Status of the Northwest Atlantic Mackerel Stock - 1979

by

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Laboratory Reference No. 79-35
August 1979

INTRODUCTION

This report analyzes the status of the Atlantic mackerel (Scomber scombrus) stock distributed throughout ICNAF Subareas 3, 4, and 5 and Statistical Area 6 (SA 3-6) (Figure 1). The analysis reported herein is an update of the assessment by Anderson and Overholtz (1979a) and utilizes procedures described in Anderson (1979) and Anderson and Overholtz (1979a). Included in this report are international commercial and USA recreational catch statistics; USA research vessel bottom trawl survey abundance indices; fishing mortality and stock size estimates from cohort analysis; recruitment estimates; and projected options for catch in 1980, given various levels of catch in 1979, with resulting spawning stock biomasses in 1980.

CATCH

The international mackerel catch (commercial and recreational) in ICNAF SA 3-6 increased from 12,310 tons in 1960 to 431,606 tons in 1972, and subsequently dropped to only 33,450 tons in 1978 (Table 1). The USA commercial catch has ranged between 938 and 4,364 tons during 1960-78 and averaged 2,200 tons per year; the 1978 catch was 1,604 tons. Estimated USA recreational catches have varied from 522 to 33,303 tons (average of 13,200 tons) and increased sharply from 522 tons in 1977 to 6,571 tons in 1978. Canadian catches during 1960-78 have varied from 5,459 to 24,444 tons (1978) and averaged 13,400 tons each year. Catches by countries other than the USA and Canada increased from 11 tons in 1961 to 396,759 tons in 1973 and decreased to only 831 tons in 1978.

The 1978 catch statistics are presently provisional (Table 2). The Canadian catch of 24,444 tons comprised 73% of the total, followed by the USA with 8,175 tons or 24% (commercial and recreational). A total of 24,913 tons was taken in SA 3-4 and 8,537 tons in SA 5-6. The USA imposed a catch

limitation for 1978 of 15,500 tons for the portion of the overall stock under USA jurisdiction, with only 1,200 tons allocated to distant water fleets as incidental catch in other fisheries. Of this latter amount, only 362 tons was taken; the balance (469 tons) of the distant water fleet catch was taken in SA 4 (Canadian waters).

The estimate of mackerel catch from the USA recreational fishery in 1978 was based on a survey of the spring recreational mackerel fishery in the Middle Atlantic area conducted by personnel of the NMFS, Northeast Fisheries Center, Sandy Hook Laboratory in cooperation with personnel from New Jersey, Delaware, and New York (Christensen et al. 1979a). It was estimated that 6,103 tons were caught by anglers aboard party, charter, and private boats in the area from Virginia to Maine. Assuming that the proportion of mackerel caught from boats compared to that caught from shore was the same in 1978 as estimated in the national marine angler survey conducted in 1970 (Deuel 1973) (Virginia-New Jersey, 99.6%; New York-Maine, 90.9%), an additional 468 tons was caught by shore-based anglers. The total estimated recreational catch of mackerel in 1978 was, therefore, 6,571 tons.

CATCH COMPOSITION

The international mackerel catch in numbers at age for 1978 is presented in Table 3. The bulk of the data are Canadian (calculated by Hunt[1] and Moores[2]), although numbers at age were estimated for portions of the USA

[1]Hunt, J. J. Fisheries and Oceans Canada, Fisheries and Marine Service, Marine Fish Division, St. Andrews, New Brunswick EOG 2XO Canada, personal communication.

[2]Moores, J. A. Fisheries and Oceans Canada, Research and Resource Services, Newfoundland Environment Center, P.O. Box 5667, St. John's, Newfoundland A1C 5X1 Canada, personal communication.

recreational and commercial catch. There were no sampling data from distant water fleet catches. About 86% of the total catch in tons was accounted for by sampling data (Canada -73%, USA - 13%). The remaining 14% was assumed to be of the same age composition as the cumulative age composition of the sampled catch.

The 1974 and 1973 year classes comprised 29 and 22%, respectively, of the total 1978 catch in numbers. The catch of age 1-3 fish was low in comparison to other years. Age 1 (1977 year class) and 2 (1976 year class) fish comprised only 0.2 and 0.4%, respectively, of the 1978 catch, which were the lowest percentage contributions by either age group during 1962-78. The catch in numbers of age 3 fish (1975 year class) was 7.6%, the lowest percentage contribution by that age group since the mid-1960's. These unusually poor catches of age 1-3 fish reflect, in large part, the apparent low abundance of these year classes (1975, 1976, and 1977), and, to a lesser extent, the decrease in distant-water-fleet (DWF) catches. In the past, the percentage contribution of age 1-3 fish was greater in DWF catches than in Canadian and USA catches. Mean age of the catch increased from 2.8 years in 1975 to 3.8 years in 1977 and then climbed sharply to 5.8 years in 1978 (Table 5), reflecting the passage of the 1973 and 1974 year classes through the fishery and the scarcity of younger fish in the catch in the last several years.

An estimate of the age composition of the 1978 USA spring recreational catch of mackerel was made by Christensen et al. (1979b). Approximately half of the catch was comprised of fish from the strong 1967 (age 11-27%) and 1969 (age 9-23%) year classes (Table 4). In contrast, only about 6% of the sampled commercial catch consisted of these two year classes. Furthermore, mackerel catches during a January-March 1978 USSR bottom trawl survey and the USA spring bottom trawl survey indicated low proportions of these older age groups and 50-60% of age 4 (1974 year class) and 5 (1973 year class) fish

(Anderson and Overholtz 1978b). Since the survey catches occurred primarily in offshore waters whereas the recreational fishery is conducted generally within 10-15 miles of shore, the difference in catch composition is consistent with what is known about the size and age composition of spring migrating and spawning mackerel. Sette (1943, 1950) reported that the larger, older fish were the first to move inshore to spawn followed later by smaller, younger fish.

Sampling of the spring recreational catch was also done in 1979 (Christensen[3]). Results indicate that the 1969 and 1967 year classes again comprised about half of the catch (Table 4). The age composition in 1978 and 1979 is consistent in indicating that the spring recreational catch is comprised mainly of large, old mackerel. Unfortunately, since sampling data were not collected prior to 1978, it is not known if this represents the typical situation or is unique to the last several years. In view of Sette's findings, however, it is likely that this is typical. The summer recreational catch of mackerel in the New England region, although less than that in the spring Middle Atlantic fishery based on past national marine angler survey results, likely includes a greater proportion of smaller fish, particularly when strong year classes of young fish are present. Although sampling data from this component of the recreational fishery are lacking, young fish are frequently caught from shore in summer (Bigelow and Schroeder 1953).

The international mackerel catch in numbers at age for 1962-78 is given in Table 5.

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[3]Christensen, D. J. National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory, Highlands, New Jersey 07732, personal communication.

MEAN WEIGHTS AT AGE

Mean weights at age, adopted by scientists in the ICNAF Assessments Subcommittee (ICNAF 1974), were used in this assessment (Table 6). As described by Anderson (1979), these values were multiplied by the appropriate numbers at age (Table 5) and summed by calendar year to obtain calculated catches (tons). Ratios between observed and calculated catches varied from 0.906 to 1.302 (Table 5) and averaged 1.031. Mean weight values were applied to stock size numbers at age calculated from cohort analysis (Table 10), with the products summed by calendar year to obtain stock biomass. Annual biomass values were corrected using the appropriate observed/calculated catch ratios. Projected catch and stock biomass levels for 1979-81 were not corrected.

STOCK ABUNDANCE INDICES

USA spring and autumn research vessel bottom trawl survey catch-per-tow indices (Table 7, Figure 3) have generally monitored trends in mackerel abundance since 1963. Surveys conducted since the previous assessment (Anderson and Overholtz 1979a) indicate a substantial increase in mean catch per tow (kg, retransformed) during the autumn survey from 0.027 in 1977 to 0.191 in 1978, but a decrease during the spring survey from 0.447 in 1978 to 0.221 in 1979. Year-to-year changes exhibited by survey catch-per-tow indices are much less reliable than longer-term trends due to the high variability of the data (Grosslein 1971; Anderson 1976, 1979; Pennington and Grosslein 1978; Sissenwine 1978). As a result, the changes in the survey indices in 1978-79 should be interpreted cautiously. Both the spring and autumn indices increased sharply from 1977 to 1978, but the actual improvement in stock

abundance was probably less than either the 2-fold or 6-fold increase indicated by the two surveys, respectively. Results from cohort analysis (Table 10) indicate the beginning of stock recovery from 1977 to 1978, but the increase was estimated as less than 10%. There is no logical basis for an abrupt change in actual stock size as indicated by the drop in the spring survey index from 1978 to 1979. Available information suggests that the low survey catch of mackerel in 1979 relative to 1978 was due, in part, to warmer bottom water temperatures at the time of the survey in 1979. A greater porportion of the mackerel were caught in sampling strata farther north and east (Southern New England - Georges Bank area) in 1979 compared to 1978. It is likely, therefore, that a substantial portion of the mackerel normally sampled in SA 5-6 during the spring survey may, in 1979, have already migrated east and north into Canadian waters enroute to the Gulf of St. Lawrence. Anderson and Almeida (1977) were able to associate northward shifts in spring survey catches of mackerel during 1968-76 with increases in water temperature.

The standardized USA commercial catch-per-day index (Anderson 1976) decreased slightly from 0.52 tons in 1977 to 0.48 tons in 1978 (Table 8, Figure 4). This index has remained fairly constant since 1975. Although this measure of relative stock abundance has generally monitored the gross fluctuations in mackerel abundance since 1964, it is limited as a reliable indicator of year-to-year change, particularly in recent years, since the index is determined from catches which have averaged less than 1% of the total catch from the stock (Anderson 1979).

NATURAL MORTALITY

Instantaneous natural mortality (M) was assumed to be 0.30 for all ages in all years, as adopted earlier by scientists in the ICNAF Assessment Subcommittee (ICNAF 1974).

FISHING MORTALITY

Instantaneous fishing mortality (F) for fully-recruited age groups in 1978 was estimated using a method first proposed by Anderson et al. (1976) and employed in subsequent assessments. The technique, based on a linear relationship between mean annual F values (ages 3 and older) derived from cohort analysis and relative exploitation indices (ratio between international catch and spring survey catch per tow), predicted an F of 0.153 for 1978 (Table 9, Figure 5). In previous assessments (Anderson 1979; Anderson and Overholtz 1979a), the 1968-77 survey values were smoothed by exponential curve and values predicted from the curve were used in calculating the relative exploitation indices. The 1968-77 time-series was smoothed because of the aberrant 1969 value and the year-to-year fluctuations in the other values; an exponential curve appeared to best describe the continuously decreasing trend. Since the 1978 value deviated sufficiently from the decreasing trend of the previous years to reflect a true increase in abundance, the actual 1978 survey value was used to calculate the relative exploitation index for 1978.

Age-specific fishing mortality (F) rates for 1962-77 (Table 10) were determined from cohort analysis (Pope 1972) assuming F = 0.153 at ages 4 and older in 1978. Mean annual F values for ages 3 and older increased from 0.04 in 1962-64 to a high of 0.67 in 1976 and then decreased to 0.34 in 1977 and to an estimated 0.15 (ages 4 and older) in 1978.

RECRUITMENT

The sizes of the 1961-74 year classes at age 1, estimated from cohort analysis, ranged from 433 million (1963 year class) to 8,417 million fish (1967 year class) (Table 10, Figure 9), with a mean size of 2,138 million and a median size of 1,551 million.

Power curve relationships, fitted by least squares, between (1) autumn survey catch per tow at age 0 (numbers, retransformed) and year-class size

at age 1 estimated from cohort analysis for 1963-74 (Table 11, Figure 6), (2) spring survey catch per tow at age 1 and year-class size at age 1 for 1967-74 (Table 11, Figure 7), and (3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-74 (Table 11, Figure 8) were used to estimate the sizes of the 1975-78 year classes. Previous assessments (Anderson et al. 1976; Anderson 1979; Anderson and Overholtz 1979a) utilized linear catch-per-tow indices for ages 0, 1, and 2. The present analysis, however, modified the procedure by using a ln transformation of the station catches prior to calculation of the catch-per-tow indices, followed by a retransformation to the linear scale. Ln transformation and retransformation for the catch-per-tow-at-age indices employed the same general procedures (Anderson 1979) as used for the catch-per-tow indices (kg) given in Table 7. The purpose for and result of this modification to the technique was to reduce some of the variability inherent to the unadjusted linear survey data (Anderson 1979).

The 1975 year class was estimated to be 538 and 966 million fish at age 1 based on the autumn (age 0) and spring (age 1) survey catch-per-tow indices, respectively, and 374 million at age 2 based on the spring age 2 index (Table 11, Figures 6-8). The catch (C_2) of 26.9 million fish at age 2 in 1977 (Table 5) and a year-class size (N_2) of 374 million fish implied from:

$$C_2 = N_2 \frac{F_2}{Z_2} (1-e^{-Z_2}) \qquad (1)$$

an F_2 of 0.087. A year-class size of 519 million at age 1 then followed from cohort analysis. Based on three estimates of its size at age 1 (538, 966, and 519 million fish), which averaged 674 million, and considering that two of the three estimates were less than the mean, the 1975 year-class size was assumed to be 600 million at age 1.

Estimates were also obtained similarly for the 1976 year class at age 1 (0, 416, and 749 million). The zero estimate obtained from the autumn survey age 0 index, although indicative of a poor year class, was not used quantitatively in determining the size of the 1976 year class. The mean of the remaining estimates was 582 million, and, therefore, the 1976 year class was considered to be 600 million at age 1.

The 1977 year class was estimated to be 709 and 813 million fish at age 1 based on the autumn (age 0) and spring (age 1) survey catch-per-tow indices, respectively, but only 94 million fish at age 2 based on the spring age 2 index (Table 11, Figures 6-8). The catch (C_1) of 115,000 fish at age 1 in 1978 (Table 3) and a year-class size (N_2) of 94 million at age 2 in 1979 implied from:

$$\frac{N_2}{C_1} = \frac{Z_1 \, e^{-Z_1}}{F_1(1-e^{-Z_1})} \qquad (2)$$

an F of 0.00105. A year-class size (N_1) of 126 million at age 1 was then implied from Equation 1. However, in view of the above two estimates of this year class at age 1 (709 and 813 million), 126 million was considered to be unrealistically low. It was indicated previously (see STOCK ABUNDANCE INDICES) that catch per tow of mackerel during the spring survey decreased from 1978 to 1979 although other evidence indicates that stock abundance improved, and that the decrease was related to increased water temperature which may have stimulated an earlier migration of mackerel from the survey area into Canadian waters. Therefore, the estimate of 126 million fish at age 1 was ignored, and the 1977 year class was assumed to be 700 million at age 1.

The 1978 year class was estimated to be 3,342 million fish at age 1 based on the autumn (age 0) survey catch-per-tow index (Table 11, Figure 6).

Because of the low mackerel catch during the 1979 spring survey, as described earlier, this year class was estimated to be only 468 million at age 1 based on the spring (age 1) index (Table 11, Figure 7). This latter value was considered to be a gross underestimate of the true size of the 1978 year class. In addition to the results of the 1978 USA autumn survey which predicted a large 1978 year class, results from a bottom trawl survey conducted during 10 February - 4 March 1979 in the Georges Bank - Southern New England area by the Federal Republic of Germany R/V ANTON DOHRN also tend to suggest a large 1978 year class. The mackerel catch during this survey was larger than that from the last several ANTON DOHRN spring surveys and consisted almost entirely of 1978 year-class fish. These fish were all caught in stratum 10 (Figure 2), south of Cape Cod. Since this survey was conducted 1-2 months prior to the USA spring survey, it is possible that the bulk of these fish had migrated from the survey area into Canadian waters by the time the USA survey sampled the same area.

An attempt was made to correct for the unusually low catch-per-tow index at age 1 in 1979. As mentioned above, the catch-per-tow index at age 2 in 1979 (1977 year class) predicted a year class of only 126 million at age 1 compared to estimates of 709 and 813 million at age 1 based on age 0 and 1 survey indices (Table 11). Assuming that the mean (761 million) of the latter two estimates represented the true size of the year class at age 1, the catch of 115,000 fish at age 1 in 1978 (Table 3) implied a year-class size of 564 million at age 2 in 1979, instead of 94 million. The survey catch-per-tow index at age 2 in 1979 needed to predict 564 million fish from the calculated power curve relationship (Table 11, Figure 8) would be 0.229 instead of 0.009.

The hypothetical index (0.229) differed from the observed index (0.009) by a factor of 25.44. Assuming that the survey catch of age 1 mackerel in the spring of 1979 was proportionately as low as the catch of age 2 mackerel, increasing the observed age 1 catch-per-tow index (0.029) by a factor of 25.44 resulted in a hypothetical index of 0.738. A year-class size of 1,555 million fish at age 1 was predicted from the calculated power curve relationship (Table 11, Figure 7) using the index of 0.738. Given two estimates of 3,342 million and 1,555 million (average = 2,448 million), the 1978 year class was, therefore, considered to be 2,400 million fish at age 1.

For the purposes of catch and stock size projections and lacking any information, the 1979 year class was arbitrarily set at 600 million fish at age 1 or equal to the low 1975 and 1976 year classes.

Based on results of cohort analysis and estimates based on survey catch-per-tow-at-age indices, the 1978 year class is the largest to enter the fishery since the 1969 year class (Table 10), followed by the 1973 year class. The 1975-77 year classes appear to be low in abundance (2-3 times smaller than the 1973-74 year classes) and of a size comparable to the 1962-64 year classes.

PARTIAL RECRUITMENT

Partial recruitment of an age group to the fishery in a given calendar year is defined here as the ratio of the fishing mortality (F) at that age to the average fishing mortality of fully-recruited ages in that year. Based on age-specific F values from cohort analysis (Table 10), mackerel appear to have become fully-recruited to the fishery in many years by about age 3. Exceptions to this have occurred as a result of the variability in year-class sizes and to shifts in fishing patterns and effort. Partial recruitment coefficients for ages 1-3 during 1962-78 are given in Table 12. Partial

recruitment during 1962-78 has varied from 0.1 to 100.0% (average = 29.3%) at age 1, 0.4 to 100.0% (average = 48.7%) at age 2, and 7.0 to 100.0% (average = 70.9%) at age 3. Partial recruitment was especially high (76%) at age 1 in 1975 (1974 year class), with 100% recruitment of that year class at ages 2 and older. The 1973 year class did not experience high partial recruitment at age 1 (13%), but was fully recruited at ages 2 and older. Full recruitment (at or near 100%) at age 3 occurred in about half of the years (1962-78), but in 8 of the last 12 years which was the period of the recent intensive international fishery.

Partial recruitment at age 1 decreased sharply from 76% in 1975 to 3.6% in 1976 and continued to drop to only 0.1% in 1978 (Table 12). Partial recruitment also declined at age 2 from 100% in 1976 to 22% in 1977 and 0.4% in 1978, and at age 3 from 100% in 1977 to 12% in 1978. These coefficients may not be totally accurate as the F values from which they were derived were determined from estimated year-class sizes and known catches. However, the decreases do reflect changing conditions in the mackerel fishery. The abrupt drop in partial recruitment at age 1 in 1976 is due in part to a minimum size limit of 25 cm (total length) adopted beginning that year by ICNAF to effectively exclude the harvest of age 1 mackerel. However, this regulation in itself would not have resulted in such a decrease in fishing mortality relative to older ages, as it authorized up to 25% by number of the total catch on board vessels to be undersized fish. The decreased fishing mortality and partial recruitment evident for the 1975-77 year classes in 1976-78 appears to be due primarily to the low abundance of these year classes and the fact

that the fishery during the last several years has been supported by older fish, particularly the 1973 and 1974 year classes.

The sudden change in partial recruitment in recent years complicates the selection of coefficients for the projection of catches in 1979 and 1980. Since 73% of the catch in numbers in 1978 was Canadian (Table 13) and indications are that the bulk of the catch in 1979 and possibly in 1980 will also be Canadian, it was decided to examine the age composition of the Canadian catch and estimate the age-specific fishing mortalities of that component of the international catch. Age composition of the Canadian mackerel catch in thousands of fish at age in SA 3-6 (see Anderson and Paciorkowski, in press) during 1968-78 is given in Table 13. These data indicate considerable year-to-year variability in the age composition reflecting in large part the passage of dominant as well as weak year classes through the fishery. About 50% of the 1968 catch was age 1 fish from the outstanding 1967 year class; the catch from this year class at ages 1-6 exceeded the catch of any other age group each year through 1973. In 1971 and 1973, small quantities of age 0 mackerel were caught. Until the last several years and the entry of the 1975-77 year classes to the fishery, age 1-3 mackerel were well represented in the Canadian catch. Estimates of age-specific fishing mortality attributable to the Canadian fishery were determined by applying the ratio between the Canadian catch in numbers (Table 13) and the international catch in numbers (Table 5) at each age in each calendar year to the appropriate F calculated from cohort analysis for the entire fishery (Table 10). From this analysis it appeared, as for the entire fishery, that fish in most years were fully recruited to the Canadian fishery at age 3. Partial recruitment coefficients were determined for ages 1-3 as ratios of F at each age to the mean F (F at each age

weighted by stock size at that age) at ages 3 and older (Table 14). As with the partial recruitment coefficients determined for the entire fishery (Table 12), the Canadian values exhibited considerable variation and the same general year-to-year pattern, although, on average (for 1968-78), they were lower at each age (18 vs 20% at age 1; 33 vs 50% at age 2; 67 vs 81% at age 3). The 1978 values for both the Canadian and the entire fishery were low at ages 1-3 (0.1, 0.4, and 12%, respectively). With an estimated strong 1978 year class entering the fishery in 1979 and the 1974 and older year classes continuing to decline in abundance as they advance through the fishery, it was felt that partial recruitment coefficients at ages 1-3 fish in 1979-80 would increase from those estimated for 1978. Lacking any additional rationale for selecting coefficients for 1979-80, means for each age were determined by eliminating from consideration the high and low value at each age in the 1968-78 series. The resulting values were 15% at age 1, 33% at age 2, and 70% at age 3, with full or 100% recruitment at ages 4 and older (Table 15).

STOCK SIZE

Age-specific stock size estimates generated from cohort analysis and annual biomass values obtained by applying mean weights at age (Table 6) to the stock size estimates are given in Table 10. Total stock biomass (ages 1 and older) increased from about 600,000 tons during 1962-65 to 2.5 million tons in 1969 (Figure 9) and then declined sharply to 485,000 tons at the beginning of 1977. The total stock has since increased about 30% to an estimated 631,000 tons at the beginning of 1979. Spawning stock biomass, defined as 50% of the age 2 fish and 100% of the age 3 and older fish, increased from about 500,000 tons in 1962-67 to 1.9 million tons in 1970-72 and then declined to an estimated 358,000 tons at the beginning of 1979.

CATCH AND STOCK SIZE PROJECTIONS

Projections of spawning stock biomass available at the beginning of 1980 were made assuming various levels of catch in 1979 ranging from 30,000 to 100,000 tons (Table 16). Fishing mortality estimated to generate these catches varied between 0.103 (30,000 tons) and 0.380 (100,000 tons). Spawning stock biomass available at the beginning of 1980 will vary from an estimated 488,000 tons (36% increase from 1979) assuming a 1979 catch of 30,000 tons, to 421,000 tons (18% increase from 1979) assuming a catch of 100,000 tons.

Projected catches in 1980 at fishing mortality rates ranging from 0.05 to 0.50 and resultant spawning stock biomass levels available at the beginning of 1981 were made (Table 17) for each 1979 catch option. If the 1979 catch was only 30,000 tons, or about the same level as in 1978, catches in 1980 would vary from 17,600 tons at F = 0.05 to 150,700 tons at F = 0.50. Resultant spawning stock biomass at the beginning of 1981, given this range in catch in 1980, would vary from 657,000 tons (84% increase from 1979 and 35% increase from 1980) to 515,000 tons (44% increase from 1979 and 6% increase from 1980).

If the 1979 catch was as high as 100,000 tons, catches in 1980 would vary from 15,000 tons at F = 0.05 to 128,900 tons at F = 0.50. Resultant spawning stock biomass in 1981, given this range in catch in 1980, would vary from 595,000 tons (66% increase from 1979 and 41% increase from 1980) to 472,000 tons (32% increase from 1979 and 12% increase from 1980).

Given the range in catch in 1979 from 30,000 to 100,000 tons, fishing in 1980 at $F_{0.1}$ = 0.40 would result in catches ranging from 124,600 to 106,500 tons and result in spawning stock biomass increases of 52-38% from 1979 to 1981 and of 11 to 18% from 1980 to 1981.

Under all catch assumptions presented for 1979-80, there is an accompanying projection of stock increase in 1980-81, which is due to the recruitment of the estimated strong 1978 year class. Continued recovery of the stock will depend largely on the strength of this and subsequent year classes as well as the magnitude of the catch in the next few years. There is no definite basis for predicting levels of future recruitment given present and projected levels of spawning biomass. However, examination of the 1962-78 spawning stock-recruitment pattern indicates a greater probability of stronger recruitment with a spawning stock biomass in excess of 700,000 tons. During the 17-year period of 1962-78, the estimated spawning biomass was less than 700,000 tons during 8 of those years, and only 25% (2) of the year classes spawned during those 8 years were above median size. During the remaining 9 years, spawning biomass was equal to or greater than 900,000 tons and 78% (7) of the year classes were at or above the median size. Since all of the years which resulted in good recruitment were consecutive, it is possible that favorable environmental conditions may have persisted during that time which were equally or more influential in determining year-class size than spawning stock size. The available knowledge is not sufficient to distinguish the key factor(s), but does suggest a higher probability of improved recruitment as the stock continues to rebuild.

LITERATURE CITED

Anderson, E. D. 1976. Measures of abundance of Atlantic mackerel off the northeastern coast of the United States. Int. Comm. Northw. Atlant. Fish., Res. Bull. 12:5-21.

_____. 1979. Assessment of the Northwest Atlantic mackerel, *Scomber scombrus*, stock. U.S. Dept. Commer., NOAA Tech. Rept.,NMFS SSRF-732, 13 p.

_____, and F. P. Almeida. 1977. Distribution of Atlantic mackerel in ICNAF Subarea 5 and Statistical Area 6 based on research vessel spring bottom trawl surveys, 1968-76. Int. Comm. Northw. Atlant. Fish., Sel. Pap. 2:33-44.

_____, and W. J. Overholtz. 1979a. Status of the Northwest Atlantic mackerel stock-1978. Int. Comm. Northw. Atlant. Fish., Res. Doc. 79/VI/90, Ser. No. 5452, 21 p.

_____. 1979b. Summary of mackerel catch data from the USSR R/V ARGUS 1978 winter mackerel survey and the USA R/V ALBATROSS IV 1978 spring bottom trawl survey. NMFS, NEFC, Woods Hole Lab. Ref. No. 78-58, 8 p.

_____, and A. J. Paciorkowski. In press. A review of the Northwest Atlantic mackerel fishery. Rapp. P.-v. Réun. Cons. int. Explor. Mer.

_____, P. W. Wood, B. B. Ackerman, and F. P. Almeida. 1976. Assessment of the mackerel stock in ICNAF Subareas 3-6. Int. Comm. Northw. Atlant. Fish., Res. Doc. 76/XII/137, Ser. No. 4033, 21 p.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wild. Serv., Fish. Bull. 53(74):1-577.

Christensen, D. J., W. J. Clifford, P. G. Scarlett, R. W. Smith, and D. Zacchea. 1979a. A survey of the 1978 spring recreational fishery for Atlantic mackerel, Scomber scombrus, in the Middle Atlantic region. NMFS, NEFC, Sandy Hook Lab. Rept. No. SHL 78-43, 21 p.

_____, J. A. Penttila, and L. M. Dery. 1979b. Age composition of the 1978 spring recreational catch of Atlantic mackerel, Scomber scombrus, in the Middle Atlantic region. NMFS, NEFC, Sandy Hook Lab. Rept. No. SHL 79-13, 7 p.

Deuel, D. G. 1973. 1970 salt-water angling survey. U.S. Dept. Commer., NOAA, NMFS, Curr. Fish. Stat. 6200, 54 p.

Grosslein, M. D. 1971. Some observations on accuracy of abundance indices derived from research vessel surveys. Int. Comm. Northw. Atlant. Fish., Redbook 1971 (Part III):249-266.

ICNAF. 1974. Report of Standing Committee on Research and Statistics-January 1974. App. I. Report of Assessments Subcommittee. Ann. I. Report of the ad hoc Mackerel Working Group. Int. Comm. Northw. Atlant. Fish., Redbook 1974:31-36.

Pennington, M. R., and M. D. Grosslein. 1978. Accuracy of abundance indices based on stratified-random trawl surveys. Int. Comm. Northw. Atlant. Fish., Res. Doc. 78/VI/77, Ser. No. 5264, 42 p.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northw. Atlant. Fish., Res. Bull. 9:65-74.

Sette, O. E. 1943. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 1. Early life history, including growth, drift, and mortality of the egg and larvae populations. U.S. Fish. Bull. 50 (38):149-237.

_____. 1950. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 2. Migrations and habits. U.S. Fish. Bull. 51(49): 251-358.

Sissenwine, M. P. 1978. Using the USA research vessel spring bottom trawl survey as an index of Atlantic mackerel abundance. Int. Comm. Northw. Atlant. Fish., Sel. Pap. 3:49-55.

Table 1. Mackerel catch (tons) from SA 3-6 during 1960-78.

Year	USA Commercial	USA Recreational	Canada	Other countries	Total
1960	1,396	4,957[1]	5,957	-	12,310
1961	1,361	6,828	5,459	11	13,659
1962	938	8,698	6,801	175	16,612
1963	1,320	8,348	6,363	1,299	17,330
1964	1,644	8,486	10,786	801	21,717
1965	1,998	8,583[1]	11,185	2,945	24,711
1966	2,724	10,172	11,577	7,951	32,424
1967	3,891	13,527	11,181	19,047	47,646
1968	3,929	29,130	11,134	65,747	109,940
1969	4,364	33,303	13,257	114,189	165,113
1970	4,049	32,078[1]	15,690	210,864	262,681
1971	2,406	30,642	14,735	355,892	403,675
1972	2,006	21,882	16,254	391,464	431,606
1973	1,336	9,944	21,247	396,759	429,286
1974	1,042	7,640[1]	16,701	321,837	347,220
1975	1,974	5,968	13,544	271,719	293,205
1976	2,712	4,202[1]	15,746	223,275	245,935
1977	1,376	522[1]	22,477[2]	53,745[2]	78,120
1978	1,604	6,571[1]	24,444[2]	831[2]	33,450

[1]From angler survey; remaining years estimated (see text).

[2]Provisional.

Table 2. Provisional mackerel catch (tons) in 1978 by country from SA 3-6.

Country	Total
Bulgaria	30
Canada	24,444
Cuba	18
Italy	64
Japan	13
Mexico	1
Poland	2
Romania	20
Spain	28
USSR	655
USA (comm.)	1,604
USA (rec.)	6,571
Total	33,450

Table 3. Age composition (thousands of fish at age) of 1978 commercial and recreational catch of mackerel in SA 3-6.

Country	Area	Age 1	2	3	4	5	6	7	8	9	10	11+	Total	Tons
Sampled catch														
Canada	SA 3	-	-	1,087.9	6,025.7	6,381.9	4,044.3	2,053.8	865.1	459.4	671.7	1,119.4	22,709.2	13,630
Canada	SA 4	2.0	174.7	2,595.0	8,135.7	4,745.2	2,068.1	981.3	719.5	888.6	383.1	225.3	20,918.5	10,814
USA(rec.)	SA 6	-	8.5	188.8	611.6	442.5	938.5	789.1	225.5	1,789.6	188.8	2,646.3	7,829.2	4,032
USA (comm.)	Div 5Y(Jun-Jul)	96.8	24.3	82.1	148.2	25.0	27.8	-	-	18.6	8.8	8.8	440.4	171
USA (comm.)	Subdiv. 5Zw (Apr)	-	2.8	6.1	20.0	10.9	3.2	1.4	0.3	1.5	-	1.7	47.9	20
Total		98.8	210.3	3,959.9	14,941.2	11,605.5	7,081.9	3,825.6	1,810.4	3,157.7	1,252.4	4,001.5	51,945.2	28,667
Unsampled catch														
USA (rec.)	SA 5-6													2,539
USA (comm.)	SA 5-6													1,413
Others	SA 4-6													831
Total														4,783
Total catch[1]		115.3	245.4	4,620.6	17,434.1	13,541.8	8,263.5	4,463.9	2,112.5	3,684.6	1,461.4	4,669.1	60,612.2	33,450

[1]Total numbers at age from sampled catch raised to include unsampled catch.

Table 4. Percentage age composition of USA recreational mackerel catch in the Middle Atlantic area in 1978-79.

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13+
1978	-	0.1	2.4	7.7	5.6	12.0	10.1	2.9	22.9	2.4	26.8	3.4	3.7
1979	-	0.2	0.2	0.5	5.7	1.7	5.2	3.5	8.3	30.5	7.2	20.7	16.3

Table 5. Mackerel commercial and recreational catch at age (millions of fish) from ICNAF SA 3-6 during 1962-78.

Year	Age 0	1	2	3	4	5	6	7	8	9	10	11+	Total	Observed weight [1]	Calculated weight[1,2]	Obs/calc.	Mean age
1962	-	23.3	4.0	22.1	5.5	1.7	2.3	2.1	1.1	0.6	0.2	0.4	63.3	16.6	15.3	1.085	2.8
1963	-	1.5	5.6	1.7	35.2	8.1	0.4	0.2	0.2	0.2	0.2	0.2	53.5	17.3	18.2	0.951	3.9
1964	-	15.9	8.6	5.1	4.9	24.0	5.1	4.8	0.8	1.0	0.3	-	70.5	21.7	23.1	0.939	3.8
1965	-	10.9	4.3	3.5	4.9	6.3	23.6	5.1	4.8	0.9	-	-	64.3	24.7	25.5	0.969	4.7
1966	-	29.0	13.9	6.4	3.2	5.7	9.6	26.4	0.6	0.2	-	-	95.0	32.4	30.7	1.055	3.9
1967	2.2	1.0	33.0	24.4	4.3	4.1	6.3	7.5	39.8	0.4	-	-	123.0	47.6	48.0	0.992	4.8
1968	1.4	175.5	76.3	73.6	47.3	17.8	8.2	0.8	1.2	7.6	0.1	-	409.8	109.9	84.0	1.302	2.3
1969	4.5	8.1	298.8	183.2	75.0	6.5	3.4	2.3	3.5	2.5	9.5	-	597.3	165.1	144.7	1.141	2.8
1970	5.1	206.1	58.1	556.0	173.5	29.4	7.5	5.6	10.5	10.6	4.0	3.0	1069.4	262.7	276.8	0.949	3.0
1971	2.5	77.3	304.8	132.0	579.0	210.8	35.8	9.2	3.7	4.4	8.4	7.5	1375.4	403.7	429.2	0.941	3.6
1972	3.6	22.4	87.0	260.0	185.3	396.2	88.6	24.4	4.3	8.3	3.8	5.7	1089.6	431.6	396.2	1.089	4.2
1973	4.0	161.4	282.4	284.3	233.0	191.9	196.7	31.1	10.9	4.1	3.8	1.6	1405.2	429.3	435.4	0.986	3.6
1974	2.0	95.9	242.2	264.4	101.5	114.3	111.8	108.3	25.7	6.4	2.5	0.8	1075.8	347.2	346.9	1.001	3.8
1975	3.7	374.7	432.6	114.0	101.1	58.8	68.0	52.0	50.6	12.5	2.3	1.0	1271.3	293.2	308.1	0.952	2.8
1976	-	12.5	353.5	272.5	85.7	52.4	27.3	40.5	34.6	22.6	13.4	1.4	916.4	245.9	271.3	0.906	3.5
1977	-	2.0	26.9	100.7	53.9	11.9	9.9	5.6	6.3	3.8	3.6	0.6	225.2	78.1	73.1	1.068	3.8
1978	-	0.1	0.2	4.6	17.4	13.5	8.3	4.5	2.1	3.7	1.5	4.7	60.6	33.4	28.0	1.193	5.8

[1] Thousands of tons.

[2] Using mean weights at age from Table 6.

Table 6. Mean weights at age (kg) for Atlantic mackerel (ICNAF 1974).

Age 1	2	3	4	5	6	7	8	9	10+
.095	.175	.266	.350	.432	.506	.564	.615	.659	.693

Table 7. Stratified mean catch (kg) per tow (linear, Ln, and retransformed) of mackerel from USA bottom trawl surveys in the spring (strata 1-25, 61-76) and autumn (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26). See Figure 2 for location of sampling strata.

	Spring[1]			Autumn[2]		
Year	Linear	Ln	Retransformed	Linear	Ln	Retransformed
1963	-	-	-	.016	.013	.016
1964	-	-	-	<.001	<.001	<.001
1965	-	-	-	.089	.046	.073
1966	-	-	-	.098	.057	.085
1967	-	-	-	.740	.195	.372
1968	18.228	.575	3.998	.299	.117	.217
1969	.177	.029	.065	2.592	.154	.459
1970	7.138	.471	2.039	.110	.068	.099
1971	10.213	.425	1.969	.082	.052	.073
1972	5.012	.354	1.332	.126	.070	.107
1973	21.901	.228	.748	.045	.034	.043
1974	2.103	.277	.769	.205	.046	.108
1975	.500	.121	.255	.018	.010	.016
1976	.823	.144	.317	.043	.028	.039
1977	.266	.118	.199	.029	.020	.027
1978	1.125	.181	.447	.306	.104	.191
1979	.288	.117	.221	-	-	-

[1]Based on catches with No. 41 trawl; 1968-72 catches were with No. 36 trawl and were adjusted to equivalent No. 41 catches using a 3.25:1 ratio (41/36).

[2]Based on catches with No. 36 trawl.

Table 8. Mackerel catch per standardized USA day fished.

Year	Catch per day (tons)
1964	0.43
1965	0.49
1966	0.84
1967	1.75
1968	2.80
1969	1.92
1970	2.07
1971	1.29
1972	0.84
1973	0.53
1974	0.17
1975	0.53
1976	0.59
1977	0.52
1978	0.48

Table 9. Estimation of fishing mortality (F) in 1978 for the SA 3-6 mackerel fishery.

Year	Spring survey catch per tow[1]	Catch[2] (tons)	Relative exploitation index[3]	Mean F[4] age 3+
1968	4.518	109,940	24,334	.152
1969	3.199	165,113	51,614	.142
1970	2.265	262,681	115,974	.173
1971	1.604	403,675	251,668	.251
1972	1.135	431,606	380,270	.291
1973	.804	429,286	533,938	.426
1974	.569	347,220	610,228	.468
1975	.403	293,205	727,556	.437
1976	.285	245,935	862,930	.673
1977	.202	78,120	386,733	(.330)[5,6]
1978	.447	33,450	74,832	(.153)[5]

[1]Stratified mean catch (kg) per tow indices for 1968-77 smoothed by exponential curve (see Anderson 1979); 1978 is actual value.

[2]International commercial and recreational catch.

[3]Ratio between catch and survey catch per tow.

[4]Obtained from cohort analysis assuming F = 0.153 in 1978.

[5]Calculated from regression of relative exploitation index on mean F for 1968-76: $Y = 0.110 + 0.000000568X$, $r = 0.970$.

[6]Actual value calculated from cohort analysis was 0.337.

Table 10. Fishing mortality rates (F) and stock size (millions of fish) by age for mackerel in ICNAF SA 3-6 derived from cohort analysis assuming M = 0.30 and F = 0.153 at ages 4 and older in 1978.

Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Mean[1]	Age 1+ Total	Age 1+ Wt(10^3tons)[6]	Spawning stock[5] Total	Spawning stock[5] Wt(10^3tons)[6]	Mean age
					Fishing mortality												
1962	.029	.006	.029	.126	.051	.049	.043	.073	.090	.031	(.037)[2]	.037					
1963	.004	.009	.003	.066	.312	.017	.006	.006	.019	(.043)	(.043)[2]	.043					
1964	.044	.032	.012	.014	.065	.373	.316	.032	(.039)[2]	(.039)[2]	-	.039					
1965	.023	.016	.018	.016	.024	.093	.940	.697	(.051)[2]	-	-	.051					
1966	.028	.041	.034	.022	.025	.051	.159	.285	(.058)[2]	-	-	.058					
1967	<.001	.045	.105	.032	.040	.038	.057	.432	.351	-	-	.084					
1968	.025	.038	.148	.343	.198	.117	.007	.013	.150	(.152)[2]	-	.152					
1969	.003	.059	.135	.248	.079	.058	.048	.041	.037	.319	-	.142					
1970	.073	.029	.165	.205	.161	.137	.143	.362	.185	.085	(.173)[2]	.173					
1971	.060	.164	.096	.290	.468	.339	.278	.147	.284	.246	(.251)[2]	.251					
1972	.015	.098	.229	.212	.373	.413	.464	.226	.655	.482	(.291)[2]	.291					
1973	.144	.289	.606	.373	.400	.360	.277	.440	.396	.848	(.426)[2]	.426					
1974	.061	.375	.550	.513	.356	.489	.389	.441	.576	.510	(.468)[2]	.468					
1975	.330	.482	.341	.475	.743	.421	.504	.357	.452	.475	(.437)[2]	.437					
1976	(.024)[3]	.687	.748	.533	.554	1.172	.547	.887	.299	1.756	(.673)[2]	.673					
1977	(.004)[3]	(.074)[3]	.478	.353	.141	.209	.960	.166	.238	.078	(.337)[2]	.337					
1978	(<.001)[3]	(.001)[3]	(.018)[3]	.153	.153	.153	.153	.153	.153	.153	.153	.153[4]					
					Stock size (10^6)												
1962	956.3	773.5	891.7	53.8	40.1	56.1	57.8	18.1	8.1	7.6	12.7		2875.8	641.3	1532.8	469.3	3.3
1963	434.2	688.4	569.5	641.5	35.1	28.2	39.6	41.0	12.5	5.5	5.5		2501.0	599.7	1722.6	503.2	3.6
1964	433.1	320.4	505.2	420.5	445.0	19.1	20.6	29.2	30.2	9.1	-		2232.4	597.6	1639.1	532.7	4.0
1965	551.6	307.1	230.0	369.8	307.3	309.0	9.7	11.1	20.9	-	-		2116.5	593.0	1411.4	516.1	4.4
1966	1217.4	399.2	223.8	167.3	269.8	222.2	208.6	2.8	4.1	-	-		2715.2	690.7	1298.2	531.8	4.6
1967	3181.5	876.9	283.8	160.3	121.2	194.9	156.4	131.8	1.6	-	-		5108.4	901.3	1488.5	525.4	4.2
1968	8416.9	2356.0	621.2	189.2	115.1	86.3	139.0	109.4	63.4	0.8	-		12097.3	2245.6	2502.4	936.2	3.4
1969	3155.7	6084.3	1679.7	396.9	99.5	69.9	56.9	102.3	80.0	40.4	-		11765.6	2515.1	5567.8	1565.6	2.9
1970	3404.6	2330.8	4250.2	1086.7	229.5	68.1	48.9	40.1	72.8	57.1	21.8		11610.6	2401.7	7040.6	1901.2	3.3
1971	1550.9	2344.8	1676.7	2670.1	655.7	144.7	44.0	31.4	20.7	44.8	38.9		9222.7	2268.2	6499.4	1936.5	3.7
1972	1792.5	1082.4	1474.7	1128.5	1479.7	304.3	76.4	24.7	20.1	11.5	25.9		7420.7	2219.0	5086.7	1930.4	4.0
1973	1401.8	1308.6	727.0	868.7	676.5	755.2	149.2	35.6	14.6	7.7	5.3		5950.2	1635.4	3894.1	1391.2	4.2
1974	1885.1	899.6	726.4	293.9	443.2	336.0	390.1	83.8	17.0	7.3	2.4		5084.8	1284.8	2749.9	1026.8	4.4
1975	1550.8	1314.0	458.0	310.6	130.3	229.8	152.7	195.8	39.9	7.1	3.2		4392.2	971.4	2184.4	721.7	4.1
1976	(600.0)[7]	826.3	601.1	241.2	143.1	46.0	111.7	68.4	101.5	18.8	3.3		2761.4	650.8	1748.3	533.6	4.0
1977	(600.0)[7]	433.8	307.9	210.7	104.9	60.9	10.5	47.9	20.9	55.7	2.4		1855.6	485.0	1038.7	383.6	4.2
1978	(700.0)[7]	442.8	298.4	141.4	109.7	67.5	36.6	3.0	30.1	12.2	38.2		1879.9	515.0	958.5	389.4	4.1
1979	(2400.0)[7]	518.5	327.9	217.1	89.9	69.7	42.9	23.3	1.9	19.1	32.0		3742.3	631.3	1083.0	357.9	4.0

[1] Mean F for ages 3 and older weighted by stock size at age.

[2] Mean F for ages 3 and older in that year.

[3] Determined from estimated stock size and known catch.

[4] Ages 4 and older.

[5] 50% age 2, 100% ages 3 and older.

[6] Adjusted using observed/calculated catch ratios in Table 5.

[7] Estimated.

Table 11. Stratified mean catch per tow (number, retransformed) of age 0, 1, and 2 mackerel from USA autumn and spring bottom trawl surveys and year-class sizes at ages 1 and 2 from cohort analysis assuming F = 0.153 at ages 4 and older in 1978.

Year-class	Autumn survey Age 0	Spring survey Age 1	Spring survey Age 2	Cohort analysis Age 1	Cohort analysis Age 2
1963	0.080	-	-	433.1	307.1
1964	0.021	-	-	551.6	399.2
1965	0.114	-	-	1217.4	876.9
1966	0.158	-	1.726	3181.5	2356.0
1967	1.833	40.240	0.198[1]	8416.9	6084.3
1968	0.095	0.238[1]	2.625	3155.7	2330.8
1969	0.690	1.010	2.779	3404.6	2344.8
1970	0.023	0.929	1.368	1550.9	1082.4
1971	0.169	1.894	0.787	1792.5	1308.6
1972	0.085	0.915	0.383	1401.8	899.6
1973	0.214	0.826	1.277	1885.1	1314.0
1974	0.141	3.186	0.787	1550.8	826.3
1975	0.012	0.204	0.109	(538.5)[2]	(965.8)[3] (373.6)[4]
1976	0.000	0.021	0.221	(0)[2]	(415.9)[3] (553.0)[4]
1977	0.021	0.128	0.009	(709.2)[2]	(812.6)[3] (93.6)[4]
1978	0.490	0.029	-	(3341.8)[2]	(468.0)[3] -

[1]Values not used in calculating curves.

[2]Calculated from power curve relationship between survey catch per tow at age 0 and year-class size at age 1 for 1963-74 year classes: ln Y=ln 4747.251+ 0.492 ln X, r = 0.761.

[3]Calculated from power curve relationship between survey catch per tow at age 1 and year-class size at age 1 for 1967-74 year classes: ln Y = ln 1740.750+0.371 ln X, r = 0.801.

[4]Calculated from power curve relationship between survey catch per tow at age 2 and year-class size at age 2 for 1966-74 year classes: ln Y = ln 1278.129+0.555 ln X, r = 0.847.

Table 12. Percentage of fishing mortality (F) at ages 1, 2, and 3 compared to mean F at ages 3 and older (partial recruitment) for the international mackerel fishery in SA 3-6.

Year	Age 1	Age 2	Age 3
1962	78.4	16.2	78.4
1963	9.3	20.9	7.0
1964	100.0	82.1	30.8
1965	45.1	31.4	35.3
1966	48.3	70.7	58.6
1967	0.4	53.6	100.0
1968	16.4	25.0	97.4
1969	2.1	41.5	95.1
1970	42.2	16.8	95.4
1971	23.9	65.3	38.2
1972	5.2	33.7	78.7
1973	33.8	67.8	100.0
1974	13.0	80.1	100.0
1975	75.5	100.0	78.0
1976	3.6	100.0	100.0
1977	1.2	22.0	100.0
1978[1]	0.1	0.4	11.8

[1]F at ages 1-3 compared to mean F at ages 4 and older.

Table 13. Age composition (thousands of fish at age) of Canadian mackerel catch in SA 3-6 during 1968-78.

Year	Age 0	1	2	3	4	5	6	7	8	9	10	11+	Total	Tons	% of total catch
1968	-	22,991	3,821	5,522	3,947	1,505	720	385	885	5,566	52	-	45,394	11,134	10.1
1969	-	4,049	18,751	12,845	1,442	661	608	782	313	329	6,869	-	46,649	13,257	8.0
1970	-	15,146	2,730	25,085	6,010	1,865	337	318	1,178	1,228	870	2,368	57,135	15,690	6.0
1971	909	4,305	4,445	1,024	21,613	4,584	1,054	1,325	918	1,130	597	2,722	44,626	14,735	3.7
1972	-	-	99	3,199	4,028	18,046	3,616	3,815	56	397	2	4,965	38,223	16,254	3.8
1973	250	5,051	11,351	5,311	5,137	7,690	12,270	4,578	1,525	461	369	514	54,507	21,247	4.9
1974	-	3,223	9,103	9,987	5,461	4,710	4,644	5,751	1,516	641	315	339	45,690	16,701	4.8
1975	-	5,306	9,302	4,874	4,346	2,634	2,811	2,038	1,463	308	121	96	33,299	13,544	4.6
1976	-	803	10,082	12,910	5,230	3,686	1,842	2,344	1,894	1,487	340	215	40,833	15,746	6.4
1977	-	714	6,892	21,793	10,930	3,557	2,481	782	1,393	867	1,329	333	51,071	22,477	28.8
1978	-	2	175	3,683	14,162	11,127	6,112	3,035	1,585	1,348	1,055	1,345	43,629	24,444	73.1

Table 14. Percentage of fishing mortality (F) at ages 1, 2, and 3 compared to mean F at ages 3 and older (partial recruitment) for the Canadian mackerel fishery in SA 3-5 during 1968-78.

Year	Age 1	Age 2	Age 3
1968	16.7	11.1	61.1
1969	12.5	50.0	100.0
1970	62.5	12.5	87.5
1971	33.3	22.2	11.1
1972	0.0	1.0	30.0
1973	31.3	75.0	68.8
1974	8.0	56.0	84.0
1975	27.8	55.6	83.3
1976	5.6	55.6	97.2
1977	1.4	25.7	100.0
1978[1]	<0.1	0.4	12.8

[1] F at ages 1-3 compared to mean F at ages 4 and older.

Table 15. Summary of parameters used in projection of catch and stock size options for mackerel in SA 3-6.

Parameter		Value
Fishing mortality (F) in 1978 (ages 4 and older)		0.153
Recruitment at age 1:	1975 year class	600×10^6 fish
	1976 year class	600×10^6 fish
	1977 year class	700×10^6 fish
	1978 year class	$2{,}400 \times 10^6$ fish
	1979 year class	600×10^6 fish
Partial recruitment in 1979-80:	Age 1	15%
	Age 2	33%
	Age 3	70%
	Ages 4 and older	100%
Total stock biomass at beginning of 1979		631,300 tons
Spawning stock biomass at beginning of 1979		357,900 tons

Table 16. Various levels of catch of mackerel in SA 3-6 in 1979 and associated fishing mortality at ages 4 and older with resulting spawning stock biomass in 1980 and its percentage change from 1979. Catch and stock are expressed as thousands of tons.

Stock in 1979	Catch in 1979	F in 1979	Stock in 1980	% change in stock from 1979
357.9	30.0	0.103	488.0	+36.4
357.9	40.0	0.139	478.5	+33.7
357.9	50.0	0.176	468.9	+31.0
357.9	60.0	0.215	459.3	+28.3
357.9	70.0	0.254	449.8	+25.7
357.9	80.0	0.295	440.3	+23.0
357.9	90.0	0.337	430.8	+20.4
357.9	100.0	0.380	421.3	+17.7

Table 17. Projected mackerel catch in SA 3-6 in 1980 with fishing mortality ranging from 0.05 to 0.50 assuming eight options for catch in 1979, and the resulting spawning stock biomass in 1981 and its percentage change from 1979 and 1980. Catch and stock are expressed as thousands of tons.

Fishing mortality (F)	Catch in 1980	Stock in 1981	% change in stock from 1979	% change in stock from 1980	Catch in 1980	Stock in 1981	% change in stock from 1979	% change in stock from 1980	Catch in 1980	Stock in 1981	% change in stock from 1979	% change in stock from 1980
	1979 catch = 30.0				1979 catch = 40.0				1979 catch = 50.0			
0.05	17.6	657.0	+83.6	+34.6	17.2	648.2	+81.1	+35.5	16.8	639.3	+78.6	+36.3
0.10	34.6	638.9	+78.5	+30.9	33.8	630.4	+76.2	+31.8	33.1	621.9	+73.8	+32.6
0.15	50.9	621.5	+73.6	+27.3	49.9	613.3	+71.4	+28.2	48.8	605.1	+69.1	+29.1
0.20	66.7	604.6	+68.9	+23.9	65.3	596.8	+66.7	+24.7	63.9	588.9	+64.6	+25.6
0.25	82.0	588.3	+64.4	+20.6	80.2	580.8	+62.3	+21.4	78.5	573.3	+60.2	+22.3
0.30	96.7	572.6	+60.0	+17.3	94.6	565.4	+58.0	+18.2	92.6	558.2	+56.0	+19.0
0.35	110.9	557.5	+55.8	+14.2	108.6	550.6	+53.8	+15.1	106.2	543.6	+51.9	+15.9
0.40[1]	124.6	542.9	+51.7	+11.2	122.0	536.2	+49.8	+12.1	119.4	529.5	+48.0	+12.9
0.45	137.9	528.8	+47.7	+ 8.4	135.0	522.4	+46.0	+ 9.2	132.1	515.9	+44.2	+10.0
0.50	150.7	515.1	+43.9	+ 5.6	147.5	509.0	+42.2	+ 6.4	144.4	502.8	+40.5	+ 7.2
	1979 catch = 60.0				1979 catch = 70.0				1979 catch = 80.0			
0.05	16.5	630.4	+76.2	+37.3	16.1	621.5	+73.7	+38.2	15.7	612.6	+71.2	+39.1
0.10	32.4	613.4	+71.4	+33.6	31.6	604.8	+69.0	+34.5	30.9	596.3	+66.6	+35.4
0.15	47.7	596.9	+66.8	+30.0	46.6	588.7	+64.5	+30.9	45.5	580.5	+62.2	+31.8
0.20	62.5	581.1	+62.4	+26.5	61.1	573.2	+60.1	+27.4	59.7	565.2	+57.9	+28.4
0.25	76.8	565.7	+58.1	+23.2	75.1	558.2	+56.0	+24.1	73.4	550.5	+53.8	+25.0
0.30	90.6	550.9	+53.9	+20.0	88.6	543.6	+51.9	+20.9	86.6	536.3	+49.9	+21.8
0.35	103.9	536.6	+49.9	+16.8	101.6	529.6	+48.0	+17.7	99.3	522.6	+46.0	+18.7
0.40[1]	116.8	522.8	+46.1	+13.8	114.2	516.1	+44.2	+14.7	111.6	509.3	+42.3	+15.7
0.45	129.3	509.5	+42.4	+10.9	126.4	503.0	+40.5	+11.8	123.6	496.5	+38.7	+12.8
0.50	141.3	496.6	+38.8	+ 8.1	138.2	490.4	+37.0	+ 9.0	135.1	484.1	+35.3	+ 9.9
	1979 catch = 90.0				1979 catch = 100.0							
0.05	15.3	603.6	+68.7	+40.1	15.0	594.6	+66.1	+41.1				
0.10	30.2	587.6	+64.2	+36.4	29.4	579.0	+61.8	+37.4				
0.15	44.5	572.2	+59.9	+32.8	43.4	563.9	+57.6	+33.8				
0.20	58.3	557.3	+55.7	+29.4	56.9	549.3	+53.5	+30.4				
0.25	71.6	542.9	+51.7	+26.0	69.9	535.2	+49.5	+27.0				
0.30	84.5	529.0	+47.8	+22.8	82.5	521.6	+45.7	+23.8				
0.35	97.0	515.5	+44.0	+19.7	94.7	508.4	+42.1	+20.7				
0.40[1]	109.1	502.5	+40.4	+16.6	106.5	495.7	+38.5	+17.7				
0.45	120.7	490.0	+36.9	+13.7	117.9	483.4	+35.1	+14.7				
0.50	132.0	477.8	+33.5	+10.9	128.9	471.5	+31.7	+11.9				

[1] $F_{0.1}$.

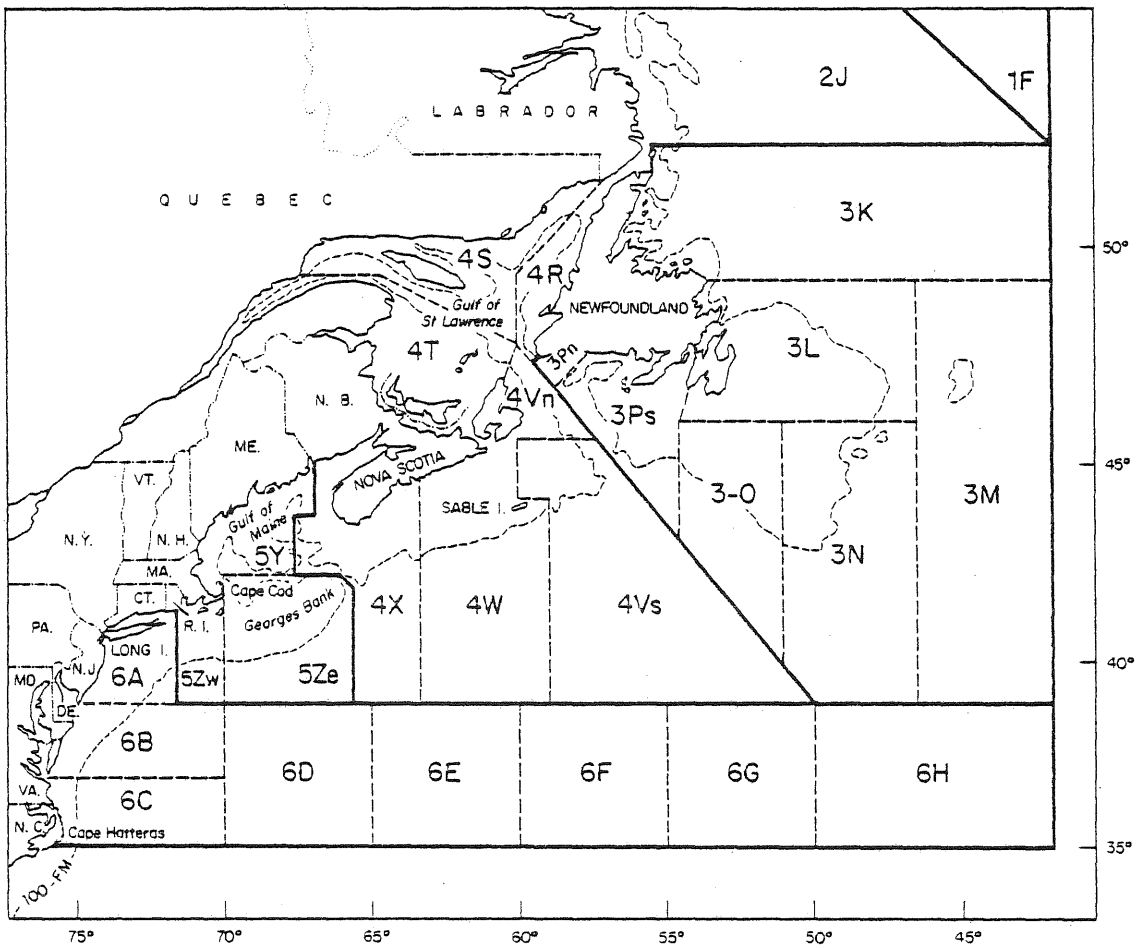

Figure 1. Northwest Atlantic from North Carolina to Labrador showing ICNAF SA 3-6.

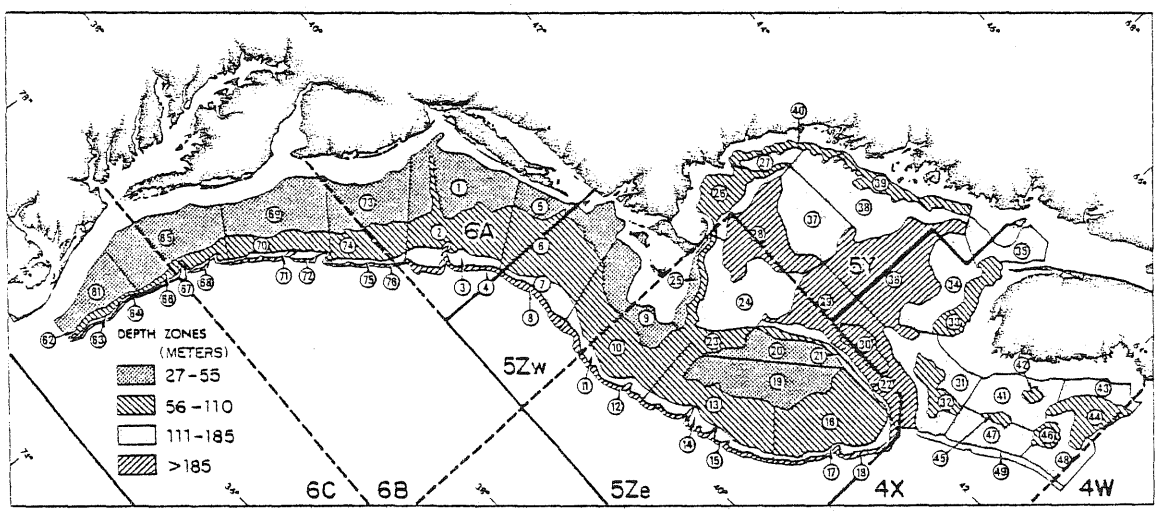

Figure 2. USA bottom trawl survey sampling strata in the Northwest Atlantic between Cape Hatteras and Nova Scotia.

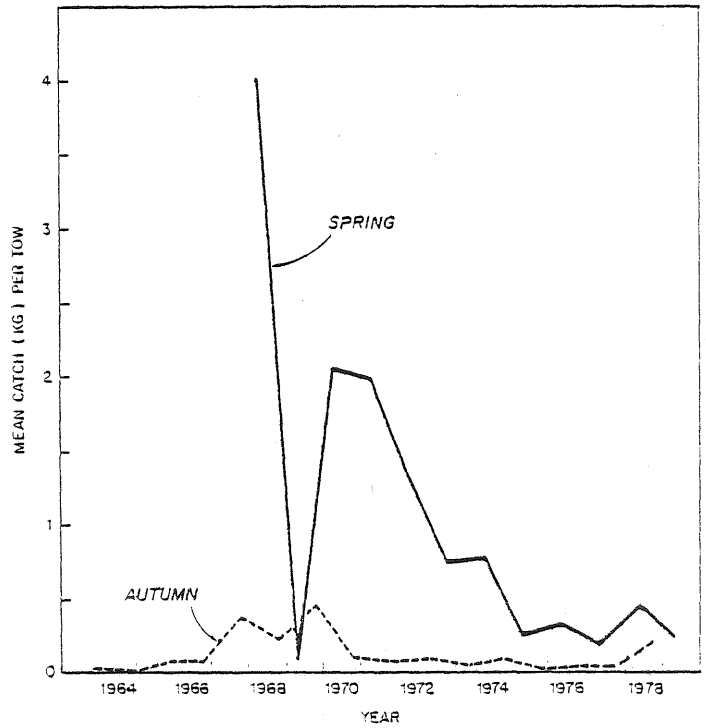

Figure 3. Stratified mean catch per tow (kg-retransformed) of mackerel from USA spring (1968-79) and autumn (1963-78) bottom trawl surveys in SA 5-6.

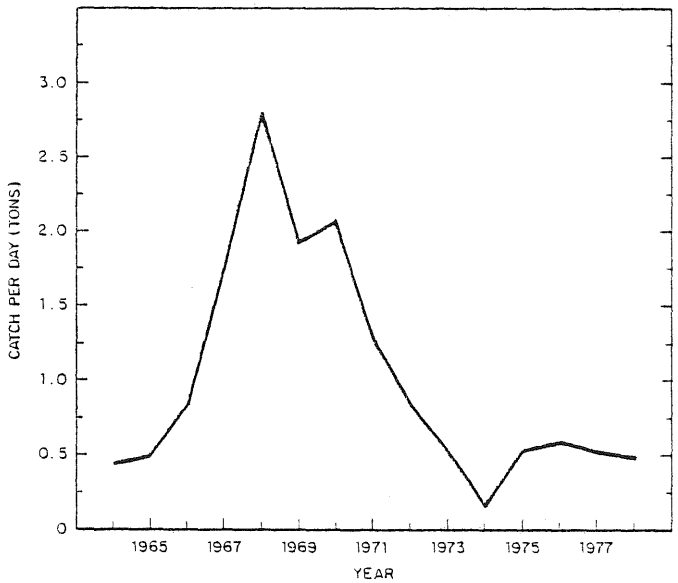

Figure 4. Catch per standardized day fished for the USA commercial mackerel fishery in SA 5-6.

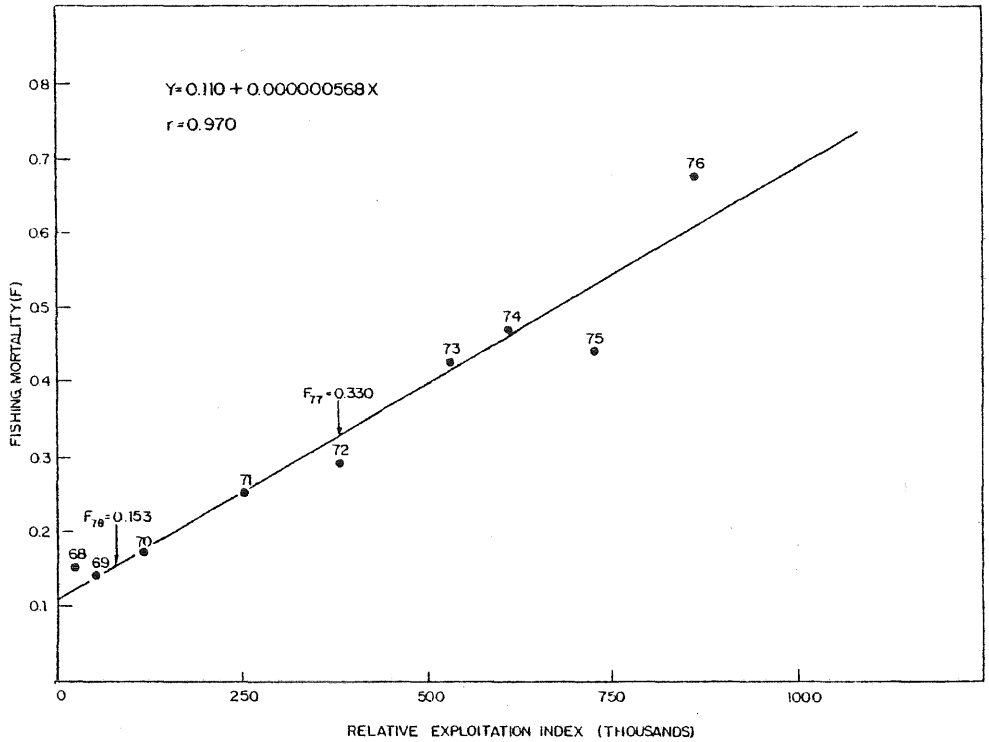

Figure 5. Relationship between fishing mortality from cohort analysis assuming F = 0.153 at ages 4 and older in 1978 and a relative exploitation index derived from USA spring survey catch per tow for mackerel and the international catch of mackerel in SA 3-6.

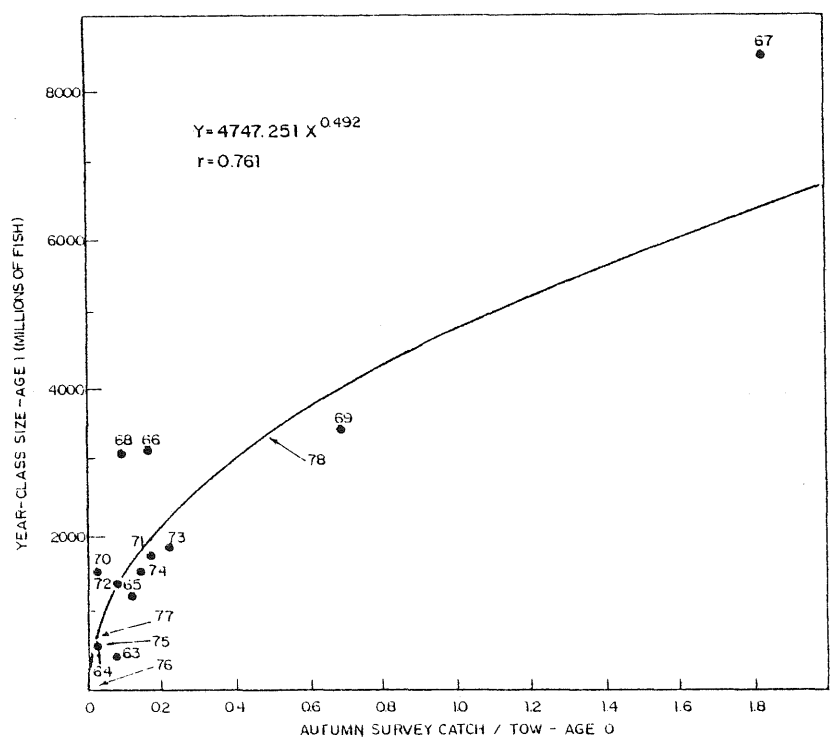

Figure 6. Power curve relationship between mackerel year-class size at age 1 from cohort analysis assuming F = 0.153 at ages 4 and older in 1978 and USA autumn survey catch per tow at age 0.

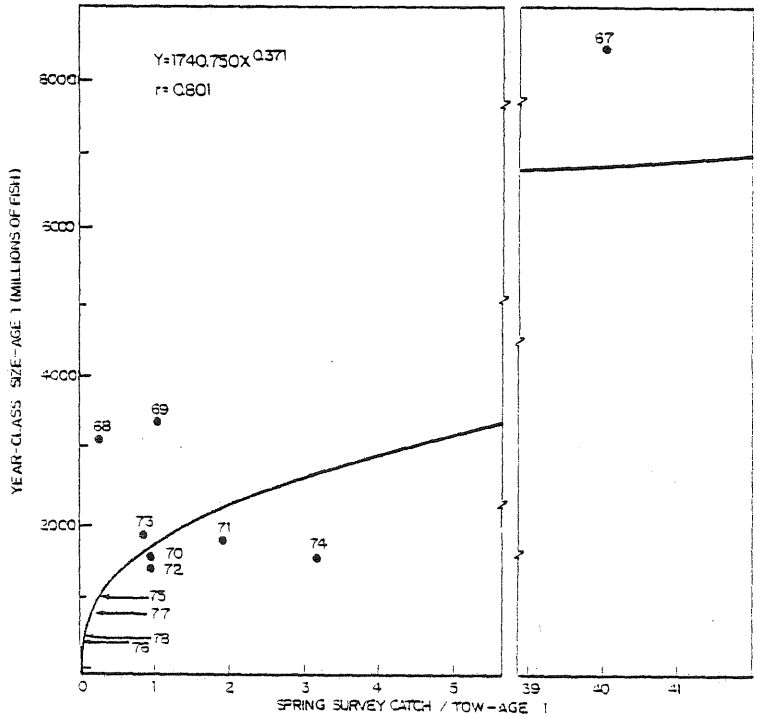

Figure 7. Power curve relationship between mackerel year-class size at age 1 from cohort analysis assuming F = 0.153 at ages 4 and older in 1978 and spring survey catch per tow at age 1 (1968 value omitted from calculation).

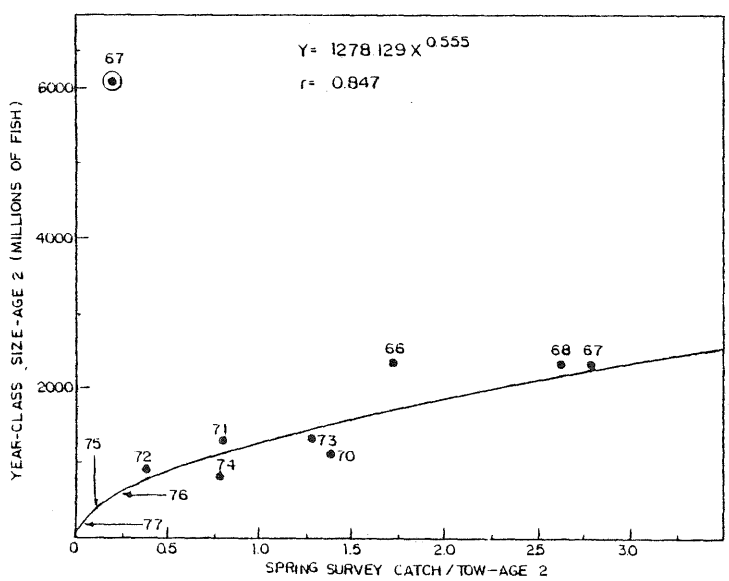

Figure 8. Power curve relationship between mackerel year-class size at age 2 from cohort analysis assuming F = 0.153 at ages 4 and older in 1978 and spring survey catch per tow at age 2 (1967 value omitted from calculation).

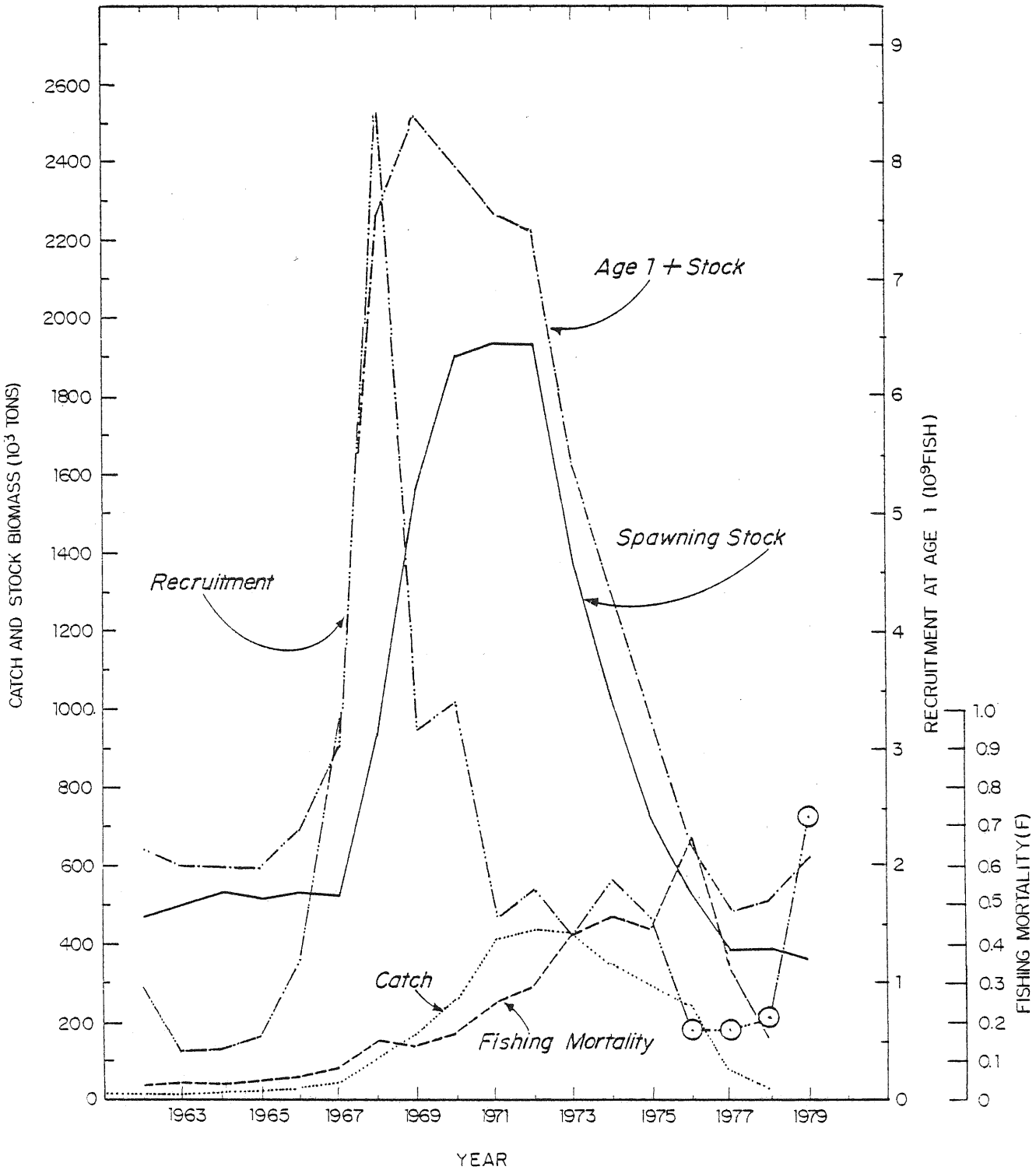

Figure 9. Total mackerel stock biomass (ages 1 and older) and spawning stock biomass (50% age 2 and 100% ages 3 and older) during 1962-79 from cohort analysis assuming F = 0.153 at ages 4 and older in 1978, abundance at age 1 of the 1961-78 year classes (open circles represent estimates based on survey data; others determined from cohort analysis), total international catch (commercial and recreational) during 1961-78, and fishing mortality (mean for ages 3 and older, except in 1978 when ages 4 and older) during 1962-78 in SA 3-6.