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Assessment of Atlantic Mackerel in ICNAF Subarea 5 and Statistical Area 6 [1]

by

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INTRODUCTION

Atlantic mackerel (Scomber scombrus) landings from waters along the east coast of the United States have undergone a virtual exponential increase from 1,000 metric tons (MT) in 1962 to nearly 349,000 MT in 1971. Preliminary reports indicate that landings in 1972 exceeded 400,000 MT. A total allowable catch of 450,000 MT was proposed for 1973 at the January, 1973, Special ICNAF Commission Meeting as a means of preventing the continued, uncontrolled harvest of this resource. This paper provides an initial attempt at assessing the status of the mackerel stock in ICNAF Subarea 5 and Statistical Area 6.

BIOLOGY

Migration and Spawning

Mackerel are found on both sides of the Atlantic and range in the western Atlantic from Labrador to North Carolina. On the basis of size and age composition, migration pattern and timing, and results from a limited series of tagging experiments, Sette (1950) hypothesized the existence in the northwest Atlantic of a southern and a northern contingent, each an identifiable element of the overall mackerel population capable of maintaining its particular characteristics through several years but not necessarily genetically distinct. MacKay (1967) also found differences in the length and age composition of samples from the two groups but attributed these to possible inadequate sampling of the southern component. He detected no differences in most meristic characters and enzyme patterns between samples from the two groups.

Sette (1943, 1950) determined that the southern contingent first appears in continental shelf waters in the offing of Chesapeake Bay in mid-April and proceeds northeastward along the coast occurring in May off New Jersey and New York and in June off southern Massachusetts, with maximum spawning

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occurring in mid-May in the triangular bight between New Jersey and Long Island. This contingent continues northeasterly around Cape Cod, is joined by additional schools moving inshore from the edge of the shelf, and occupies the western part of the Gulf of Maine in the summer. The main portion of the northern contingent moves inshore off southern New England in late May and is mixed during this time with the southern contingent. It then continues along the Nova Scotian coast and is joined by additional schools moving inshore before it finally reaches the Gulf of St. Lawrence where it spawns in June and early July and remains for the summer. The southern group withdraws from the Gulf of Maine in October and returns to deep water near the edge of the shelf. The northern group begins to vacate the Gulf of St. Lawrence in September, passes through the Gulf of Maine in November and early December, and also returns to the deep water. Sette (1950) concluded that wintering occurs primarily at mid-depths above 100 fathoms along the continental shelf edge from the middle of the southern edge of Georges Bank to Cape Hatteras, with the southern contingent from Long Island and southward and the northern contingent from Long Island and eastward.

The fishery in Subarea 5 and Statistical Area 6 possibly harvests from both of the proposed contingents. This paper considers only the stock as found in these areas and not in other ICNAF areas, where landings (mostly from Divisions 4T, 4W, and 4X) have ranged from 5,470 MT in 1961 to 24,496 MT in 1971. Inferences in this paper are based on data from 1968-1971, during which time mackerel landings from the other areas comprised only 26 percent (1968) to 6 percent (1971) of the overall total. However, since the work of both Sette (1950) and MacKay (1967) implies that the two contingents are not genetically distinct, future consideration should perhaps be given to assessing all mackerel in the northwest Atlantic as a unit stock.

Sette (1943, 1950), Bigelow and Schroeder (1953), and MacKay (1967) offer excellent reviews of the life history of the mackerel. Sexual maturity occurs at age two. Spawning which apparently is temperature dependent takes place primarily 10-30 miles from shore. Normal egg incubation requires about a week, with newly-hatched larvae measuring about 3 mm. The adult body form and schooling habit are assumed at about 30-50 mm or a month after hatching. A length of 200 mm may be attained by the first autumn.

Fluctuations in mackerel year-class strength are suggested by the widely variable landings reported since the early 1800's (see later section) but are not well documented by scientific research. Bigelow and Schroeder (1953) presented evidence based on observations of the size composition of landings between 1910 and 1932 which suggested that fluctuations in landings were associated with marked variations in year-class strength. Sette (1943) implied that variations in abundance were related primarily to environmental factors, particularly wind movements and plankton abundance, both of which influence larval mortality. He further attributed the failure of the 1932 year-class to extremely high mortality during the transition from larval to post-larval stages resulting from (1) the prevalence of northeasterly winds which caused the drift of the planktonic larvae farther than usual from their nursery grounds and (2) a general scarcity of plankton in the nursery grounds.

Growth

Growth rate of mackerel was estimated from samples collected aboard the Albatross IV during the 1972 fall groundfish survey cruise. Ages were determined from otolith readings (unpublished data provided by F. Nichy, NMFS, Woods Hole). Fork length was used in the analysis; a ratio of 1.10 was estimated for converting from fork length to total length. The von Bertalanffy growth equation was fitted to back-calculated lengths at age by the method of Tomlinson and Abramson (1961) and Abramson (1964). The resulting growth curve is shown in Figure 1. Growth parameters obtained are: L_∞ = 35.1 cm (total length = 38.6), K = 0.536, and t_0 = -0.586. Mean length and weight at age are given in Table 1. A length-weight equation calculated from U.S.A. research vessel survey data (ln W = -11.8365 + 3.3194 ln L, where W = weight in lb and L = fork length in cm) was used to calculate the mean weight.

The results of this growth study are considered preliminary. Values generally agree with those given by Castello and Hamre (1969) and Postuma (1969) for North Sea mackerel.

COMMERCIAL LANDINGS

Atlantic mackerel have been harvested off the New England shores since the 1600's. Landings from 1804 to 1965 underwent considerable fluctuation in response to the interaction of a number of factors including changing economic conditions, improvement in fishing methods, shifting from one fishing region to another, and primarily the natural fluctuations in abundance (Sette and Needler, 1934; Hoy and Clark, 1967). Landings during 1930-1949 averaged 20,300 MT and varied from 3,800 to 33,600 MT, whereas those during 1950-1964 averaged only 1,500 MT.

Table 2 provides landings by nation during 1961-1971. Total landings increased dramatically from only 1,000 MT in 1962 to nearly 349,000 MT in 1971 (Figure 2). This increase is attributed to an apparent improvement in stock size as well as to a diversion of fishing effort from declining sea herring stocks. Intensive fisheries were begun by the U.S.S.R. in 1967, Poland in 1968, and by the German Democratic Republic and Bulgaria in 1971.

Landings during 1961-1968 came primarily from Subarea 5 (70-89 percent), but by 1971 the amount from Statistical Area 6 increased to 67 percent of the total.

Landings for 1969-1971 are listed according to Division and month in Table 3. Data indicate that the annual fishing pattern followed closely with the migration pattern described by Sette (1950). Landings were heaviest from Divisions 6A, 6B, and 6C during January-May, while the stock was concentrated in deep, offshore waters, and later as movements inshore began. Landings from 5Zw and 5Ze improved markedly in April-June as the northeasterly migration developed. Landings from 5Y were almost entirely by the small U.S.A. fishery. Landings from 5Ze, 5Zw, and 6A improved in November-December as the fish migrated southwesterly and offshore.

FISHING EFFORT AND CATCH/EFFORT

Data Source

Catch and effort statistics reported to ICNAF by the U.S.S.R., Poland, Romania, Bulgaria, and the German Democratic Republic were utilized to calculate estimates of fishing effort and catch/effort. Data were extracted from Table 4 of the ICNAF Statistical Bulletins and from the STANA 1W or STATLANT 21B Forms submitted to the ICNAF Secretariat. German Democratic Republic data for 1969 and 1970 were taken from ICNAF Summary Document 73/3. Hours fished was selected as the fishing effort measure.

Nearly all mackerel were landed by vessels specifying the main species sought as mixed. Data for each country and gear-tonnage class were examined by month and ICNAF Division to determine directed mackerel fishing effort. Effort was selected when the nominal catch reported for mackerel was greater than for any other species. Monthly catch and effort were summed for each year to give an annual value by country, gear-tonnage class, and ICNAF Division for 1968-1971.

Standardization of Fishing Effort

Mackerel in Subarea 5 and Statistical Area 6 were virtually all caught by various types and sizes of otter trawlers. Total fishing effort by vessels from the five countries included in the analysis was standardized by the use of relative catchability coefficients. These were computed from the mackerel catch/effort data utilizing an analysis of variance procedure proposed by Robson (1966), outlined by Snedecor and Cochran (1967), and described and employed by Brown et al. (1973).

The various otter trawler gear-tonnage classes fished by the respective countries were categorized for the analysis of variance by the arrangement shown in Table 4, whereby a given type or class within a tonnage class for a particular country (see note in Table 4) was matched with those of other countries having similar catch/effort values. Relative catchability coefficients were expressed for each country-gear-tonnage class in relation to a standard category which was arbitrarily selected as the U.S.S.R. SRT 151-500 GRT side trawler class.

Adjustment for Learning

Whenever a new fishery develops, it is assumed that an initial period exists during which time the participants are engaged in a learning process, the result of which is improved efficiency. Borkowska-Kwinta (1964, 1970), Schumacher and Anthony (1972), and Brown et al. (1973) have suggested that learning requires a period of two years, with the latter report showing that the learning function is exponential with approximately a 50 percent increase in efficiency in each of the two years. This function was applied over that time period to each country-gear-tonnage class (Subarea 5 and Statistical Area 6 treated separately) included in the analysis (Table 5). The adjustment for learning amounted to dividing the effort of each country-gear-tonnage class in its first year in the fishery by four and the effort in its second year by two. The first year in the directed mackerel fishery for a particular country-gear-tonnage class was defined as the first year in which effort was directed specifically towards mackerel according to the criterion mentioned earlier in the Data Source section.

Results

Analysis of variance was computed without and with fishing effort adjusted for learning (Table 6). Gear-tonnage class differences in both cases and country differences in the latter case were significant at the 0.01 probability level. Interactions were insignificant in both analyses. Relative catchability coefficients are listed in Table 7.

The coefficients obtained from the analysis involving effort adjusted for learning were, on the average, 1.6 times larger than those obtained without the learning adjustment. This resulted from the learning adjustment not being applied to all country-gear-tonnage classes in the same years (see Table 5) which caused an unproportional change among the various classes in the average of the catch/effort values available during 1968-1971 derived from adjusted effort relative to that obtained from unadjusted effort. The coefficients for the vessel classes of the German Democratic Republic were particularly larger following the learning adjustment which, for several classes, was applied to the only year (1970) for which effort was available. However, since the standardized hours fished (described in the next paragraph) contributed by the German Democratic Republic vessels comprised only 2.6 and 2.2 percent of the total in 1969 and 1970, respectively, the effect of those unusually large coefficients on the overall result is insignificant.

The hours fished by each country-gear-tonnage class per year for Subarea 5 and Statistical Area 6 combined was multiplied by the appropriate relative catchability coefficient, summed over all classes, and divided into the summed landings from that effort to obtain the standardized landings/hour. Standardized total annual hours fished was calculated by dividing total landings (including that taken by effort and gear not included in the analysis of variance - 37 percent of the 1968-1971 landings) by standardized landings/hour. Results are given in Table 8 without and with adjustments for learning.

Standardized fishing effort adjusted for learning exhibited a 12-fold increase from 33, 146 hours fished in 1968 to 383,235 hours in 1971, whereas only a 3-fold increase occured when the learning adjustment was not applied. Standardized landings/hour adjusted for learning underwent a 50 percent decrease from 1968 to 1971 (Figure 2), while landings/hour without the learning adjustment increased 93 percent from 1968 to 1970 and declined only slightly in 1971.

RESEARCH VESSEL SURVEYS

Data from U.S.A. research vessel survey cruises (Grosslein, 1969) were utilized to estimate yearly changes in relative mackerel abundance and length composition. Although the groundfish survey cruises were not specifically designed for pelagic species, data from spring cruises have provided evidence of the sea herring decline (Schumacher and Anthony, 1972) that agrees well with other estimates and appear to offer a good indication of the trend in mackerel abundance. Larger mackerel catches by the research vessel Albatross IV were achieved in the spring than in the fall because of greater availability of the fish to the gear during the former period in the offshore waters south of Cape Cod.

Data used to calculate the spring abundance index (stratified mean catch/tow in pounds, ln scale) were obtained from catches in sampling strata 1-14, 61-76 (Figure 3). Summer and fall indices were also calculated using data from strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26. Ln transformations of the individual catch/tow values were used to reduce the effect of large variations among tows.

The spring 1973 survey employed a modified high-opening No. 41 bottom trawl in place of the previously-used No. 36 Yankee trawl. A 1972 gear comparison experiment between a modified No. 41 trawl similar to that used in 1973 and the No. 36 Yankee indicated a 2:1 catch ratio for mackerel (unpublished NMFS data). A 1973 gear comparison experiment between the modified No. 41 trawl and the No. 36 Yankee trawl indicated a 11:1 ratio for mackerel. Therefore, the 2:1 ratio represents a conservative estimate of the actual catch ratio between the two trawls for mackerel. The spring 1973 data were adjusted by the 2:1 ratio to provide an abundance index more comparable to previous years. The unadjusted and adjusted 1973 ln (catch/tow) indices were 0.44 and 0.33, respectively.

The spring U.S.A. abundance index decreased 55 percent from 1968 to 1973 (Table 9, Figure 4). The extremely low 1969 value resulted more from the timing of the cruise than from actual abundance. Virtually all of the mackerel were caught in stratum 62 indicating that the inshore, northerly migration had just begun at the time the survey occurred and that mackerel were not present in other areas. Spring indices for other pelagic species such as sea herring and alewife did not exhibit a similar drop, thus suggesting that the sampling gear did function as usual that year.

Summer indices are available only for 1963-1965 and 1969 and do not constitute a continuous series. Fall indices are given for both U.S.A. and U.S.S.R. survey cruises which were conducted jointly using the same stratified sampling design and procedures. The U.S.A. indices (1963-1972) are small relative to the spring and exhibited greater statistical variance but, nevertheless, do indicate a downward trend after 1967 (Table 9, Figure 4). The larger U.S.S.R. values (1967-1972) resulted from the use of trawls larger than the one employed by the U.S.A., but they also exhibited somewhat greater statistical variance than the U.S.A spring indices. Furthermore, the U.S.S.R. values for 1969 and 1971 are not comparable with other years because the trawls used were different and demonstrated greater fishing power relative to that of the No. 36 Yankee trawl utilized by the U.S.A. Therefore, the series of U.S.S.R. fall indices is not considered to indicate the trend in mackerel abundance as well as the U.S.A. spring indices. In spite of the differences between the results from the various surveys, it is apparent from the U.S.A. spring surveys that mackerel abundance has indeed decreased in recent years.

The length composition of the spring stratified mean number/tow is illustrated in Figure 5. A strong 1967 year-class at age one was very evident in 1968. Survey data do not indicate that any succeeding year-classes are comparable in strength to that of 1967. The 1971 year-class appears to be the strongest since 1967 on the basis of the number of 18-22 cm fish caught in 1972 compared to 1969-1971 and 1973. The 1972 length composition indicates a marked decrease in fish age two and older compared to 1970 and 1971.

The increased number of fish measuring 30-35 cm in the 1973 length frequency resulted from an unusually large catch of mackerel (5,180 kg) in a single tow in stratum 7. Fish of this size are presumed to be 4-6 years old. Contrary to this length frequency which suggests increased abundance of older fish, the U.S.A. spring ln (catch/tow) index indicated a continued decline in 1973.

LENGTH AND AGE COMPOSITION OF COMMERCIAL LANDINGS

Length and age composition data from landings in recent years are very limited. Percentage age compositions of U.S.S.R. and Polish landings in 1969-1971 are given in Table 10 (sources referenced there). Length frequencies of commercial landings were reported only for April-July, 1971, by Poland and Japan (ICNAF Sampling Yearbook, Vol. 16).

Landings since 1969 have been dominated by fish from the 1967 year-class and to a lesser extent by the 1966 year-class. The 1967 year-class comprised 84, 50, and 51 percent of the U.S.S.R. landings in Division 5Z in 1969, 1970, and 1971, respectively; 53 and 35 percent in Statistical Area 6 in 1970 and 1971, respectively; and 50 and 54 percent of the Polish landings in 5Z in 1970 and 1971, respectively. The 1966 year-class during this time varied from 13 to 24 percent of the total each year. There was a significant percentage contribution of age one fish (1969 year-class) in 1970 (16 and 11 percent of the U.S.S.R. landings in 5Z and 6, respectively, and 12 percent of the Polish landings in 5Z), but in

1971 the percentage of age two fish was high only in Statistical Area 6 (26 percent of the U.S.S.R. landings) and not in Division 5Z (9 percent of the U.S.S.R. and Polish landings). The 1969 year-class appeared stronger in the commercial landings than either the 1968 or 1970 year-classes but much less than the 1967 year-class.

The 1969 age composition of U.S.S.R. landings differed markedly from other years by the absence of fish at age one and ages greater than six. This discrepancy essentially invalidates any meaningful comparison of these data with the 1970 data for the purpose of determining survival rates of the various year-classes. One can speculate as to the reasons why such an age composition might be representative of the actual landings. This would perhaps lead to questioning the authenticity of the 1970 and 1971 data as well. The sources from which the U.S.S.R. and Polish age compositions were taken provide no explanation of the sampling procedures used nor the time(s) of the year nor specific area(s) from which the samples were collected. Therefore, it is not known whether discrepant data (e.g. the U.S.S.R. percentage composition of age two fish in Division 5Z and Statistical Area 6 in 1971) indicate an actual difference or merely result from inadequate or biased sampling. It is obvious that the presently available age and length data are glaringly inadequate to provide a reasonably accurate age analysis of the mackerel landings on which further assessment studies can be based. However, the data are of necessity used in this paper, but any results and conclusions on which they are based must be considered accordingly.

The number of mackerel landed at each age in 1969-1971 was estimated using the U.S.S.R. and Polish percentage age compositions (Table 10) and the Polish commercial age/length data reported for April-June 1971 for Division 5Z and Statistical Area 6 (ICNAF Sampling Yearbook, Vol. 16). The Polish age/length keys for each area were applied to the accompanying monthly length compositions to determine the age/length composition. Mean length at age was calculated for each area and converted to mean weight at age using the length-weight equation given earlier. The mean lengths at age were not exactly comparable with those determined from the growth curve described earlier over the full range of ages but did agree reasonably well at the ages comprising the bulk of the landings. The estimated mean weights at age were multiplied by the respective percentage age compositions to give the average weight per fish for each component of the landings as determined by the following procedure: in 1969, U.S.S.R. 5Z data were applied to all landings; and in 1970 and 1971, U.S.S.R. and Polish 5Z data were applied to the respective landings by those countries, the average of those data was applied to the remaining landings in Subarea 5, and the U.S.S.R. Statistical Area 6 data were applied to all landings from that area. Total number landed in each component was determined by dividing the total weight landed by the average weight per fish. Number at age in each component was determined by applying the percentages from the appropriate age composition to the total number. Numbers at age from all components were summed to give a total estimated number landed at each age (Table 11, Figure 6).

The estimated number landed increased from 682 million in 1969 to 1.3 billion in 1971. The 1967 year-class comprised the bulk of the landings in each year. The estimated number landed from the 1969 year-class at age two in 1971 was 277 million compared with 571 million from the 1967 year-class at age two in 1969.

Number landed at each age per standardized hour fished (Table 12, Figure 7) was estimated by dividing the number landed at age (Table 11) by the standardized hours fished adjusted for learning (Table 8). Total number landed per hour for all ages declined from 7,972 in 1969 to 3,394 in 1971. Number landed per hour from the 1967 year-class decreased from 6,681 in 1969 to 1,366 in 1971. Number landed per hour from the 1969 year-class at age two was only 11 percent of the number per hour taken from the 1967 year-class at age two. Without the adjustment for learning, the number landed per hour from the 1969 year-class at age two was 21 percent of the number landed per hour from the 1967 year-class at age two.

MORTALITY

Survival rates (S) were obtained for mackerel in 1970 by virtual population analysis (Gulland, 1965) from numbers landed at age (Table 11). A decrease in the survival rate occurred with age (Table 13) with S ranging from 0.74 at age two (equivalent to an instantaneous total mortality (Z) of 0.30) to 0.30 at age nine (Z = 1.20)). The mean survival rate obtained from the ratio of the summed virtual populations at ages 4-11 in 1971 and 3-10 in 1970 was 0.55 (Z = 0.60). The mean rate for ages 6-11/5-10 was 0.44 (Z = 0.82).

Survival rates were also calculated between successive ages of each year-class in 1970-1971 from the number of mackerel landed per standardized hour fished adjusted for learning (Table 12). The rate showed a general decrease with age (Table 14) varying from 0.77 between ages four and five (Z = 0.26) to 0.22 at ages 9-10 (Z = 1.51). The mean rate from the ratio of the summed numbers landed per hour at ages 4-11 in 1971 and ages 3-10 in 1970 was 0.63 (Z = 0.46), whereas the rate from the ratio of ages 6-11 and 5-10 was 0.41 (Z = 0.89).

The Z values calculated by the two methods do not attain stability after any particular age but increase with age. The results do suggest, however, that full recruitment to the fishery occurs between ages three and five. If full recruitment at age five is assumed, then the results of the present study suggest a Z for the fully-recruited year-classes between 0.82 and 0.89.

Aasen (1969) and Postuma (1969) have suggested an M of 0.20 for the North Sea mackerel. Assuming M = 0.20, the mean F for the fully-recruited year-classes in 1970-1971 was between 0.62 and 0.69.

YIELD

Yield per Recruit

Yield per recruit values were computed for mackerel using the Beverton and Holt (1957) model. The following parameters were used: W_∞ = 442 gm, K = 0.536, t_0 = -0.586, t_r = 1, t_λ = 12, and M = 0.20. Results are given in Table 15 with age at recruitment to the fishery (t_c) varying from 1 to 4 years. Yield per recruit curves for t_c at 1, 2, and 3 years are plotted in Figure 8. A yield isopleth diagram is shown in Figure 9.

The values of F giving maximum yield per recruit (F_{max}) at t_c of 1, 2, and 3 years are 0.50, 1.00, and >2.00, respectively (Table 16). The respective values of $F_{0.1}$ are 0.28, 0.35, and 0.43. The change in yield per recruit from $F_{0.1}$ to F_{max} varies from 6 percent at $t_c = 1$ to 17 percent at $t_c = 3$. However, the change in F from $F_{0.1}$ to F_{max} ranges from 79 percent at $t_c = 1$ to >365 percent at $t_c = 3$.

Maximum yield per recruit increases 18 percent by doubling t_c from 1 to 2 years and F from 0.50 to 1.00, and increases 26 percent by tripling t_c from 1 to 3 years and quadrupling F from 0.50 to 2.00.

Assuming a mean F in 1970-1971 of 0.65, maximum yield per recruit would have occurred at $t_c = 2.5$ (Table 15, Figure 9). Data are not available from which to determine the actual t_c in the fishery. If t_c was 1.5 years or less, then F_{max} would have been reached or exceeded at an F of 0.65. For t_c between 1.5 and 3 years, yield per recruit at F = 0.65 would have been within 8 percent of the maximum yield per recruit at those ages. However, F in 1970-1971 was beyond $F_{0.1}$ for all levels of t_c.

Maximum Sustainable Yield

An estimate of maximum sustainable yield (MSY) for the mackerel stock in Subarea 5 and Statistical Area 6 was obtained by a simplified application of the Schaefer-logistic-type model. An equilibrium relationship between fishing effort and catch/effort was determined by fitting a regression line by the least squares method to the standardized landings/hour index versus standardized hours fished (from effort adjusted for learning) for the years 1968-1971 as given in Table 8. The relationship (Figure 10) is described by the equation: $Y = 1.6593 - 0.00000222X$, where Y = landings/hour and X = hours fished. The coefficient of determination of 0.77 indicates a good fit of the data. The equilibrium catch-effort relationship is illustrated in Figure 11.

An MSY of 310,000 MT was obtained by this method. The estimate of effort required to produce the MSY was 374,000 standardized hours. These results indicate that the 1971 landings and fishing effort exceeded the estimated MSY level by 39,000 MT and 9,000 standardized hours, respectively.

This estimate of MSY is imprecise because of the use of only four years of catch-effort data. It probably over-estimates MSY because of the necessary simplified application of the Schaefer model which does not adjust for the disequilibrium created by rapid expansion of effort and marked fluctuations in year-class strength exhibited by a stock such as mackerel. However, it does imply that the fishery in 1971 perhaps exceeded the MSY which agrees with the yield per recruit studies. Since the present estimate of 310,000 MT is based upon the strong 1967 and 1966 year-classes, a long-term MSY at that level would have to be maintained by a continued recruitment pattern which would include comparably strong year-classes. It may thus be reasonable to assume that the long-term MSY for mackerel is less than 310,000 MT.

DISCUSSION

The recent phenominal increase in mackerel landings in Subarea 5 and Statistical Area 6 was accompanied by a marked decline in relative stock abundance as measured by standardized commercial landings/hour (50 percent decrease from 1968 to 1971) and U.S.A. research vessel ln (catch/tow) indices (55 percent decrease from 1968 to 1973). The increased landings resulted from a 12-fold increase in fishing effort from 1968 to 1971, much of this effort having been diverted from the declining sea herring stocks.

Evidence for the existence of a strong 1967 year-class was provided by percentage age compositions of U.S.S.R. and Polish commercial landings as well as by U.S.A. research vessel data. A good 1966 year-class was also indicated by the commercial landings data. These two year-classes were the mainstay of the fishery during 1969-1971.

Data are less conclusive regarding strong year-classes after 1967. U.S.S.R and Polish commercial data for 1970-1971 suggest an above-average 1969 year-class on the basis of percentage age compositions. However, the substantial contribution to the landings by that year-class resulted primarily from large increases in fishing effort. Data show, in fact, that based on the number landed per standardized hour fished the 1967 year-class at age two was five (with effort unadjusted for learning) to nine (with effort adjusted for learning) times as abundant as the 1969 year-class at age two. The U.S.A. research vessel survey data do not support the presence of any recent year-classes comparable in strength to the 1967 year-class.

The 1967 year-class has nearly completed its effective contribution to the fishery. Assuming that total mortality remained the same in 1972 and 1973 as in 1970-1971 ($Z = 0.85$), the estimated landings of the 1967 year-class would have decreased from 152,000 MT in 1971 to 84,500 MT in 1972 and 41,400 MT in 1973. Continued large landings of the magnitude reported for 1971 (349,000 MT) and 1972 (400,000 MT) must be supported by more recent year-classes. All available data suggest that these year-classes are small relative to 1967 and not capable of supporting such a harvest without a large increase in F.

Analyses have shown that in 1971 the stock was fished at a level exceeding the MSY, and that fishing mortality exceeded $F_{0.1}$ and, depending on t_c, either exceeded or approached F_{max}. Available data indicate that the increased landings in 1972 required a substantial increase in fishing effort. The Report of the Assessments Subcommittee (ICNAF Summ. Doc. 73/1) indicated that fishing effort in Subarea 5 and Statistical Area 6 underwent an increase from 1971 to 1972 considerably in excess of 10 percent. Much of that effort undoubtedly was directed towards mackerel.

The 1971 and estimated 1972 landings exceeded the estimated MSY of 310,000 MT by 39,000 and 100,000 MT, respectively, whereas the 1973 quota is 140,000 MT in excess of this figure. Such a quota could only be supported by the continued recruitment of exceptionally-good year-classes such as that of 1967, but all available data and the analyses thereof indicate that this is not evident at the present time.

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Table 1. Growth of mackerel estimated by the von Bertalanffy growth equation. Fork lengths are used with total length given in parentheses.

Age (years)	Sample Size	Length (cm) Observed	Length (cm) Calculated	Calculated Weight (gm)
1	61	20.0	20.1(22.1)	69
2	36	26.8	26.3(28.9)	170
3	23	29.6	29.9(32.9)	260
4	13	31.2	32.1(35.3)	329
5	9	33.1	33.3(36.6)	371
6	3	34.6	34.0(37.4)	398
7	1	37.4	34.5(38.0)	418
8	1	38.0	34.7(38.2)	426

Table 2. Mackerel landings (MT) from ICNAF Subarea 5 and Statistical Area 6 in 1961-1971.

Year	USA	USSR	Poland	Romania	Bulgaria
Subarea 5					
1961	1,027	-	-	-	-
1962	822	-	111	-	-
1963	1,202	896	-	-	-
1964	1,264	533	-	-	-
1965	1,467	2,475	1	-	-
1966	1,903	5,446	6	-	-
1967	3,216	11,907	507	138	-
1968	3,001	33,961	10,160	283	-
1969	3,873	47,547	13,421	140	2,083
1970	3,092	56,457	40,987	758	4,007
1971	1,593	59,074	43,682	1,774	1,632
Statistical Area 6					
1961	334	-	-	-	-
1962	116	-	-	-	-
1963	118	293	-	-	-
1964	380	94	-	-	-
1965	531	53	-	-	-
1966	821	1,252	-	-	-
1967	675	6,087	-	-	-
1968	928	7,333	448	-	-
1969	491	37,563	4,977	-	-
1970	957	68,026	27,153	-	-
1971	813	68,754	68,612	2,747	26,875
Total					
1961	1,361	-	-	-	-
1962	938	-	111	-	-
1963	1,320	1,189	-	-	-
1964	1,644	627	-	-	-
1965	1,998	2,528	1	-	-
1966	2,724	6,698	6	-	-
1967	3,891	17,994	507	138	-
1968	3,929	41,294	10,608	283	-
1969	4,364	85,110	18,398	140	2,083
1970	4,049	124,483	68,140	758	4,007
1971	2,406	127,828	112,294	4,521	28,507

- continued

Table 2. continued

Year	Fed. Rep. Germany	German Dem. Rep.	Japan	Canada	Spain	Cuba	Non-Member	Total
	Subarea 5							
1961	-	-	-	-	-	-	-	1,0
1962	-	-	-	-	-	-	-	9
1963	-	-	-	-	-	-	-	2,09
1964	-	-	-	-	-	-	-	1,79
1965	-	-	-	-	-	-	11	3,9
1966	-	-	-	-	-	-	3	7,3
1967	90	-	-	-	-	-	48	15,90
1968	119	-	1	-	-	-	3,252	50,77
1969	89	2,021	197	-	-	-	253	69,62
1970	1,004	2,920	463	-	-	-	-	109,68
1971	1,175	7,090	272	-	3	145	-	116,44
	Statistical Area 6							
1961	-	-	-	-	-	-	-	33
1962	-	-	-	-	-	-	-	11
1963	-	-	-	-	-	-	-	41
1964	-	-	-	-	-	-	-	47
1965	-	-	-	-	-	-	-	58
1966	-	-	-	-	-	-	-	2,07
1967	-	-	-	-	-	-	163	6,92
1968	2	-	-	16	-	-	158	8,88
1969	-	193	-	-	-	-	-	43,22
1970	45	2,711	1,037	-	-	-	-	99,92
1971	1,620	62,083	753	-	47	-	-	232,30
	Total							
1961	-	-	-	-	-	-	-	1,36
1962	-	-	-	-	-	-	-	1,049
1963	-	-	-	-	-	-	-	2,509
1964	-	-	-	-	-	-	-	2,27
1965	-	-	-	-	-	-	11	4,538
1966	-	-	-	-	-	-	3	9,431
1967	90	-	-	-	-	-	211	22,831
1968	121	-	1	16	-	-	3,410	59,662
1969	89	2,214	197	-	-	-	253	112,848
1970	1,049	5,631	1,500	-	-	-	-	209,617
1971	2,795	69,173	1,025	-	50	145	-	348,744

Table 3. Mackerel landings (MT) from ICNAF Subarea and Statistical Area 6 by Division and month in 1969-71.[1]

Year/Month		5Y	5Ze	5Zw	5NK	6A	6B	6C	6NK
1969	Jan	-	-	135	-	207	50	202	-
	Feb	-	-	106	-	25	677	2,204	-
	Mar	-	18	47	-	364	2,472	21,604	-
	Apr	-	177	2,323	-	2,778	5,580	2,746	-
	May	1,324	1,788	4,920	-	2,256	785	-	-
	Jun	1,093	2,142	5,585	-	15	133	-	-
	Jul	383	4,664	3,127	80	36	-	-	-
	Aug	246	5,269	2,975	20	4	-	-	-
	Sep	270	4,420	884	40	18	-	-	-
	Oct	61	5,225	2,444	-	2	-	-	-
	Nov	50	2,002	9,780	-	804	-	-	-
	Dec	36	570	4,897	-	222	40	-	-
1970	Jan	4	3,746	102	-	159	1,446	2,597	-
	Feb	-	4,651	-	-	31	3,964	12,461	-
	Mar	-	3,278	393	-	3,984	16,858	7,354	-
	Apr	-	2,547	5,211	-	13,505	20,134	209	-
	May	606	10,383	11,120	-	7,106	1,575	-	-
	Jun	544	6,956	4,824	-	412	-	-	-
	Jul	694	5,654	1,280	-	24	-	-	-
	Aug	433	7,158	335	-	7	-	-	-
	Sep	187	4,730	47	-	23	-	-	-
	Oct	170	2,462	1,546	-	21	-	-	-
	Nov	410	6,476	5,295	-	142	151	-	-
	Dec	690	8,317	4,943	-	4,728	1	-	-
1971	Jan	170	165	214	-	12,273	11,451	6,225	-
	Feb	-	37	226	-	3,748	10,005	961	-
	Mar	-	158	73	35	5,171	24,946	6,222	-
	Apr	-	8,355	1,849	2,945	9,644	24,183	296	-
	May	10	10,714	6,727	2,330	7,443	4,515	100	792
	Jun	77	6,632	2,047	1,185	578	63	-	1,449
	Jul	639	4,548	1,215	1,303	12	1	-	-
	Aug	549	5,221	427	1,406	2	1	-	-
	Sep	119	5,716	682	515	2	1	-	-
	Oct	18	2,185	1,291	188	813	-	-	-
	Nov	32	8,836	6,508	647	3,802	-	-	-
	Dec	242	8,170	12,551	2,248	35,427	75	-	-

[1]Does not include landings by Bulgaria in 1969-70, German Democratic Republic in 1971, Japan in 1969-70, Cuba in 1971, and Non-Member in 1969.

Table 4. Gear-tonnage class categories by country used in analysis of variance for estimation of relative catchability coefficients in the mackerel fishery in ICNAF Subarea 5 and Statistical Area 6.

Gear-Tonnage class category	Poland	Romania	USSR	German Dem. Rep.	Bulgaria
1	-	-	OtSi SRT 151-500	-	-
2	OtSi B-10/14 501-900	-	OtSi SRTM 501-900	Ot 501-900	-
3	OtSi B-20 501-900	-	OtSi SRTR 501-900	Mwt 501-900	-
4	OtSt B-29 901-1800	-	-	Ot and Mwt 901-1800	-
5	-	OtSt >1800	OtSt BMRT } >1800 RTM Tropic }	Mwt >1800	-
6	OtSt B-15/22 } 1801-3000 B-418 } B-18 > 3001	-	OtSt RTM Atlantic >1800	Ot >1800	OtSt BMRT } >1800 Atlantic }

Note: SRT, B-10/14, etc., refers to a vessel type or class within a given tonnage-class by which category catch /effort data are reported to ICNAF on the STANA 1W or STATLANT 21B Forms which offer a finer breakdown of statistics than is provided in Table 4 of the ICNAF Statistical Bulletin.

Table 5. Gear-tonnage class categories by country indicating years for which effort was adjusted for learning.

Country	Gear	Tonnage Class		Years Adjusted Subarea 5	Years Adjusted Statistical Area 6
Poland	OtSi	B-10/14	501-900	1970, 71	1970, 71
	OtSi	B-20	501-900	1968, 69	1969, 70
	OtSt	B-29	901-1800	1968, 71	1971
	OtSt	B-15/22	1801-3000	1968, 69	1970, 71
	OtSt	B-418	1801-3000		
	OtSt	B-18	>1800		
Romania	OtSt		>1800	1970, 71	1971
USSR	OtSi	SRT	151-500	1968, 69	1968, 69
	OtSi	SRTM	501-900	1970, 71	1969, 70
	OtSi	SRTR	501-900	1969, 70	1969, 70
	OtSt	BMRT	>1800	1968, 69	1968, 69
	OtSt	RTM Tropic	>1800		
	OtSt	RTM Atlantic	>1800	1969, 70	1969, 70
German Dem. Rep	Ot		501-900	1970	1969, 70
	Mwt		501-900	1969, 70	1970
	Ot, Mwt		901-1800	1970	1970
	Mwt		>1800	1969, 70	1970
	Ot		>1800	1970	1970
Bulgaria	Ot	BMRT	>1800	None[1]	
	Ot	Atlantic	>1800		

[1]Data only available in 1971; size of landings reported in 1969-70 suggests that learning was completed in those two years.

Table 6. Analysis of variance of ln (catch/effort) data for mackerel fishery in ICNAF Subarea 5 and Statistical Area 6.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F
	Without Learning			
Total	107.31	171		
Gear-tonnage class (unadjusted)	42.84	5		
Country (unadjusted)	8.28	4		
Gear-tonnage class (adjusted)	35.91	5	7.18	18.89**
Country (adjusted)	1.34	4	0.34	0.89
Interaction	4.23	6	0.70	
Error	58.89	156	0.38	
	With Learning			
Total	154.31	171		
Gear-tonnage class (unadjusted)	47.00	5		
Country (unadjusted)	30.97	4		
Gear-tonnage class (adjusted)	32.73	5	6.55	11.91**
Country (adjusted)	16.70	4	4.18	[illegible].60**
Interaction	4.74	6	0.79	
Error	85.87	156	0.55	

**Significant at 0.01 level.

Table 7. Estimates of relative catchability coefficients for various gear-tonnage class categories by country obtained with and without adjustments for learning.

Country	Gear	Tonnage-Class		Category	Relative Catchability Coefficients Without Learning	With Learning
Poland	OtSi	B-10/14	501-900	2	0.97	1.46
	OtSi	B-20	501-900	3	1.71	2.12
	OtSt	B-29	901-1800	4	3.30	5.82
	OtSt OtSt OtSt	B-15/22 B-418 B-18	} 1801-3000 >1800 }	6	3.60	4.36
Romania	OtSt		>1800	5	1.98	4.14
USSR	OtSi	SRT	151-500	1	1.00	1.00
	OtSi	SRTM	501-900	2	0.86	1.22
	OtSi	SRTR	501-900	3	1.52	1.78
	OtSt OtSt	BMRT RTM Tropic	} >1800	5	2.18	1.87
	OtSt	RTM Atlantic	>1800	6	3.18	3.67
German Dem. Rep.	Ot		501-900	2	1.21	2.99
	Mwt		501-900	3	1.98	4.36
	Ot Mwt }		901-1800	4	3.81	11.96
	Mwt		>1800	5	2.84	4.58
	Ot		>1800	6	4.15	8.96
Bulgaria	Ot Ot	BMRT Atlantic	} >1800	6	3.87	2.54

Table 8. Total mackerel landings, standardized landings/hour without and with adjustments for learning, and standardized hours fished without and with adjustments for learning in ICNAF Subarea 5 and Statistical Area 6 in 1968-1971.

Year	Total Landings (MT)	Standardized Landings/Hour Without Learning	Standardized Landings/Hour With Learning	Standardized Hours Fished Without Learning	Standardized Hours Fished With Learning
1968	59,662	0.46	1.80	129,700	33,146
1969	112,848	0.62	1.32	182,013	85,491
1970	209,617	0.89	1.05	235,525	199,635
1971	348,744	0.82	0.91	425,298	383,235

Table 9. Stratified mean catch (pounds, ln scale) of mackerel per tow from spring (strata 1-14, 61-76), summer (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26), and fall (same strata as summer) groundfish survey cruises with 95% confidence limits indicated.

Year	Spring	Summer	Fall	
	U.S.A.	U.S.A.	U.S.A.	U.S.S.R.
1963	-	0.07 ± 0.10	0.02 ± 0.03	-
1964	-	0.06 ± 0.07	<0.01 ± 0.00	-
1965	-	0.16 ± 0.19	0.07 ± 0.06	-
1966	-	-	0.09 ± 0.07	-
1967	-	-	0.32 ± 0.14	0.27 ± 0.10
1968	0.73 ± 0.24	-	0.17 ± 0.11	0.27 ± 0.14
1969	0.03 ± 0.02	0.47 ± 0.26	0.21 ± 0.16	0.88 ± 0.42
1970	0.56 ± 0.18	-	0.11 ± 0.08	0.23 ± 0.23
1971	0.52 ± 0.18	-	0.09 ± 0.06	0.25 ± 0.16
1972	0.42 ± 0.18	-	0.11 ± 0.07	0.60 ± 0.31
1973	0.33[1]			

[1]Preliminary calculation, confidence limits not available.

Table 10. Percentage age composition of mackerel landings from ICNAF Division 5Z and Statistical Area 6 by the USSR and Poland in 1969-71.

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12
					USSR Division 5Z[1]							
1969	-	83.8	12.7	3.2	0.2	0.1	-	-	-	-	-	-
1970	16.1	7.5	50.2	15.8	4.0	1.4	1.5	1.5	1.3	0.7	-	-
1971	0.4	8.8	8.1	51.2	24.2	4.4	0.8	0.3	0.6	0.7	0.4	0.1
					Poland Division 5Z[2]							
1970	12.5	1.7	50.1	21.4	8.0	1.9	1.3	1.4	1.3	0.4	-	-
1971	0.8	8.6	3.2	54.4	22.4	5.2	1.4	1.4	1.7	0.9	-	-
					USSR Statistical Area 6[3]							
1970	11.1	3.9	53.2	20.6	5.6	1.3	1.2	1.5	1.3	0.3	-	-
1971	8.5	26.3	8.9	35.4	16.1	2.8	0.9	0.5	0.3	0.2	0.1	-

[1]Konstantinov and Noskov (1972).

[2]Chrzan (1972).

[3]A. S. Bogdanov, personal communication.

[able 11. Estimated numbers of mackerel($x10^{-3}$) landed at each age from ICNAF Subarea 5 and Statistical Area 6 in 1969-1971.

	Age												
ear	1	2	3	4	5	6	7	8	9	10	11	12	Total
						Subarea 5							
969	-	326,375	49,463	12,463	779	389	-	-	-	-	-	-	389,469
970	64,601	22,502	221,939	80,216	25,063	7,090	6,268	6,428	5,751	2,569	-	-	442,427
971	2,097	32,026	22,068	193,178	86,115	17,423	3,881	2,805	3,951	2,886	843	232	367,505
						Statistical Area 6							
.969	-	244,779	37,097	9,347	584	292	-	-	-	-	-	-	292,099
970	43,305	15,215	207,551	80,367	21,847	5,072	4,682	5,852	5,072	1,170	-	-	390,133
.971	79,326	245,444	83,059	330,369	150,252	26,131	8,399	4,666	2,800	1,866	933	-	933,245
						Total							
1969	-	571,154	86,560	21,810	1,363	681	-	-	-	-	-	-	681,568
.970	107,906	37,717	429,490	160,583	46,910	12,162	10,950	12,280	10,823	3,739	-	-	832,560
1971	81,423	277,470	105,127	523,547	236,367	43,554	12,280	7,471	6,751	4,752	1,776	232	1,300,750

Table 12. Estimated numbers of mackerel landed per standardized hour fished (adjusted for learning) at each age from ICNAF Subarea 5 and Statistical Area 6 in 1969-1971.

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	Total
1969	-	6,681	1,012	255	16	8	-	-	-	-	-	-	7,972
1970	540	189	2,151	804	235	61	55	62	54	19	-	-	4,170
1971	212	724	274	1,366	617	114	32	19	18	12	5	1	3,394

Table 13. Survival rate (S) and instantaneous total mortality (Z) of the mackerel from ICNAF Subarea 5 and Statistical Area 6 in 1970 derived by virtual population analysis.

Value	Age 1	2	3	4	5	6	7	8	9	10	$\frac{\Sigma 4-11}{\Sigma 3-10}$	$\frac{\Sigma 6-11}{\Sigma 5-10}$
S	0.72	0.74	0.55	0.60	0.48	0.50	0.40	0.35	0.30	0.32	0.55	0.44
Z	0.33	0.30	0.60	0.51	0.73	0.69	0.92	1.05	1.20	1.14	0.60	0.82

Table 14. Survival rate (S) and instantaneous total mortality (Z) of the mackerel from ICNAF Subarea 5 and Statistical Area 6 in 1970-1971 derived from standardized catch/effort data.

Value	Age 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	$\frac{\Sigma 4-11}{\Sigma 3-10}$	$\frac{\Sigma 6-11}{\Sigma 5-10}$
S	*	*	0.64	0.77	0.48	0.52	0.34	0.29	0.22	0.26	0.63	0.41
Z	**	**	0.45	0.26	0.73	0.65	1.08	1.24	1.51	1.35	0.46	0.89

*Denotes value greater than 1.

**Denotes negative value.

Table 15. Yield per recruit (in gm) of mackerel given W_∞ = 442 gm, K = 0.536, t_o = -0.586, t_r = 1, t_λ = 12, and M = 0.2.

				Age at recruitment to the fishery (t_c)									
F	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.
.05	55	54	54	53	52	50	49	47	45	44	42	40	3
.10	90	90	89	88	87	85	83	80	78	75	72	69	6
.15	112	113	113	112	111	109	107	104	101	98	95	91	8
.20	127	128	129	129	128	127	125	122	119	115	112	108	10
.25	136	138	140	141	140	139	137	135	132	128	124	120	11
.30	141	145	148	149	149	148	147	145	142	138	134	130	12
.35	145	149	153	155	156	155	154	152	149	146	142	138	13
.40	146	152	156	159	160	160	160	158	155	152	148	144	14
.45	147	154	158	162	164	164	164	162	160	157	153	149	14
.50	147	154	160	164	166	167	167	166	164	161	157	153	14
.55	147	155	161	165	168	170	170	169	167	164	161	157	15
.60	146	155	161	166	170	172	172	171	170	167	164	160	15
.65	145	154	162	167	171	173	174	173	172	169	166	162	15
.70	144	154	161	167	172	174	175	175	173	171	168	164	16
.75	143	153	161	168	172	175	176	176	175	173	170	166	16
.80	141	152	161	168	173	176	177	177	176	174	171	168	16
.85	140	151	160	168	173	176	178	178	177	176	173	169	16
.90	139	150	160	167	173	177	179	179	178	177	174	170	16
.95	137	149	159	167	173	177	179	180	179	178	175	172	16
1.00	136	149	159	167	173	177	180	181	180	178	176	173	16
1.05	135	148	158	167	173	177	180	181	181	179	177	173	16
1.10	134	147	158	166	173	178	180	181	181	180	177	174	17
1.15	133	146	157	166	173	178	181	182	182	180	178	175	17
1.20	131	145	156	166	173	178	181	182	182	181	179	176	17
1.25	130	144	156	165	172	178	181	182	183	181	179	176	17
1.30	129	143	155	165	172	178	181	183	183	182	180	177	17
1.35	128	142	155	164	172	178	181	183	183	182	180	177	17
1.40	127	142	154	164	172	177	181	183	184	183	181	178	17
1.45	126	141	153	164	172	177	181	183	184	183	181	178	17
1.50	125	140	153	163	171	177	181	183	184	183	181	179	17
1.55	124	139	152	163	171	177	181	184	184	184	182	179	17
1.60	123	139	152	162	171	177	181	184	184	184	182	179	17
1.65	123	138	151	162	171	177	181	184	185	184	182	180	17
1.70	122	137	151	162	170	177	181	184	185	184	183	180	17
1.75	121	137	150	161	170	177	181	184	185	184	183	180	17
1.80	120	136	150	161	170	177	181	184	185	185	183	181	17
1.85	120	135	149	161	170	177	181	184	185	185	183	181	17
1.90	119	135	149	160	170	176	181	184	185	185	184	181	17
1.95	118	134	148	160	169	176	181	184	185	185	184	181	17
2.00	117	134	148	160	169	176	181	184	185	185	184	181	17

Table 16. Summary yield per recruit (Y/R) table giving the following values for t_c of 1, 2, and 3 years: (1) F_{max} and $F_{0.1}$, (2) yield per recruit at F_{max} and $F_{0.1}$, and (3) the ratio of the yield per recruit to F_{max}, t_c = 1.

t_c	F_{max}	$F_{0.1}$	Y/R		Ratio of Y/R to F_{max}, t_c = 1	
			F_{max}	$F_{0.1}$	F_{max}	$F_{0.1}$
1	0.50	0.28	147	139	1.00	0.94
2	1.00	0.35	173	156	1.18	1.06
3	>2.00	0.43	≃185	158	≃1.26	1.07

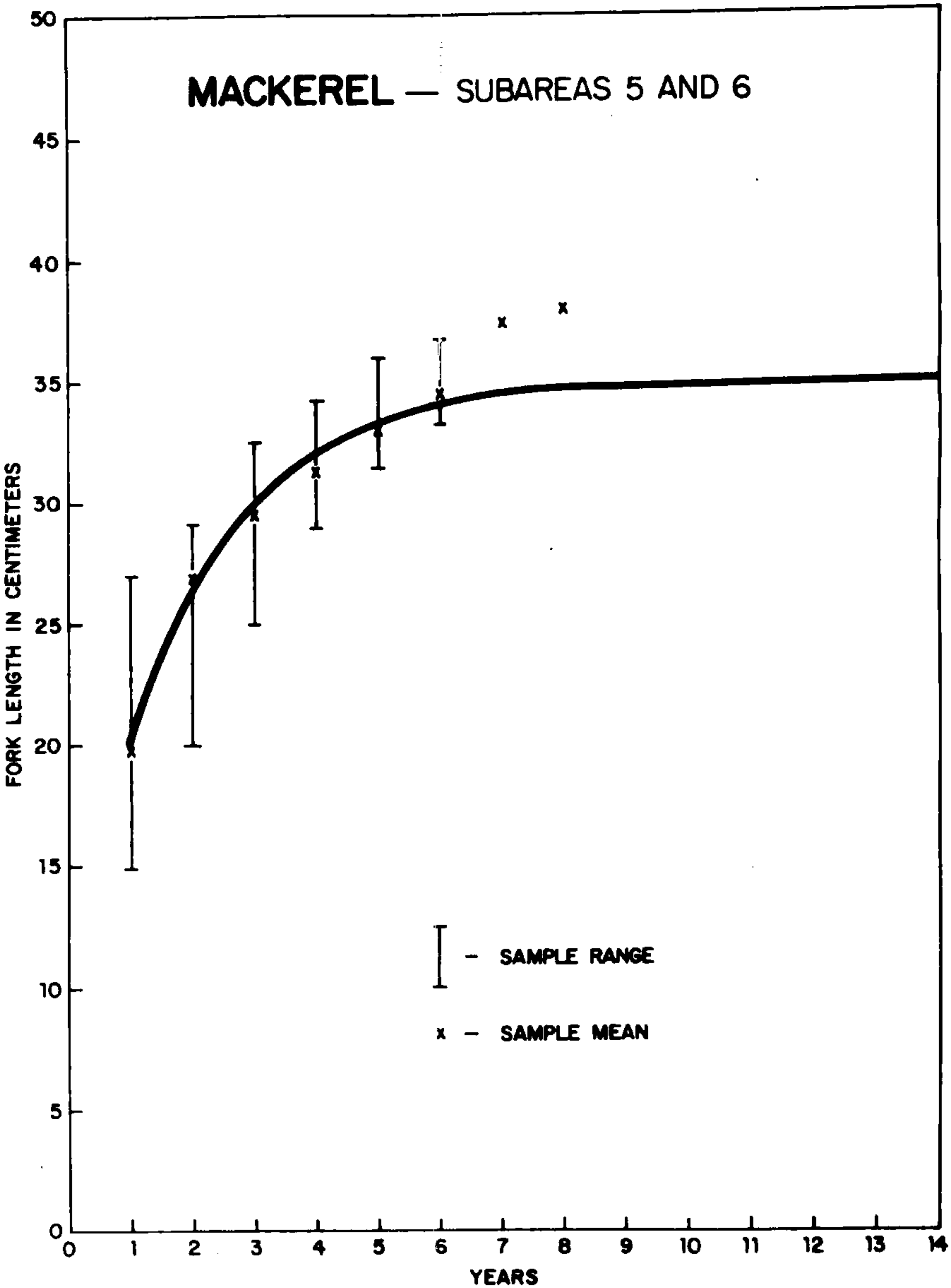

Figure 1. Von Bertalanffy growth curve for mackerel from ICNAF Subarea 5 and Statistical Area 6.

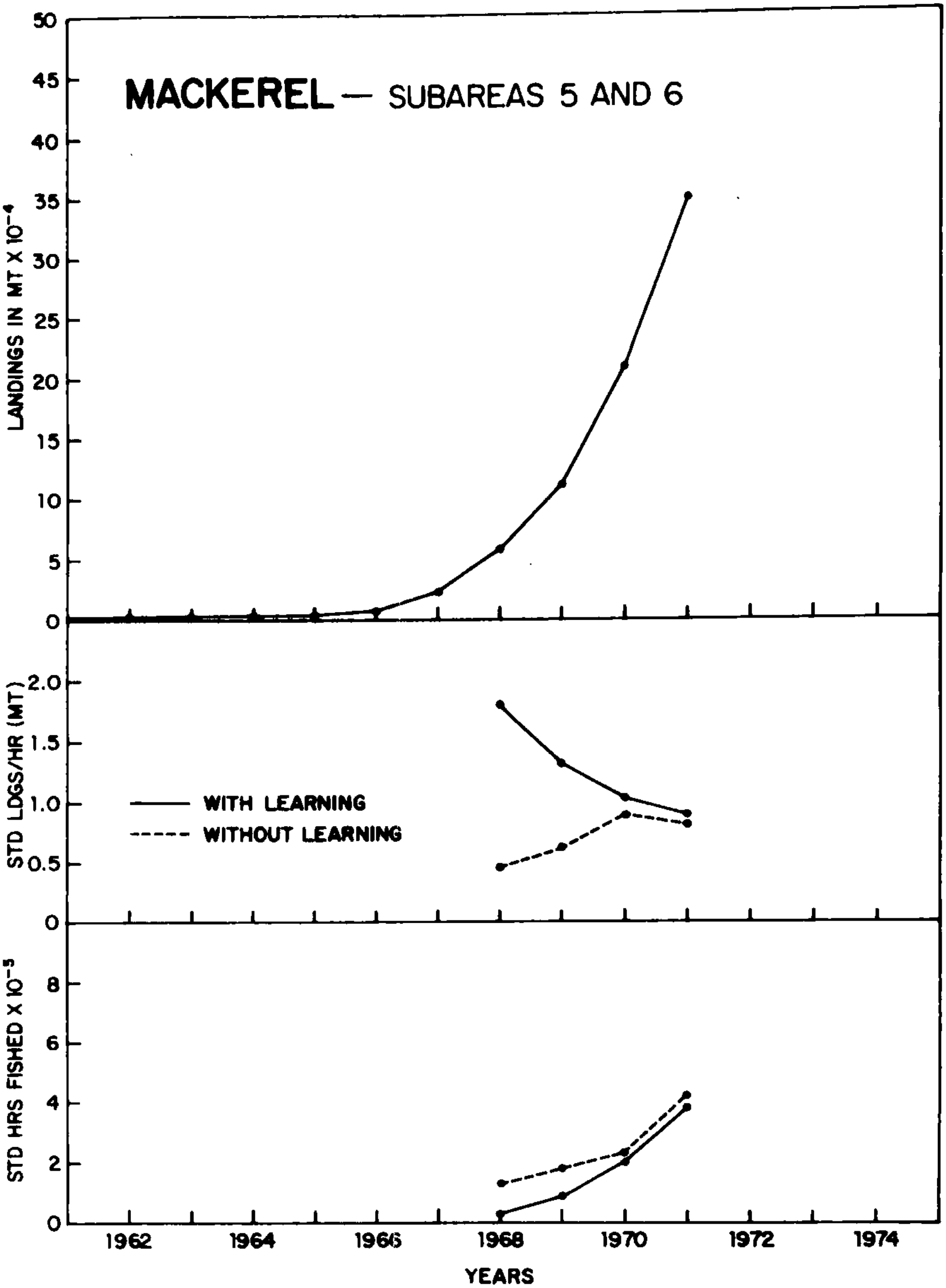

Figure 2. Landings, standardized landings/hour, and standardized hours fished for the ICNAF Subarea 5 and Statistical Area 6 mackerel stock.

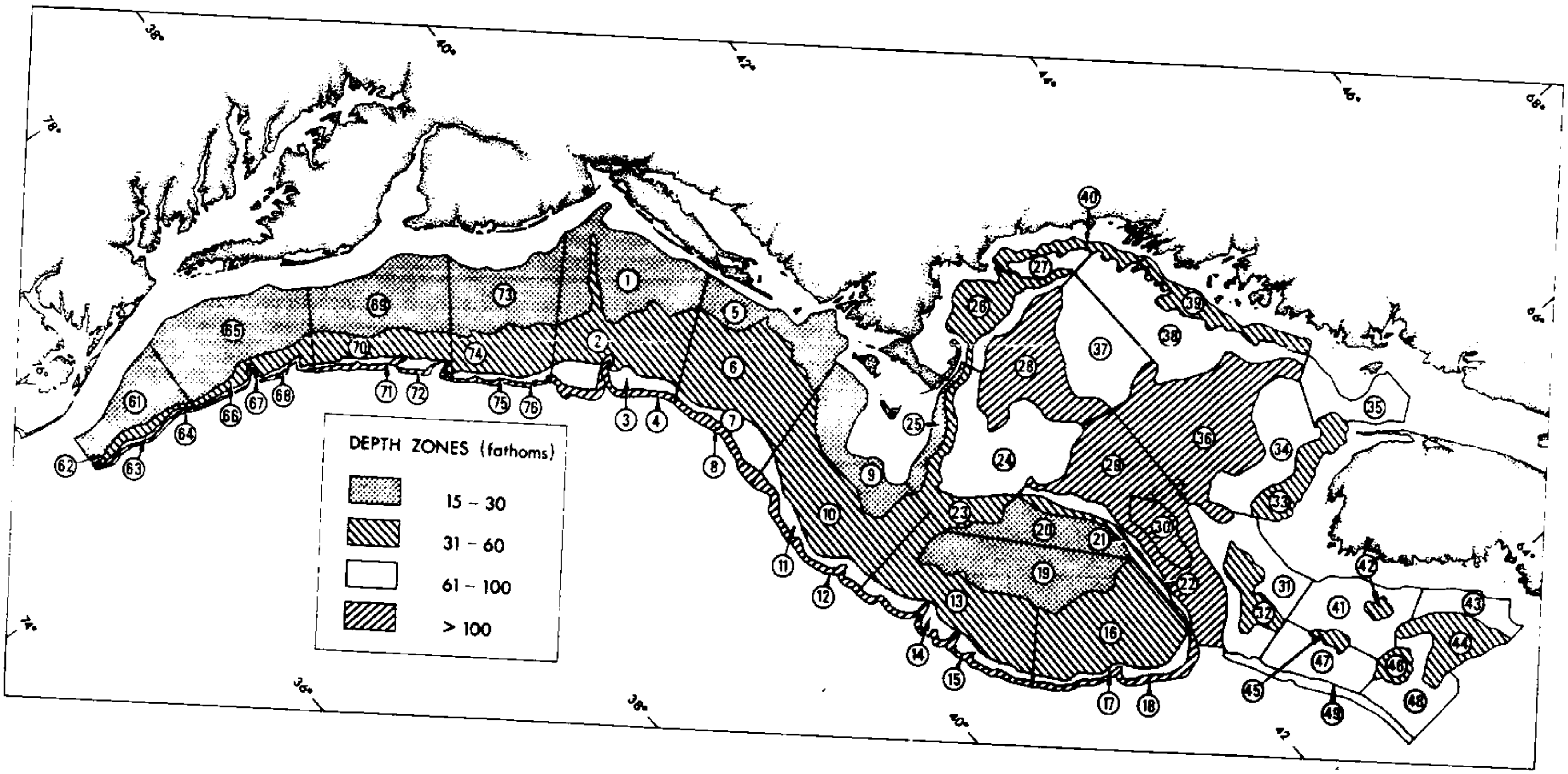

Figure 3. U.S.A.-U.S.S.R. groundfish survey sampling strata.

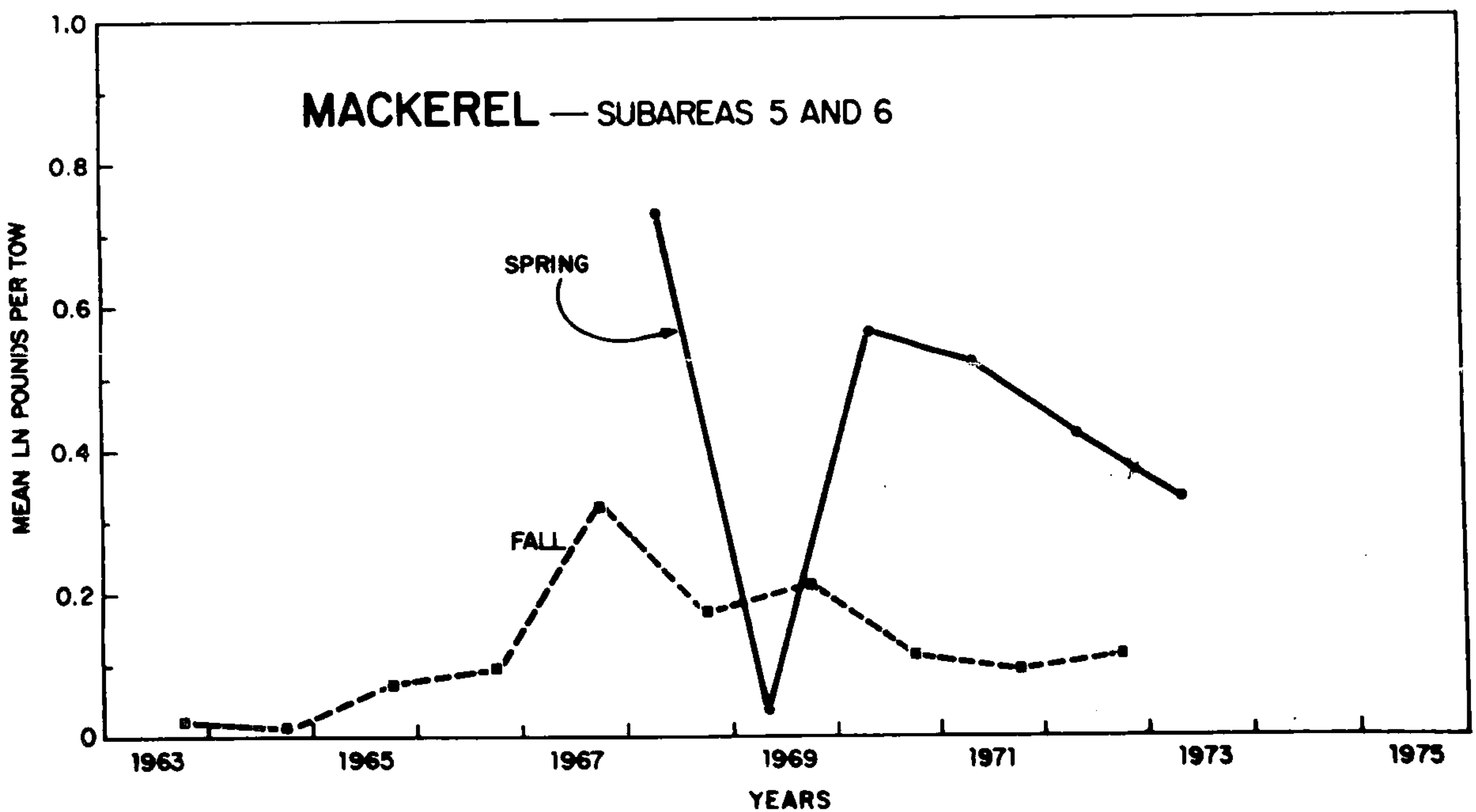

Figure 4. Stratified mean catch/tow (pounds, ln scale) of mackerel from U.S.A. spring and fall groundfish survey cruises in ICNAF Subarea 5 and Statistical Area 6.

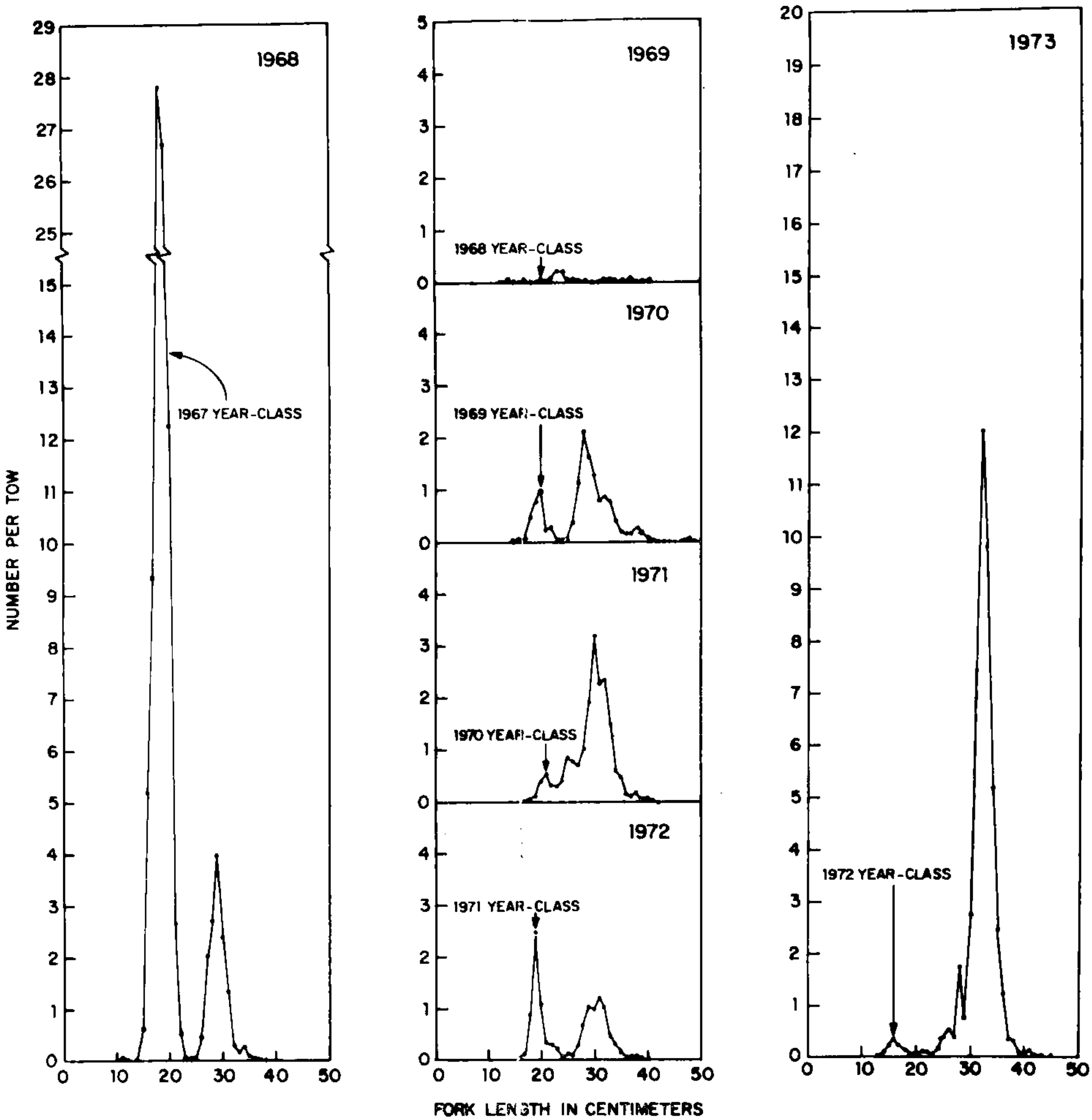

Figure 5. Length frequency distribution of the stratified mean number/tow of mackerel from U.S.A. spring groundfish survey cruises in ICNAF Subarea 5 and Statistical Area 6.

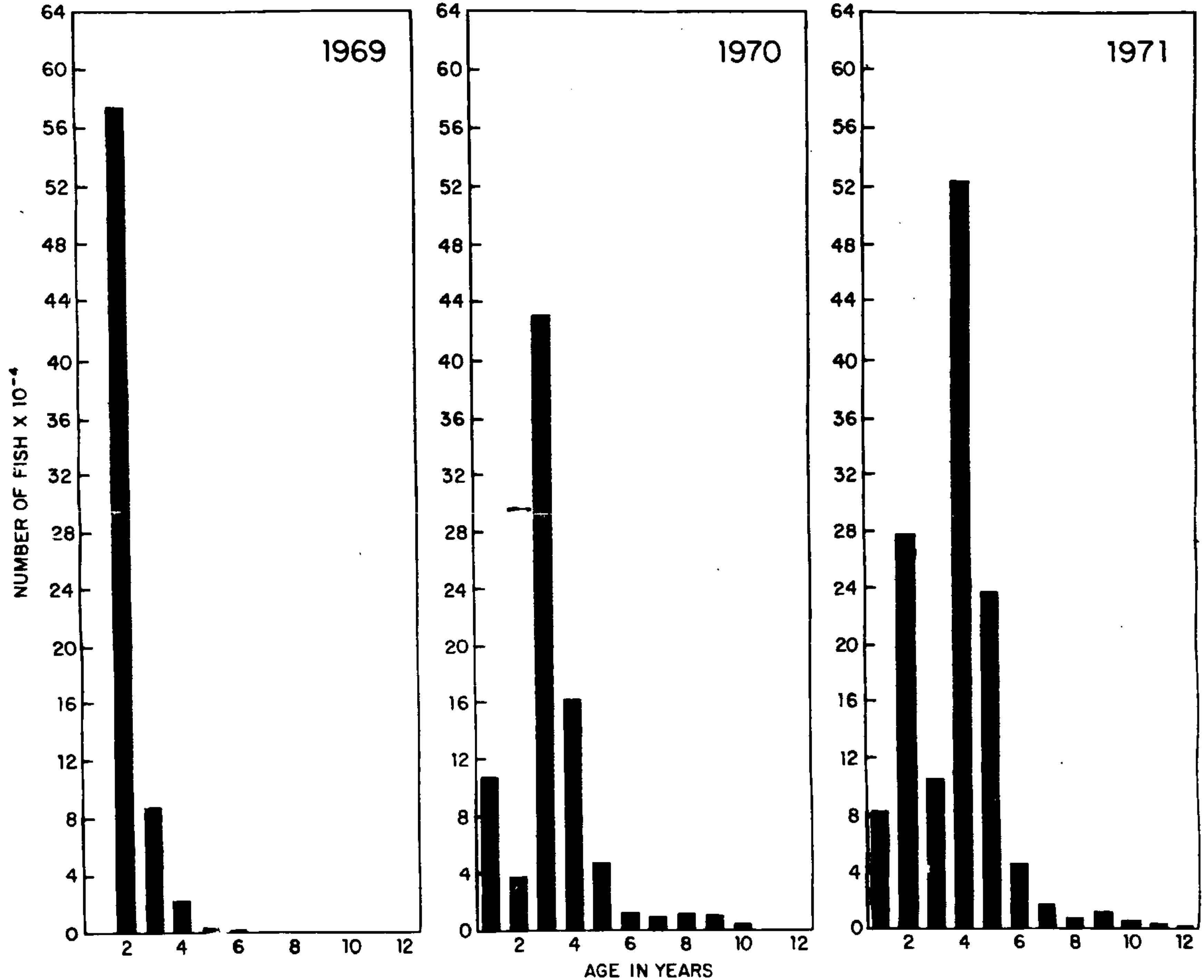

Figure 6. Number of mackerel landed at each age in 1969-1971 from ICNAF Subarea 5 and Statistical Area 6.

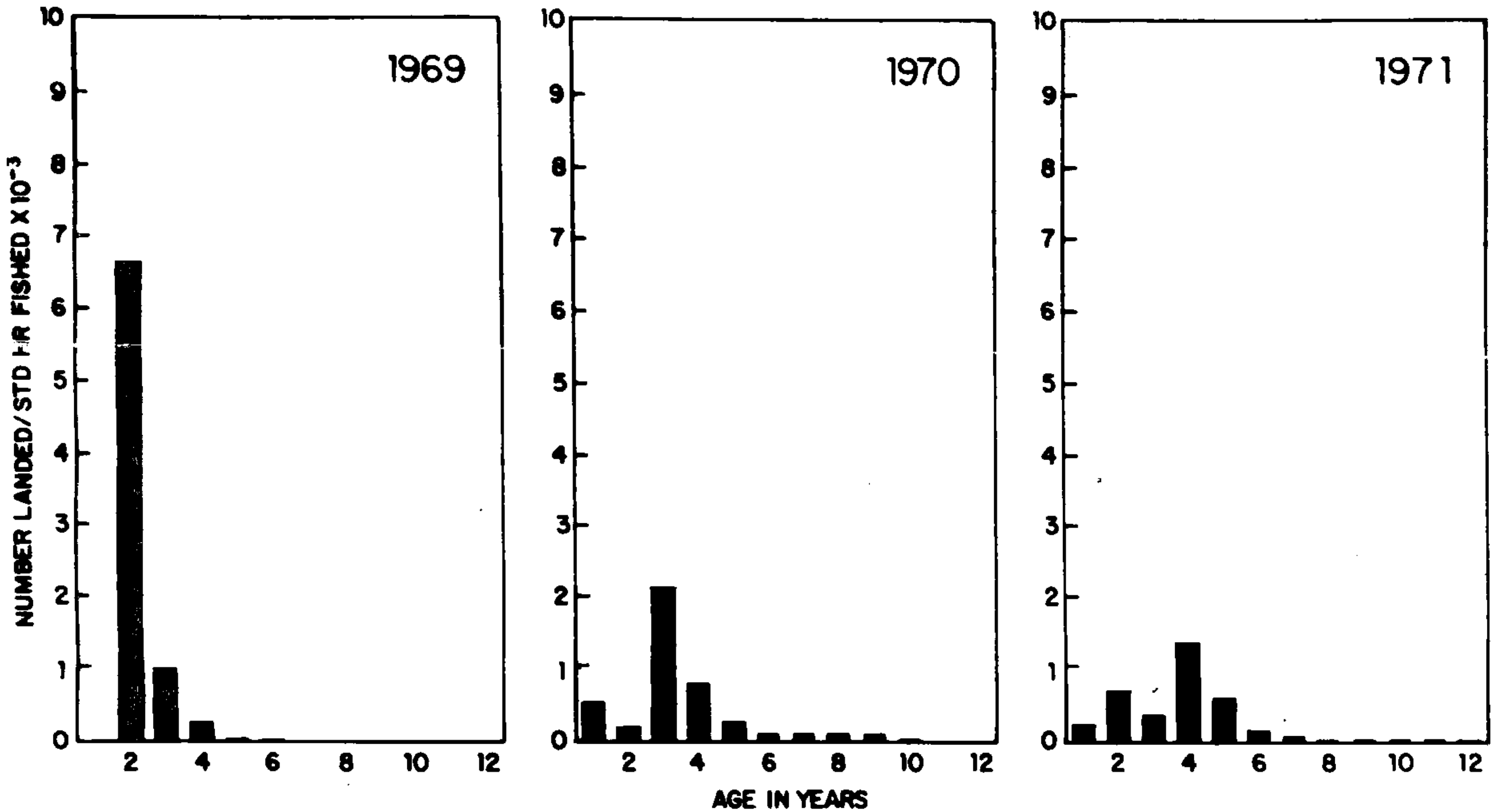

Figure 7. Number of mackerel landed per standardized hour fished (adjusted for learning) at each age in 1969-1971 from ICNAF Subarea 5 and Statistical Area 6.

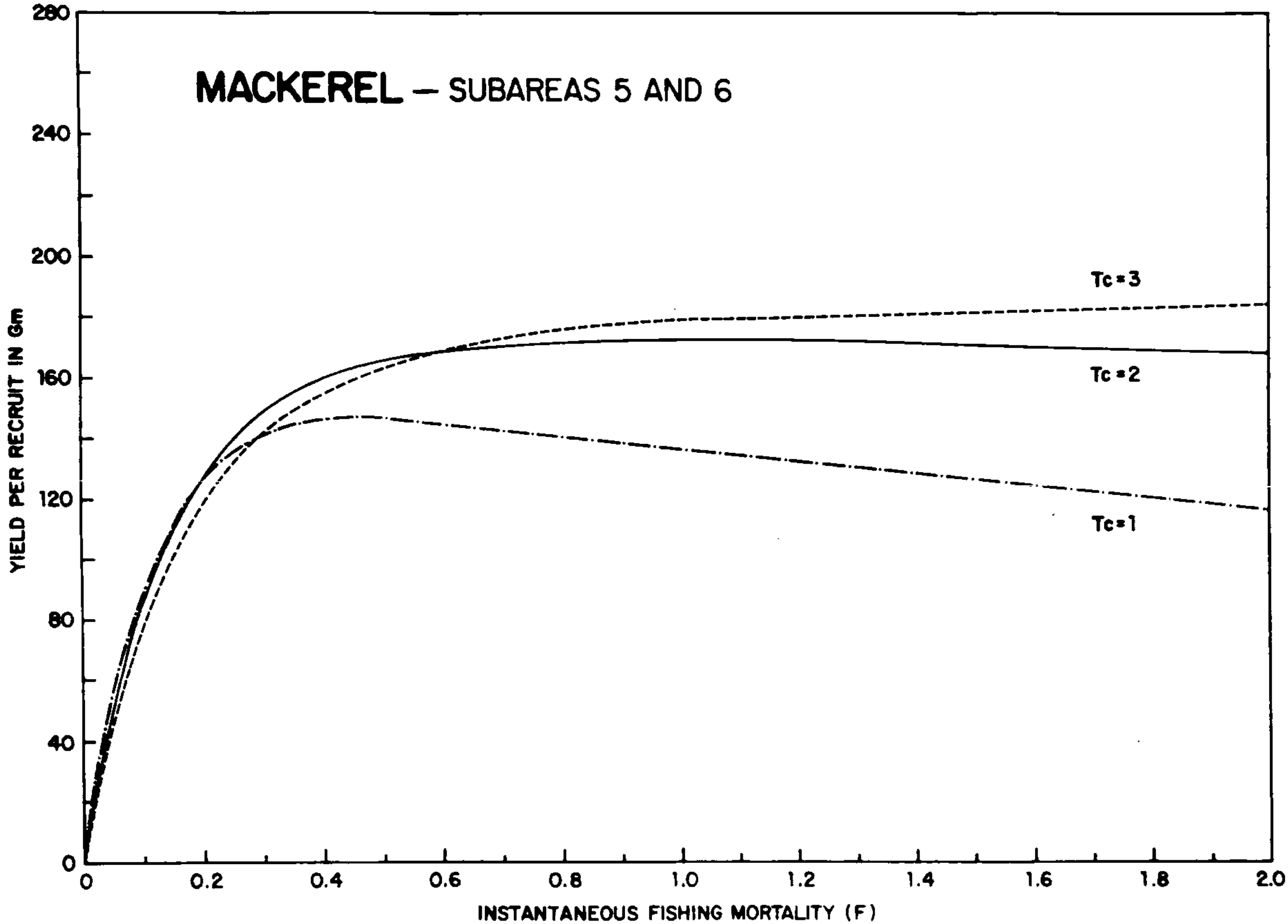

Figure 8. Yield per recruit of the ICNAF Subarea 6 and Statistical Area 6 mackerel stock with age at recruitment to the fishery (t_c) of 1, 2, and 3 years given W_∞ = 442 gm, K = 0.536, t_o = -0.586, t_r = 1, t_λ = 12 and M = 0.20

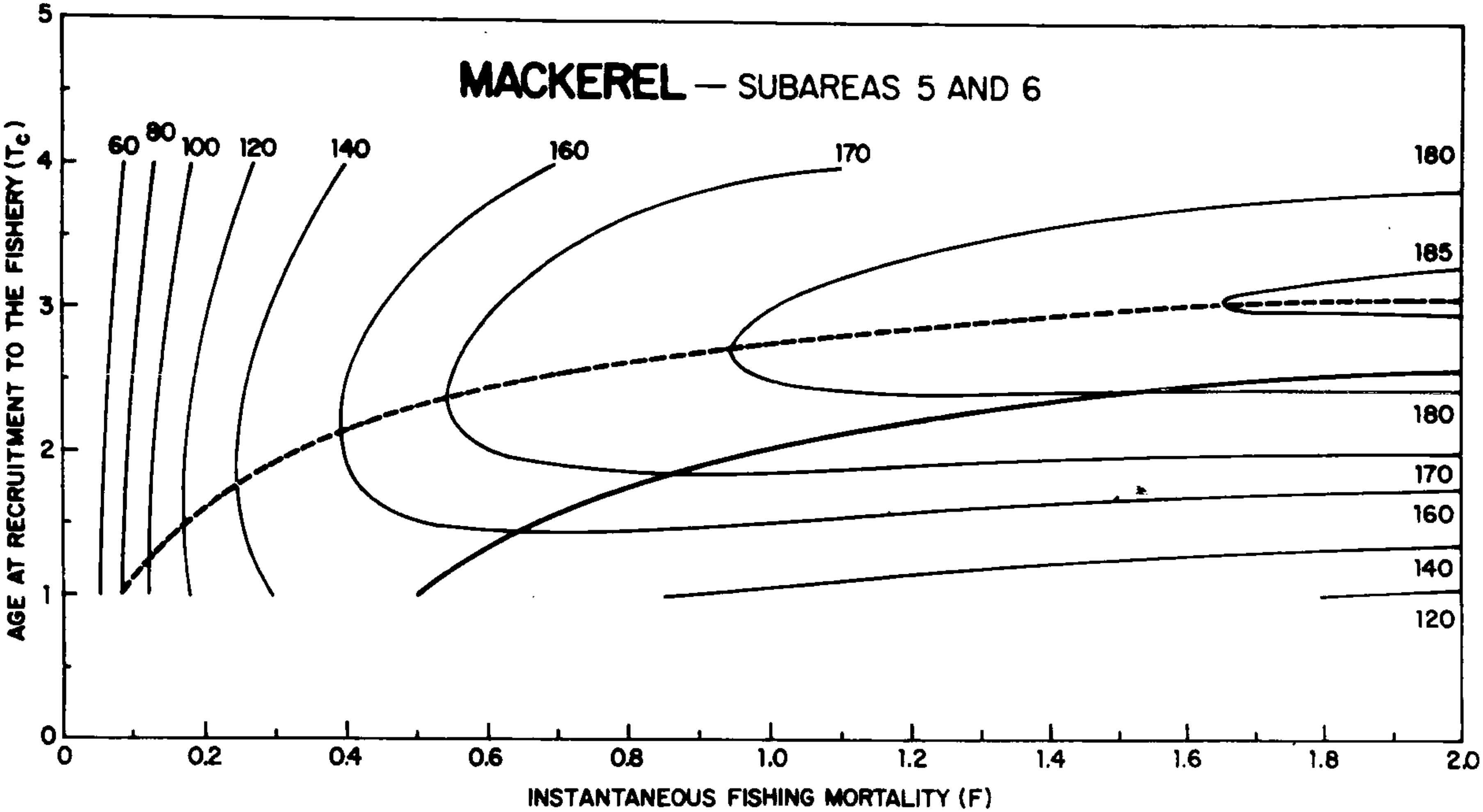

Figure 9. Yield isopleth diagram for the ICNAF Subarea 5 and Statistical Area 6 mackerel stock given W_∞ = 442 gm, K = 0.536, t_o = -0.586, t_r = 1, t_λ = 12, and M = 0.20. The heavy solid line indicates F_{max} at t_c (age at recruitment to the fishery) while the dashed line indicates the t_c giving the greatest yield per recruit at a given F.

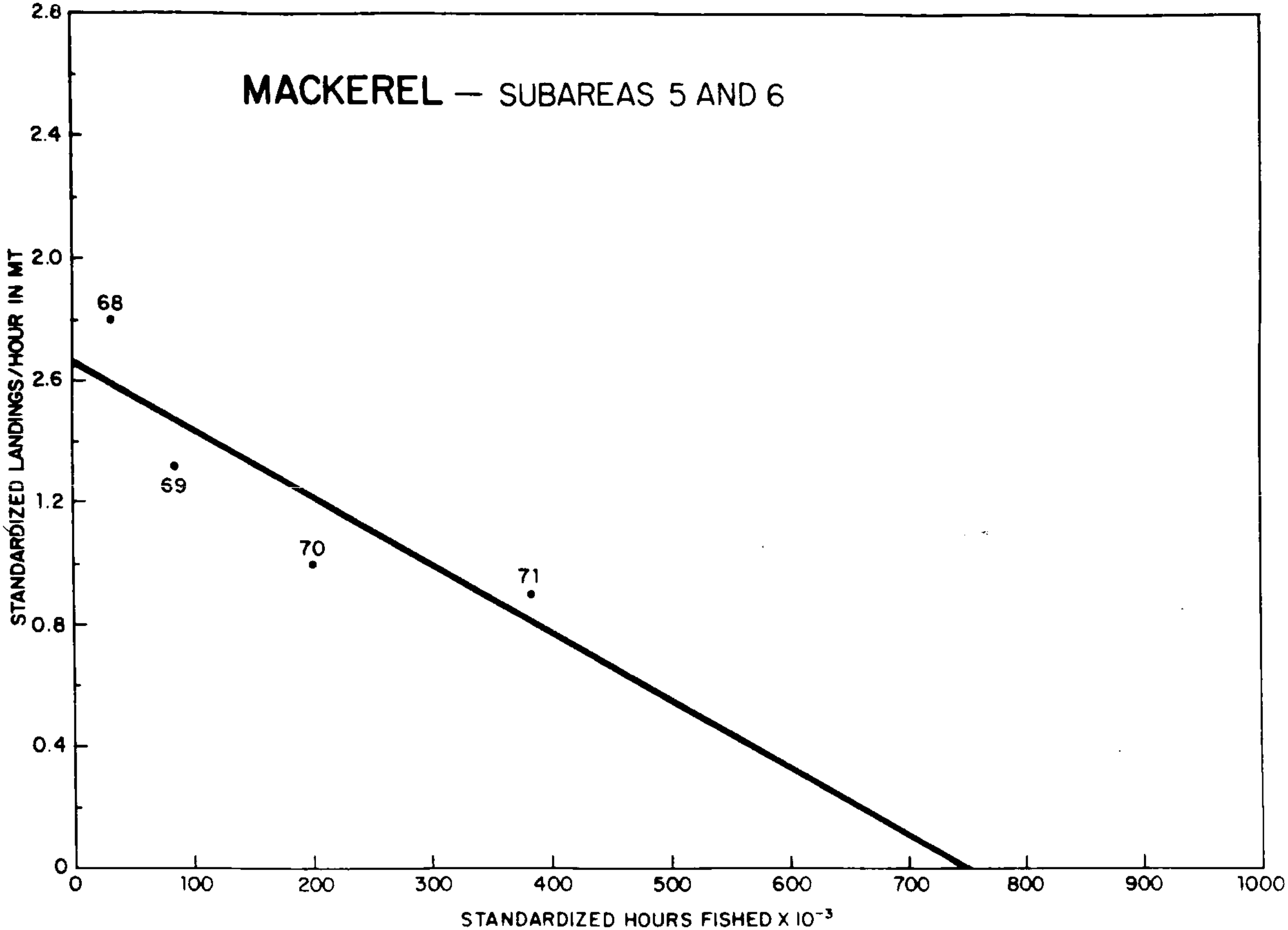

Figure 10. Relationship between standardized landings/hour adjusted for learning and standardized hours fished adjusted for learning in the ICNAF Subarea 5 and Statistical Area 6 mackerel stock.

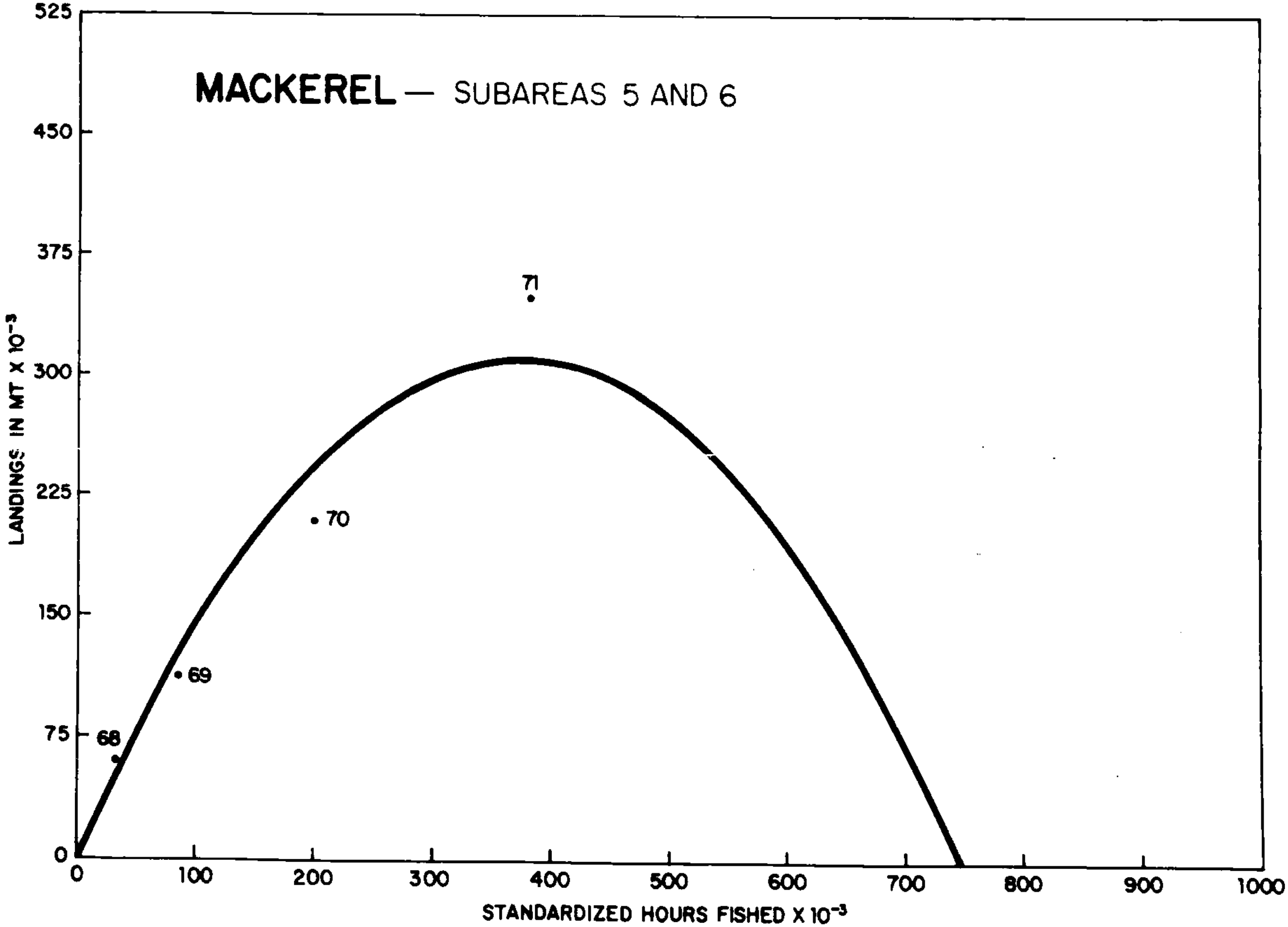

Figure 11. Relationship between landings and standardized hours fished adjusted for learning in the ICNAF Subarea 5 and Statistical Area 6 mackerel stock.