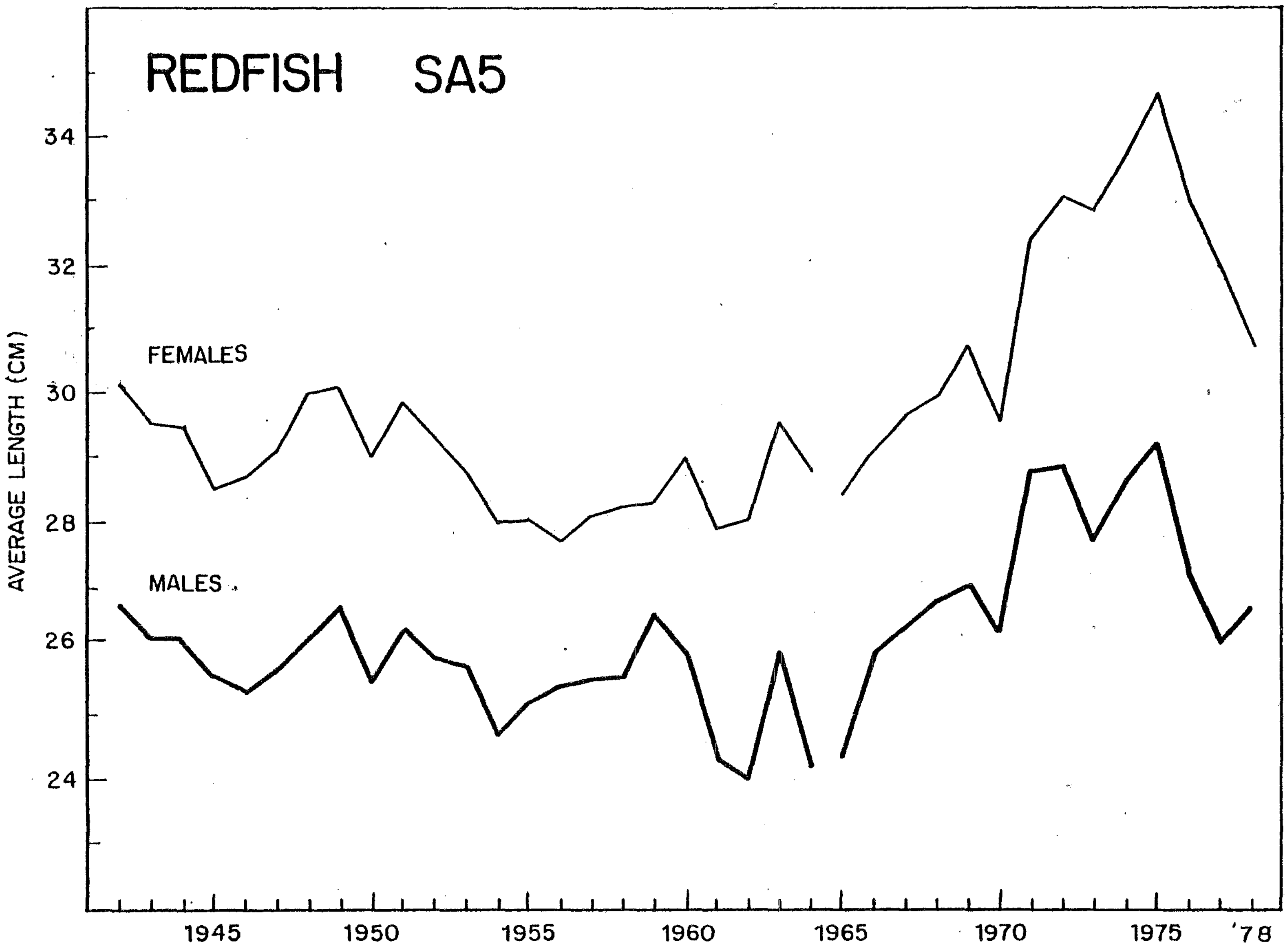


Figure 7. Trends in average length of male and female redfish in the USA commercial fishery from the Gulf of Maine. Figures from 1942 to 1964 redrawn from (Brown and Hennemuth 1965).

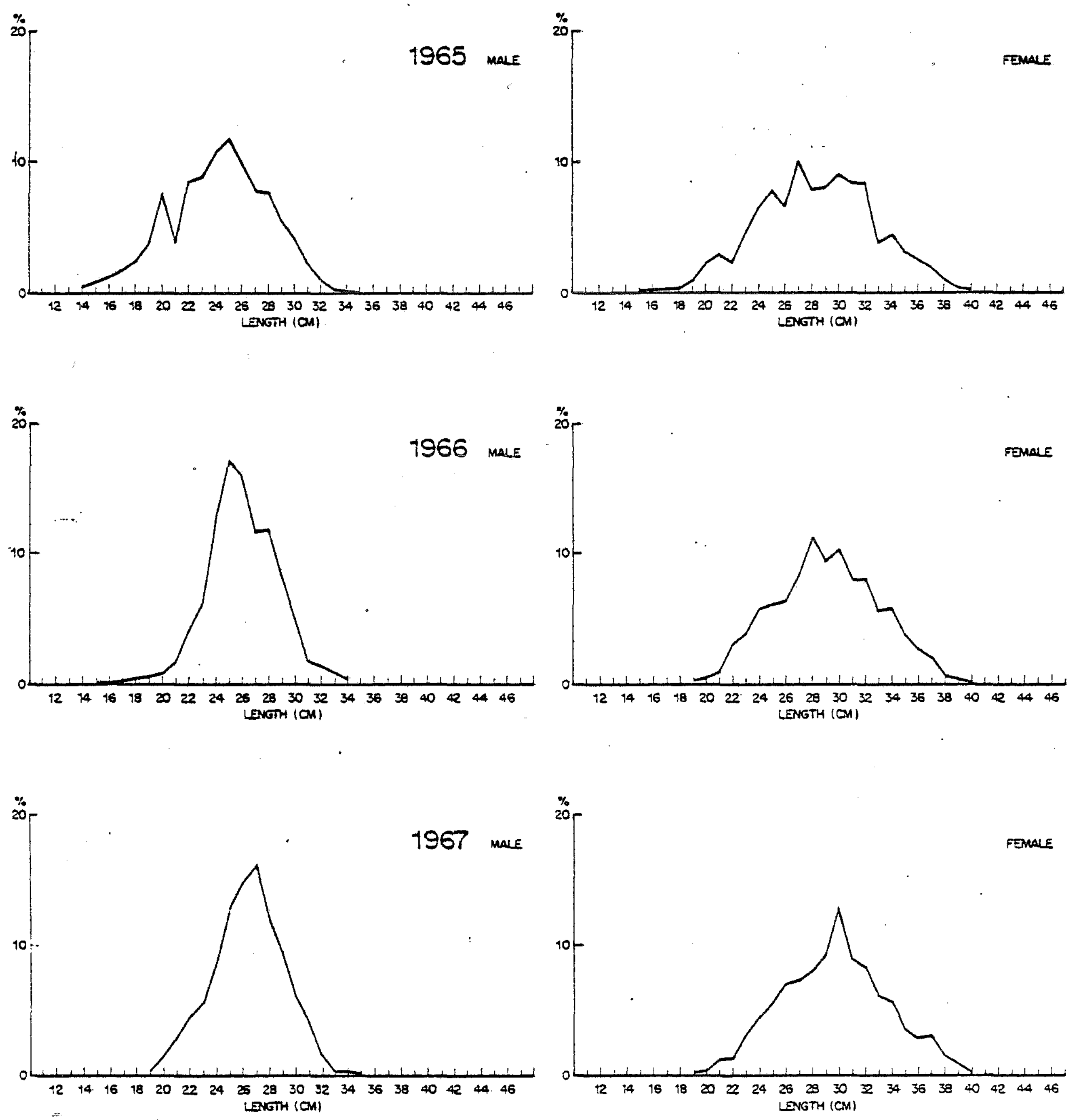
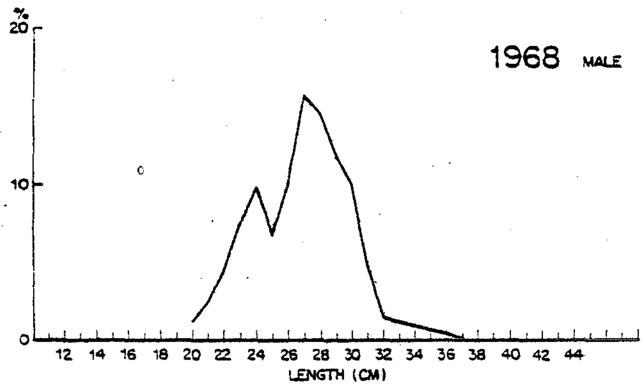
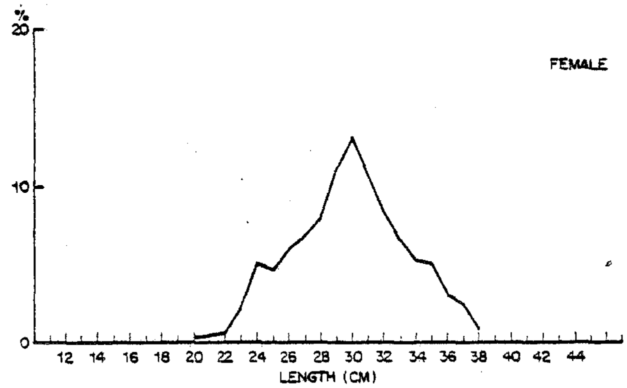
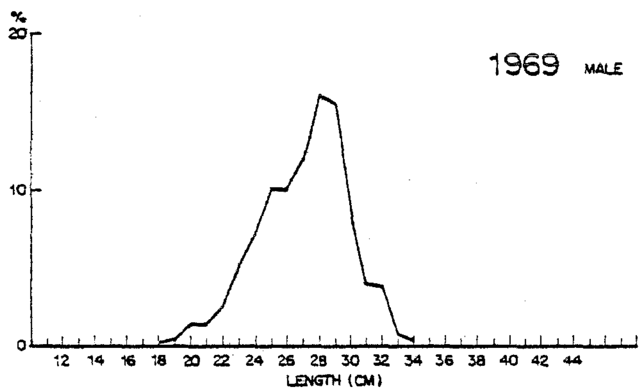
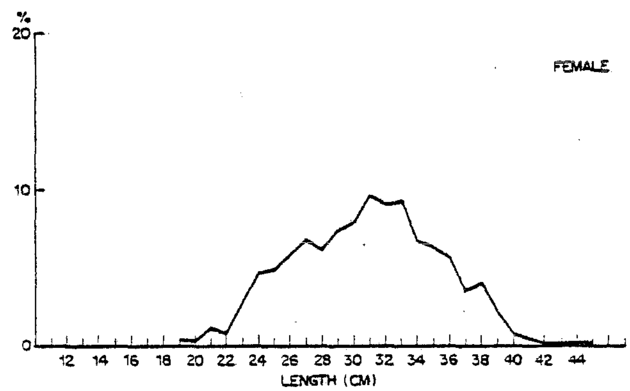


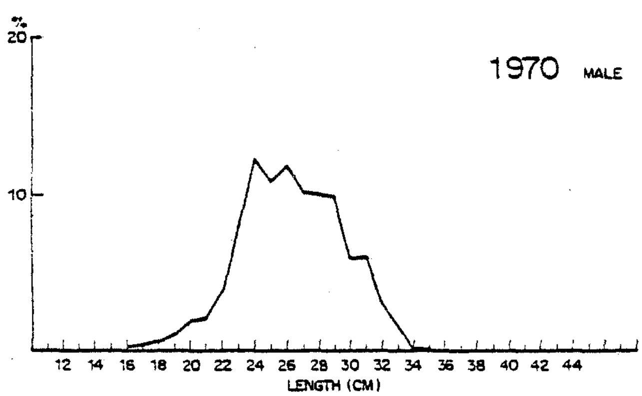
Figure 8. Length frequency distribution of male and female redfish in the USA commercial fishery from the Gulf of Maine.

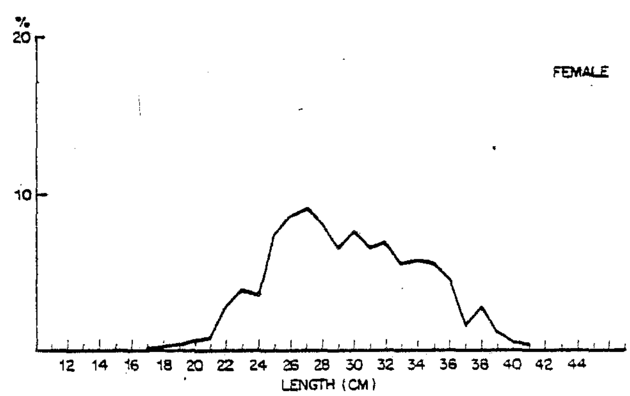

%
20
10
0
1968 MALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)

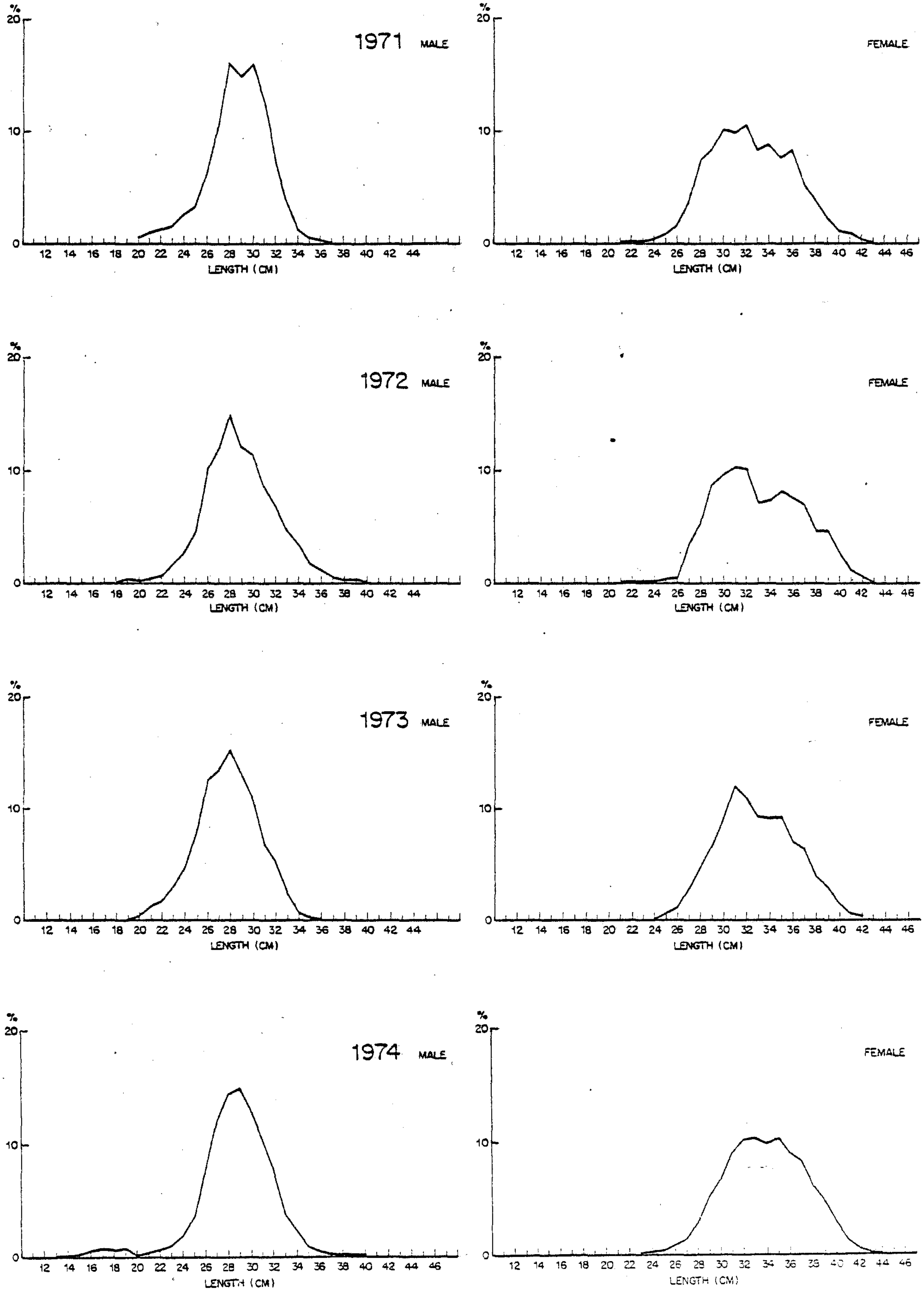

%
20
10
0
FEMALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)


%
20
10
0
1969 MALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)

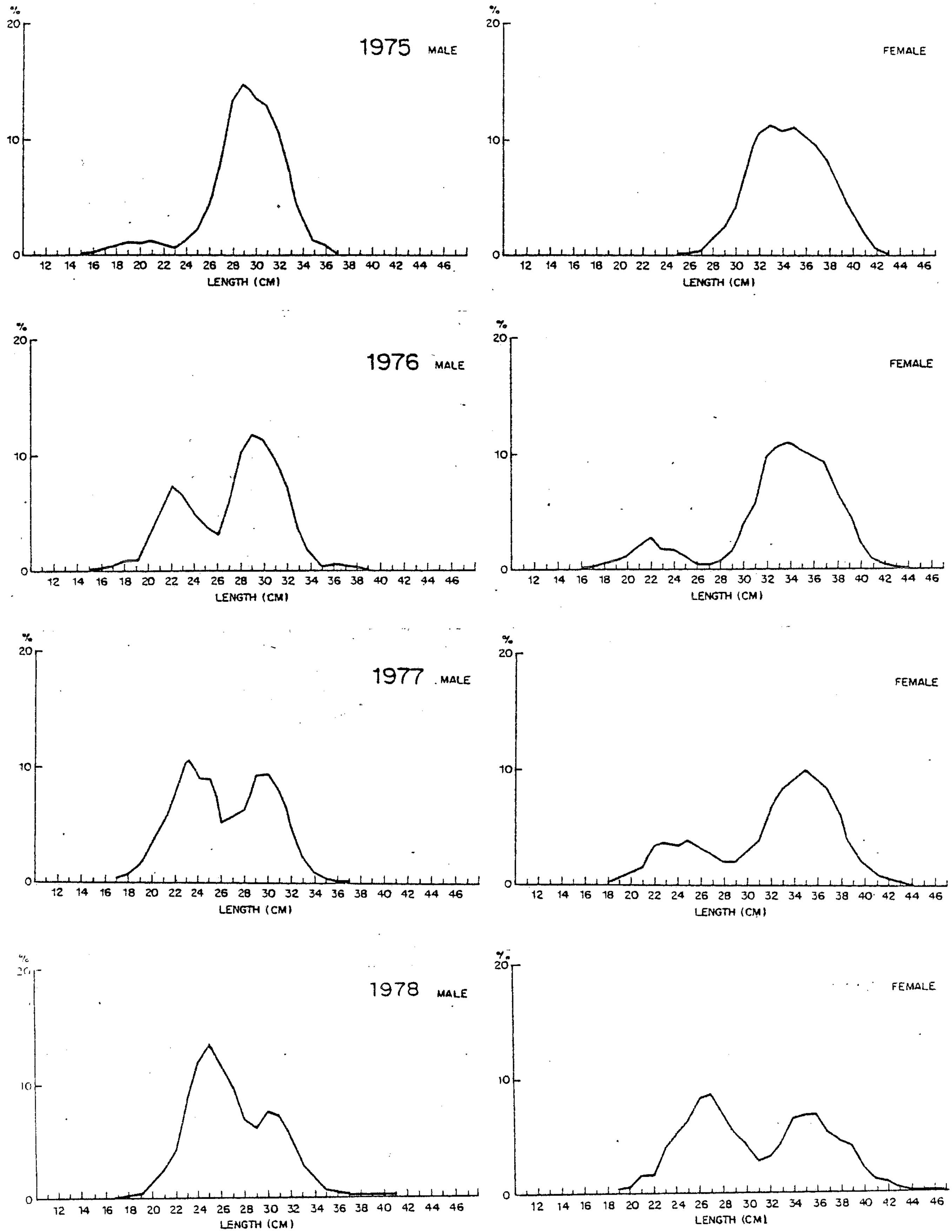

%
20
10
0
FEMALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)


%
20
10
1970 MALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)


%
20
10
FEMALE
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
LENGTH (CM)



1971 MALE
FEMALE
1972 MALE
FEMALE
1973 MALE
FEMALE
1974 MALE
FEMALE
%
20
10
0
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
LENGTH (CM)


1975 MALE
FEMALE
1976 MALE
FEMALE
1977 MALE
FEMALE
1978 MALE
FEMALE
%
20
10
0
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
LENGTH (CM)

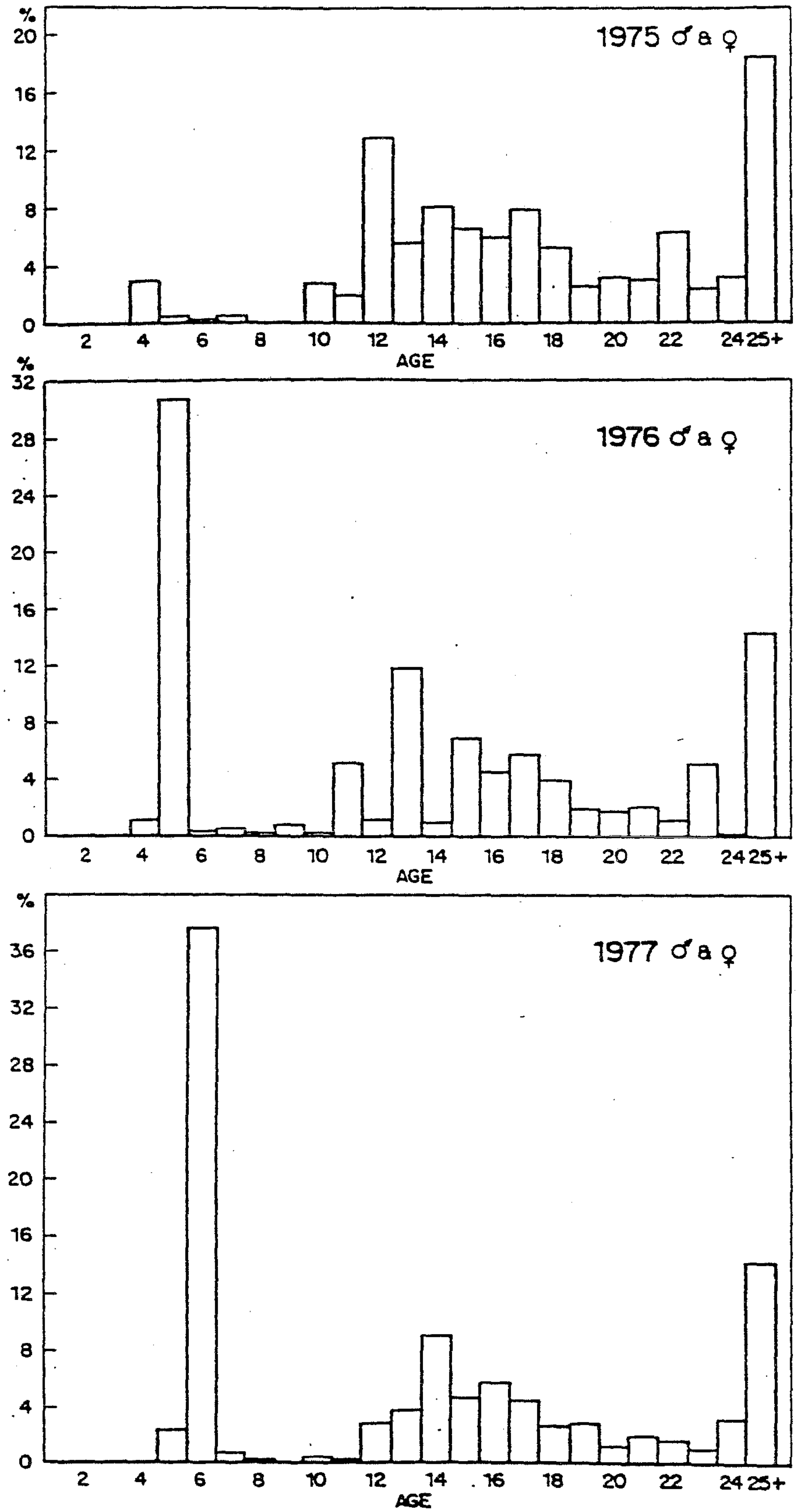


Figure 9. Age composition of redfish in the USA commercial fishery from the Gulf of Maine in 1975, 1976, and 1977.

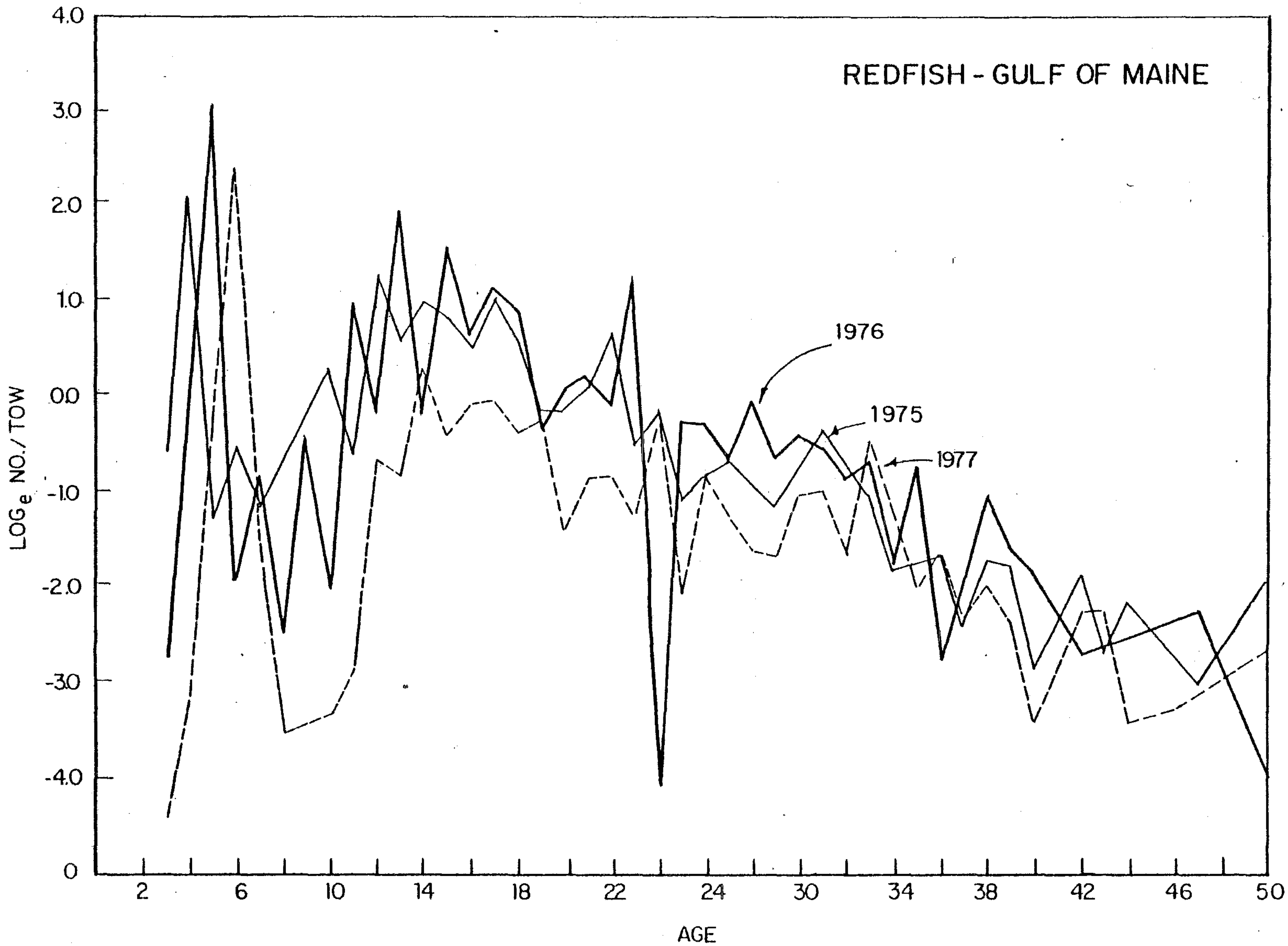


Figure 10. Catch curve derived from $\log_e$ number per tow at age in the spring bottom trawl surveys in the Gulf of Maine during 1975, 1976, and 1977.

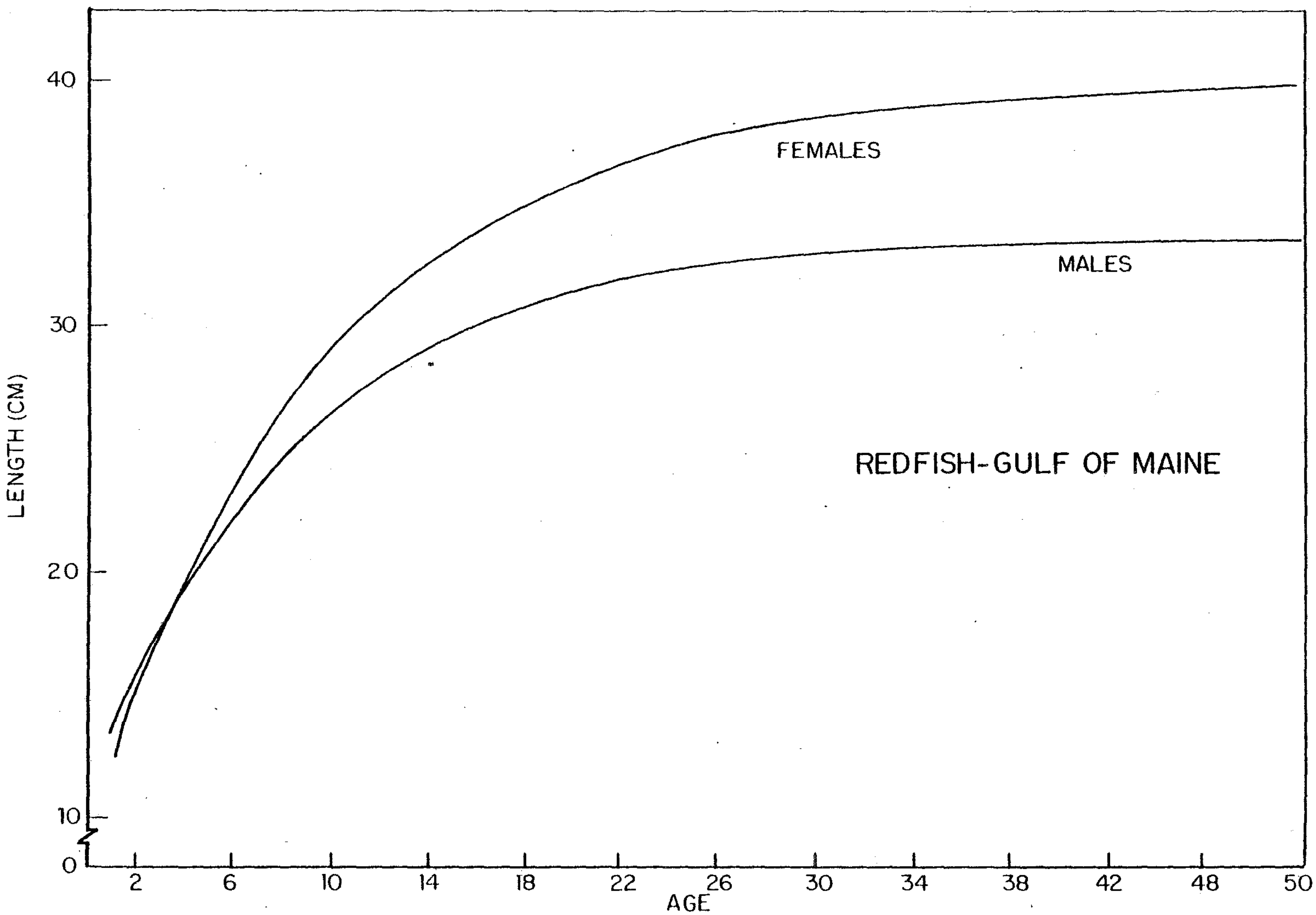


Figure 11. Calculated von-Bertalanffy growth curves for Gulf of Maine redfish for the period 1975-1977.

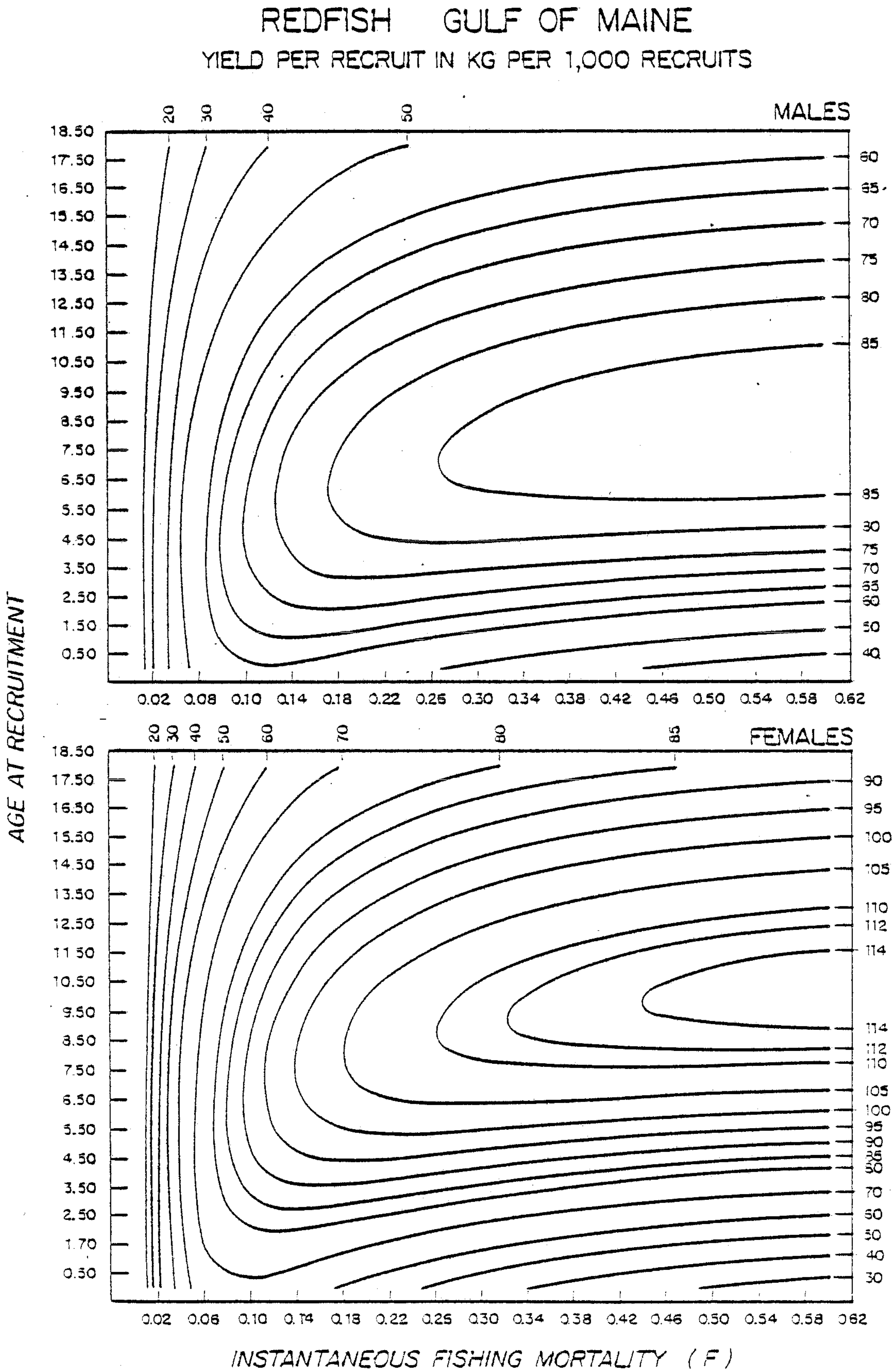


Figure 12. Yield isopleth diagrams for Gulf of Maine redfish assuming a value of M = 0.1.

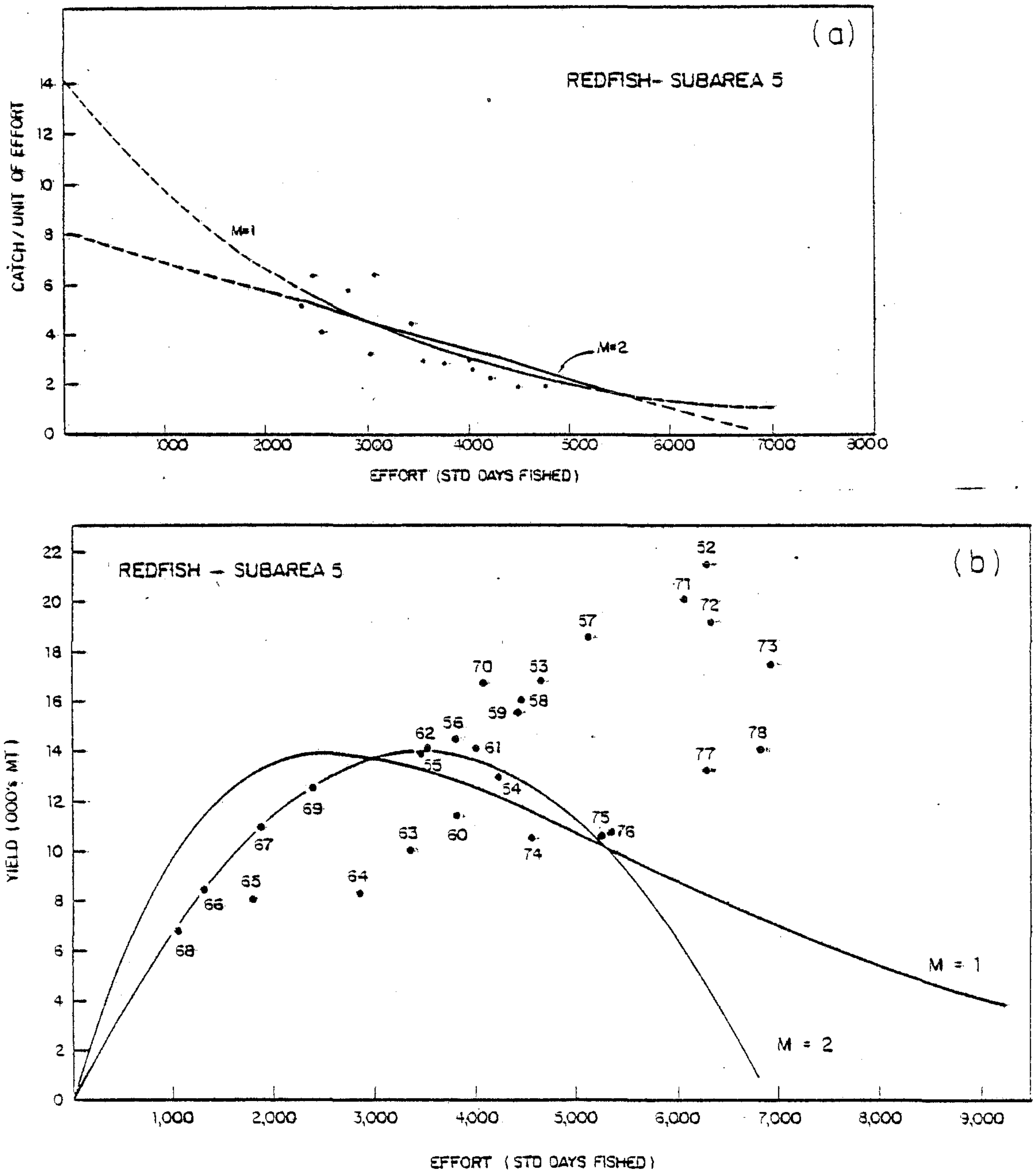


Figure 13. (a) Regressions of CPUE on effort derived from the General Production Model analysis with m = 1.0 and 2.0 and 12 year weighted average effort. Points are averaged values.

(b) Yield curves derived from the General Production Model analysis with m = 1.0 and 2.0 and 12 year weighted average effort.