Assessment of the Northwest Atlantic Mackerel Stock

by

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1. Introduction

The following report constitutes an analysis of the status of the Northwest Atlantic mackerel stock extending from Cape Hatteras to Newfoundland based on the most current data available. These data include commercial and recreational catch statistics, research vessel survey abundance indices, fishing mortality estimates, stock size estimates, recruitment estimates, and consequences of allowable catch options for 1978 in terms of spawning stock biomass remaining in 1979.

2. Catch Statistics

Table 1 contains a summary of annual mackerel catches by the USA, Canada, and other countries during 1961-77, including estimates of USA recreational catches. Angler surveys provided estimates of the 1960, 1965, 1970, 1974, and 1976 recreational catches. Catches in the intervening years were estimated by assuming that the ratio between catch and stock biomass (from cohort analysis performed using only commercial data) in each of the above five years was the same in the two years preceding and succeeding each year. Estimated recreational catch increased from about 6,800 tons (metric) in 1961 to a high of 33,300 tons in 1969 and then declined to 5,000 tons in 1976; the average for the period was about 15,000 tons. USA commercial catches varied from 938 to 4,364 tons during this period and averaged 2,300 tons. Canadian catches ranged from 5,459 to 21,247 tons and averaged 12,600 tons. Total international catches increased from 13,659 tons in 1961 to 431,606 tons in 1972 and then declined to 243,033 tons in 1976.

An international TAC (total allowable catch for commercial fisheries) of 105,000 tons was allocated for 1977. The provisional reported catch for

January-March was 52,114 tons (Table 2). For the purposes of this assessment, it was assumed that the total 1977 catch (commercial and recreational) would be 92,000 tons. It was assumed that all countries with catch allocations would harvest the full amount, except Canada, the USA, and "others." The Canadian catch was assumed to be 20,000 tons (30,000 tons allocated), the USA commercial catch was assumed to be 3,000 tons (6,000 tons allocated), and the catch by countries without specific allocations but expected to take some mackerel as by-catch was assumed to be only 100 tons (5,000 tons allocated in SA 3-4 and 100 tons allocated in SA 5-6). The USA recreational catch was assumed to be 5,000 tons, which was the estimated amount caught in 1976.

3. Catch Composition

Table 3 contains estimates of the mackerel catch in numbers at age during 1962-77. The 1962-75 numbers at age for the commercial fishery were taken from Anderson et al. (1976a). The 1976 numbers at age were revised from those used in the last assessment (ICNAF 1977). The general procedure used previously was to (1) apply the length frequencies and age-length keys reported by individual countries to their catches to obtain numbers at age by country, (2) combine all such numbers at age for respective countries, and (3) prorate the summed numbers at age upwards to include catches from countries lacking sampling data. However, significant differences were evident among age-length keys submitted by various countries for 1976 (Anderson et al. 1976b). Consequently, it was decided to combine country age-length keys by quarter for 1976 and 1977. The procedure used for the 1976 and 1977 data was to (1) determine numbers at length by country by month from available length frequencies and corresponding catches, (2) combine the numbers at length within quarters and prorate upwards to include country catches lacking sampling data, (3) apply the combined

quarterly age-length key to the quarterly numbers at length to obtain quarterly numbers at age, and (4) combine the quarterly numbers at age to obtain the annual numbers at age. The estimated numbers at age for 1977 were determined by applying the above procedure to the available January-March catch and sampling data and then prorating the results upwards to include the catch expected to be taken during the remainder of the year. Numbers at age for the 1962-77 commercial catches were prorated upwards to include the added USA recreational catches.

Mean weights at age used in previous assessments (Table 4) were applied to the numbers at age to obtain calculated catches (tons) for comparison with the observed catches (tons). Ratios between observed and calculated catches varied from 0.906 to 1.302 and averaged 1.015.

4. Abundance Indices

USA research vessel bottom trawl survey catch-per-tow data (Table 5) indicate a continued decline in mackerel abundance. The spring survey catch-per-tow (kg) index decreased 37% from 1976 to 1977. Both the spring and autumn indices have demonstrated a continuous biomass decline since 1968-69 (Figure 1). The spring survey mean catch-per-tow in numbers has also declined continuously (Table 6), and has shown a marked decrease in the number of age 1 mackerel in 1976 and 1977. The standardized USA commercial catch-per-day index (Table 7) (see Anderson 1976) has generally been consistent with estimates of abundance from survey data and with stock biomass estimates obtained from cohort analysis (see Table 10), but it increased in 1975 and 1976 while the other indices continued to decrease. The USA commercial index is limited in that it is based on inshore catches comprising less than 1% of the international catch, and it is likely that the recent increases in that index are merely a

reflection of localized changes in availability rather than overall stock abundance. Catch-per-effort data from distant water fleets are not available for 1977, but 1976 data indicated increases for certain Bulgarian, GDR, and Polish vessel-classes and decreases for some USSR vessels. Previous analyses (Anderson 1976) suggested, however, that changes in vessel efficiency invalidate distant water fleet catch-per-effort as a reliable measure of mackerel abundance. This was recognized at the time of the last assessment (ICNAF 1977) as well as the possibility of continued accessibility of schooling species like mackerel to fishing gear, even at low abundance levels.

5. Assessment Parameters

In addition to catch (numbers) at age data, parameters essential for the projection of catches in 1978 include fishing mortality in 1977, size of incoming year-classes, and estimates of partial recruitment.

a. Fishing Mortality in 1977

Fishing mortality in 1977 was estimated using a technique developed by Anderson et al. (1976a) which assumes a linear relationship between fishing effort and fishing mortality. The absence of an adequate measure of commercial catch-per-effort prevented calculation of actual fishing effort. Instead, an annual fishing effort index was determined by dividing total catch by the spring survey catch-per-tow (Table 8). Because of the aberrant 1969 spring value and the year-to-year fluctuations in the remaining values, the 1968-77 time-series was smoothed by calculating an exponential curve through the actual points (Figure 2), and the predicted values calculated from the curve were used in place of the actual values to determine the fishing effort index. Cohort analysis was performed using $F = 0.30$ for ages 4 and older in 1977 with $M = 0.30$ for all ages. This level of F was chosen as a first approximation since

the fishing effort index in 1977 was about half of the 1976 index implying a similar reduction in fishing mortality from earlier estimates for 1976 of about 0.60-0.70. A linear regression between the 1968-75 fishing effort indices and the mean fishing mortality rates (F) for ages 3 and older from the cohort analysis predicted an F of 0.374 for 1977 based on the fishing effort index for 1977. A second cohort analysis was run using 0.38 as the terminal F in 1977. A second linear regression using the revised F values from this cohort analysis predicted F = 0.389 for 1977. A third and final cohort analysis was run using F = 0.39 for 1977 (Table 9). A final linear regression predicted F = 0.391 for 1977 (Table 8, Figure 3); therefore, F = 0.39 was accepted as the best estimate.

b. Recruitment Estimates

Estimates of the size of the 1974-76 year-classes at age 1 were obtained from power curve relationships of survey catch-per-tow (numbers) of (1) age 0 fish from autumn surveys, and (2) age 1 fish from spring surveys versus year-class size at age 1 from the cohort analysis (Tables 11 and 12, Figures 4 and 5). Estimates of the size of the 1974-75 year-classes at age 2 were also obtained from power curve relationships between spring survey catch-per-tow of age 2 fish and year-class size at age 2 from the cohort analysis (Table 11, Figure 6).

The size of the 1974 year-class at age 1 was estimated to be 2,516 million fish based on the autumn survey age 0 index and 2,104 million fish based on the spring survey age 1 index. The year-class at age 2 was estimated to be 1,488 million fish based on the spring survey age 2 index. Given the reported catch of 349.5 million fish at age 2 in 1976 (Table 3) and assuming a year-class size of 1,488 million fish at age 2, implies an F of 0.314. Assuming this F in 1976 for the 1974 year-class, the size of the year-class at age 1 from cohort analysis

would be 2,447 million fish. The mean of these three different year-class estimates at age 1 was 2,335 million fish. The reported catch of 375.4 million fish at age 1 in 1975 (Table 3) applied to the year-class estimates of 2,516 and 2,104 million fish at age 1 implies year-class sizes at age 2 of 1,543 and 1,238 million fish, respectively. The mean of the three different year-class estimates at age 2 was 1,423 million fish. The reported catch of 349.5 million at age 2 applied to a year-class size of 1,423 million fish implies an F of 0.331. Cohort analysis starting with this F at age 2 in 1976 gives a year-class size of 2,358 million fish at age 1 in 1975. In view of these various estimates, the 1974 year-class at age 1 was set at 2,360 million fish.

The 1975 year-class at age 1 was estimated to be 614 million fish based on the autumn survey age 0 index and 915 million fish based on the spring survey age 1 index. This year-class at age 2 was estimated to be 652 million fish based on the spring survey age 2 index. The assumed catch of 33.0 million fish at age 2 in 1977 (Table 3) applied to a year-class size of 652 million fish gives an F of 0.060. Cohort analysis starting with F = 0.060 at age 2 in 1977 results in a year-class size of 898 million fish at age 1 in 1976. The mean of these three estimates of year-class size at age 1 was 809 million fish. Applying the reported catch of 12.3 million fish at age 1 in 1976 (Table 3) to the year-class estimates of 614 and 915 million fish at age 1 implies year-class sizes at age 2 of 444 and 667 million fish, respectively. The mean of the three year-class estimates at age 2 was 588 million fish. Given the reported catch of 12.3 million at age 2 from a year-class of 588 million fish implies an F of 0.067. Cohort analysis starting with this F at age 2 in 1977 gives a year-class size of 809 million fish at age 1 in 1976. The size of the 1975 year-class at age 1 was, therefore, set at 810 million fish.

The 1976 year-class at age 1 was estimated to be 417 million fish based on the spring survey age 1 index. Fish of this year-class were not caught at age 0 during the 1976 autumn survey. The survey catch-per-tow of this year-class at both ages 0 and 1 was the poorest of any year-classes during 1963-77 (Tables 11 and 12). It appears, therefore, that this year-class is very poor. The poorest year-classes observed since 1961 were in 1962-63 (429.5 million fish at age 1). The size of the 1976 year-class at age 1 was set at 415 million, based on the single estimate from the 1977 spring survey data, which is about the size of the poorest year-classes observed.

There are presently no estimates available concerning the size of the 1977 year-class. Since the contribution of age 1 fish to the 1978 catch is expected to be minimal, the estimation of the size of the 1977 year-class is not particularly critical to the results of the assessment. However, the consequences of overestimating the size of this year-class are much greater than of underestimating it. If the year-class is underestimated, then any losses in catch at age 1 will be regained in later years since yield-per-recruit is maximized at about age 4 (ICNAF 1973). If the year-class is overestimated, then the 1979 stock size is driven below projected levels. The 1977 year-class at age 1 was, therefore, set at the level of the poor 1976 year-class.

c. Partial Recruitment

Mackerel are considered to be fully recruited to the fishery at age 3 and older, based on age-specific fishing mortality rates (Table 9). Partial recruitment at ages 1 and 2 (the percentage of fishing mortality at those ages compared with the mean for ages 3 and older) varied considerably during 1962-77 (Table 13). Partial recruitment at age 1 ranged from 0.9 to 112.8% and at age

2 from 15.8 to 89.9%. The values prior to 1968 are less precise than those since then because the numbers-at-age data for 1962-67 were based on very limited sampling data and are not as reliable as later data (Anderson et al. 1976a). Partial recruitment at ages 1 and 2 in 1977 was calculated to be near the low end of the range of values. In view of the wide fluctuations evident in previous years, it was felt that the use of the 1977 partial recruitment coefficients in 1978 may not necessarily reflect the probable situation. For age 1, an average of the 1968-77 values (except 1970, 1973, and 1975) was used for 1978 (9%). The high values in 1970 and 1975 were excluded because they occurred when large catches were taken from strong incoming year-classes, and this did not appear to represent the expected situation in 1978. The high 1973 value was also excluded because it resulted from a large catch of age 1 fish from a below-average year-class which occurred as a consequence of intensive fishing effort being exerted on younger age-groups to maintain previous high levels of catch at a time when older age-groups had experienced a sharp decrease in abundance. For age 2, an average of the 1968-77 values (except 1974-75) was used for 1978 (39%). The values in 1974-75 were excluded because they were unusually higher than most others and did not appear to be representative of the expected situation for 1978. They resulted from (1) large catches being taken from good-strong year-classes, and (2) from apparent direction of fishing effort onto that age-group from older age-groups to maintain high levels of catch.

6. Assessment Results

The calculated fishing mortalities and stock sizes by age for 1962-77 are listed in Tables 9 and 10. The assessment parameters used are summarized in Table 14. Fishing mortality for ages 3 and older increased throughout the

period from 0.038 in 1962 to 0.745 in 1976 before decreasing in 1977 to an estimated 0.39. Total stock biomass (age 1 and older) increased from about 600,000 tons in 1962-66 to a peak of 2.4 million tons in 1969 and then declined steadily to an estimated 524,000 tons at the beginning of 1977. Spawning stock biomass (50% of age 2 and 100% of age 3 and older) increased from around 500,000 tons during 1962-67 to 1.8 million tons in 1970-72 and then decreased to 435,000 tons in 1977. Under the assumption that 92,000 tons will be caught in 1977, the spawning stock will be further reduced to 402,500 tons in 1978. Table 15 lists the projected catch in 1978 and the spawning stock in 1979 at levels of fishing mortality from 0.0 to 0.7. If no fishing were allowed in 1978, the spawning stock would increase about 6% to 428,000 tons in 1979. A catch of 23,500 tons in 1978 (F = 0.07) would maintain the 1979 spawning stock at the 1978 level. Fishing at $F_{0.1}$ = 0.35 would produce a catch of about 104,000 tons, but would reduce the spawning stock by 21% in 1979.

If the entire assessment was done assuming a total catch of 110,000 tons in 1977 (TAC of 105,000 plus 5,000 for USA recreational catch) instead of 92,000 tons, the catch projections for 1978 would differ very little. The fishing mortality estimate for 1977 would be 0.435 instead of 0.39 and projected spawning stock size in 1978 would be about 390,000 tons, instead of 402,500 tons. A catch of about 25,000 tons in 1978, instead of 23,500 tons, would maintain the 1979 spawning stock at the 1978 level.

Since mackerel migrate extensively in the area between Cape Hatteras and Newfoundland, they have been assessed and managed as a unit stock. Consequently, the overall stock comes under the jurisdiction of both the USA and Canada. Accordingly, the catch options calculated for 1978 must apply to both countries collectively.

Figure 7 shows the historical relationship between spawning stock and recruitment. The spawning biomass present in 1962-67 of about 500,000 tons produced year-classes ranging from the poorest (1962-63) to the strongest (1967). The large spawning stocks present during the late 1960's - early 1970's produced both above- and below-average year-classes. It is evident that spawning stock size exerts little influence on the size of a year-class unless perhaps the spawning stock is reduced to extremely low levels. Lett et al. (1975) found this to be evident in simulations of Gulf of St. Lawrence herring. Environmental factors are obviously the major controlling forces, but the present state of knowledge concerning the influence of these factors is inadequate for assessment use. Consequently, it is virtually impossible to define an optimum or minimum spawning stock size at or above which level adequate recruitment can be predicted or below which level poor recruitment is likely. However, since spawning stock size has continued a steady decline and recent year-classes (1975-76) appear to be as poor as any observed previously, there is obvious cause for concern if the spawning stock is allowed to decrease below the projected 1978 level.

7. Literature Cited

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Table 1. Mackerel catch (tons) from SA 3-6 during 1961-77.

Year	USA		Canada	Other countries	Total
	Commercial	Recreational			
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	19,048	47,647
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	396,723	429,250
1974	1,042	7,640[1]	16,701	321,837	347,220
1975	1,974	6,503	13,544	271,719	293,740
1976[3]	2,345	4,947[1]	15,744	219,997	243,033
1977	3,000[2]	5,000[2]	20,000[2]	64,000[2]	92,000[2]

[1]From angler survey; remaining years estimated (see text).
[2]Estimated.
[3]Provisional.

Table 2. Estimated mackerel catches (tons) in 1977 by country from SA 3-6

Country	Reported through March	Estimated remainder	Total	Allocation
Bulgaria	3,110	890	4,000	4,000
Canada	-	20,000	20,000	30,000
Cuba	683	1,317	2,000	2,000
FRG	-	1,100	1,100	1,100
GDR	7,981	4,419	12,400	12,400
Italy	50	250	300	300
Poland	17,167	3,033	20,200	20,200
Romania	-	1,100	1,100	1,100
Spain	10	-	10	-
USSR	22,586	214	22,800	22,800
USA (comm.)	527	2,473	3,000	6,000
USA (rec.)	-	5,000	5,000	-
Others	-	90	90	5,100
Total	52,114	39,886	92,000	105,000

Table 3. Mackerel catch (commercial and recreational) (millions of fish) from SA 3-6 during 1962-77.

Year-class	Year															
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1952	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1953	0.6	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1954	1.1	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
1955	2.1	0.2	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
1956	2.3	0.2	0.8	0.9	-	-	-	-	-	-	-	-	-	-	-	-
1957	1.7	0.4	4.8	4.8	0.2	-	-	-	-	-	-	-	-	-	-	-
1958	5.5	8.1	5.1	5.1	0.6	0.4	0.1	-	-	-	-	-	-	-	-	-
1959	22.1	35.2	24.0	23.6	26.4	39.8	7.6	9.5	3.0	-	-	-	-	-	-	-
1960	4.0	1.7	4.9	6.3	9.6	7.5	1.2	2.5	4.0	7.5	-	-	-	-	-	-
1961	23.3	5.6	5.1	4.9	5.7	6.3	0.8	3.5	10.6	8.4	5.7	-	-	-	-	-
1962	-	1.5	8.6	3.5	3.2	4.1	8.2	2.3	10.5	4.4	3.8	1.6	-	-	-	-
1963	-	-	15.9	4.3	6.4	4.3	17.8	3.4	5.6	3.7	8.3	3.8	0.8	-	-	-
1964	-	-	-	10.9	13.9	24.4	47.3	6.5	7.5	9.2	4.3	4.1	2.5	1.0	-	-
1965	-	-	-	-	29.0	33.0	73.6	75.0	29.4	35.8	24.4	10.9	6.4	2.3	1.4	-
1966	-	-	-	-	-	1.0	76.3	183.2	173.5	210.8	88.6	31.1	25.7	12.5	13.2	0.5
1967	-	-	-	-	-	2.2	175.5	298.8	556.0	579.0	396.2	196.7	108.3	50.7	22.4	3.8
1968	-	-	-	-	-	-	1.4	8.1	58.1	132.0	185.3	191.9	111.8	52.1	34.2	4.9
1969	-	-	-	-	-	-	-	4.5	206.1	304.8	260.0	232.9	114.3	68.1	40.0	8.1
1970	-	-	-	-	-	-	-	-	5.1	77.3	87.0	284.2	101.5	58.9	27.0	8.0
1971	-	-	-	-	-	-	-	-	-	2.5	22.4	282.3	264.4	101.3	51.8	12.2
1972	-	-	-	-	-	-	-	-	-	-	3.6	161.4	242.2	114.2	84.7	13.7
1973	-	-	-	-	-	-	-	-	-	-	-	4.0	95.9	433.3	269.4	71.0
1974	-	-	-	-	-	-	-	-	-	-	-	-	2.0	375.4	349.5	130.5
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	12.3	33.0
1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.1
Total	63.3	53.5	70.5	64.3	95.0	123.0	409.8	597.3	1,069.4	1,375.4	1,089.6	1,404.9	1,075.8	1,273.5	905.9	287.8
Obs wt[1]	16.6	17.3	21.7	24.7	32.4	47.6	109.9	165.1	262.7	403.7	431.6	429.2	347.2	293.7	243.0	92.0
Calc wt[1,2]	15.3	18.2	23.1	25.5	30.7	48.0	84.4	144.7	276.8	429.2	396.2	435.3	346.9	308.7	268.1	93.3
Obs/calc	1.085	0.951	0.939	0.969	1.055	0.992	1.302	1.141	0.949	0.941	1.089	0.986	1.001	0.951	0.906	0.986

[1]Thousands of tons.

[2]Using mean wts at age from Table 4.

Table 4. Mean weights at age (kg) for mackerel.

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

Table 5. Stratified mean catch (kg) per tow (log_e 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).

Year	Spring[1]		Autumn[2]	
	log_e	retransformed	log_e	retransformed
1963	-	-	.013	.016
1964	-	-	<.001	<.001
1965	-	-	.046	.073
1966	-	-	.057	.085
1967	-	-	.195	.372
1968	.575	3.998	.117	.217
1969	.029	.065	.154	.459
1970	.471	2.039	.068	.099
1971	.425	1.969	.052	.073
1972	.354	1.332	.070	.107
1973	.228	.748	.034	.043
1974	.277	.769	.046	.108
1975	.121	.255	.010	.016
1976	.144	.317	.028	.039
1977	.118	.199	-	-

[1]Based on catches with No. 41 trawls; 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 6. Stratified mean catch (number) per tow of mackerel by year-class from the 1973-76 USA spring bottom trawl surveys in SA 5-6, strata 1-25, 61-76.

	Number by year-class														
Year	1976	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966	1965	1964	1963+	Total
1973	-	-	-	-	1.949	6.683	8.188	15.957	3.669	21.081	6.309	3.319	.365	.574	68.094
1974	-	-	-	2.067	.749	1.347	.185	.492	.249	1.401	.440	.237	.107	-	7.274
1975	-	-	5.330	1.101	.141	.128	.030	.028	.020	.014	.001	-	-	-	6.793
1976	-	.447	4.928	.365	.070	.014	.006	.009	-	.004	-	-	-	-	5.843
1977	.043	.254	.340	.153	.050	.017	.010	.024	.011	.018	.007	.019	-	-	.946

Table 7. Mackerel catch per standardized USA day fished.

Year	Catch-per-day (tons)
1964	.43
1965	.49
1966	.84
1967	1.75
1968	2.80
1969	1.92
1970	2.07
1971	1.29
1972	.84
1973	.53
1974	.17
1975	.53
1976	.59

Table 8. Estimation of F in 1977 for the SA 3-6 mackerel fishery.

Year	Spring survey catch/tow		Catch[3] (tons)	Fishing effort index[4]	Mean F[5] age 3+
	Actual[1]	Calculated[2]			
1968	3.998	4.518	109,940	24,334	.155
1969	.065	3.199	165,113	51,614	.144
1970	2.039	2.265	262,681	115,974	.185
1971	1.969	1.604	403,675	251,668	.268
1972	1.332	1.135	431,606	380,270	.316
1973	.748	.804	429,250	533,893	.451
1974	.769	.569	347,220	610,228	.515
1975	.255	.403	293,740	728,883	.532
1976	.317	.285	243,033	852,747	(.626)[6,7]
1977	.199	.202	92,000	455,446	(.391)[6]

[1]Stratified mean catch (kg) per tow (retransformed from $\log_e$ to linear scale).

[2]Values predicted from exponential curve calculated using actual values for 1968-77 (except 1969). See Figure 2.

[3]Includes commercial and recreational catch.

[4]Catch divided by calculated spring survey catch/tow.

[5]Obtained from cohort analysis assuming F = 0.39 in 1977.

[6]Calculated from regression of fishing effort index on mean F for 1968-75: $Y = 0.121 + 0.00000059X$, $r = 0.991$.

[7]Actual value calculated from cohort analysis was 0.745, assuming F = 0.39 in 1977.

Table 9. Fishing mortality rates (F) for mackerel in SA 3-6 derived from cohort analysis (M = 0.3).

Year-class	Year															
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	(.038)[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1952	.030	(.042)[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1953	.088	(.042)[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1954	.073	.019	(.039)[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
1955	.043	.006	(.039)[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
1956	.050	.006	.033	(.052)[1]	-	-	-	-	-	-	-	-	-	-	-	-
1957	.051	.017	.321	.713	(.060)[1]	-	-	-	-	-	-	-	-	-	-	-
1958	.127	.313	.374	.946	.288	.357	(.155)[1]	-	-	-	-	-	-	-	-	-
1959	.030	.067	.066	.095	.163	.446	.156	.336	(.185)[1]	-	-	-	-	-	-	-
1960	.006	.004	.014	.025	.054	.060	.013	.039	.090	(.268)[1]	-	-	-	-	-	-
1961	.030	.010	.012	.016	.026	.040	.007	.042	.195	.262	(.316)[1]	-	-	-	-	-
1962	-	.004	.032	.018	.023	.041	.119	.049	.369	.291	.500	(.451)[1]	-	-	-	-
1963	-	-	.044	.017	.034	.032	.200	.059	.145	.150	.670	.892	(.515)[1]	-	-	-
1964	-	-	-	.024	.042	.107	.351	.081	.142	.290	.239	.426	.575	(.532)[1]	-	-
1965	-	-	-	-	.028	.045	.149	.249	.162	.342	.470	.449	.596	.503	(.745)[1]	-
1966	-	-	-	-	-	<.001	.039	.136	.207	.472	.419	.283	.454	.474	2.002	.390
1967	-	-	-	-	-	-	.027	.064	.181	.327	.441	.465	.580	.686	.888	.390
1968	-	-	-	-	-	-	-	.003	.030	.097	.215	.409	.507	.536	.990	.390
1969	-	-	-	-	-	-	-	-	.077	.173	.246	.410	.410	.523	.787	.390
1970	-	-	-	-	-	-	-	-	-	.056	.091	.545	.430	.547	.598	.390
1971	-	-	-	-	-	-	-	-	-	-	.015	.305	.598	.551	.708	.390
1972	-	-	-	-	-	-	-	-	-	-	-	.168	.463	.469	.916	.390
1973	-	-	-	-	-	-	-	-	-	-	-	-	.058	.452	.652	.390
1974	-	-	-	-	-	-	-	-	-	-	-	-	-	.202[2]	.330[2]	.220[2]
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.018[2]	.067[2]
1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.006[2]
$\bar{F}$ (age 3+)[3]	.038	.042	.039	.052	.060	.111	.155	.144	.185	.268	.316	.451	.515	.532	.745	.390[4]

[1]Mean F for age 3+ assumed.

[2]Determined from assumed stock size and known catch.

[3]Weighted by stock numbers at age from Table 10.

[4]Age 4+

Table 10. Mackerel stock size by age in SA 3-6 (millions of fish) derived from cohort analysis assuming M = 0.3 and F = 0.39 at ages 4 and older in 1977. Values in parentheses estimated.

	Year																
Year-class	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1951	12.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1952	7.8	5.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1953	8.3	5.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1954	18.1	12.5	9.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1955	57.8	41.0	30.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1956	55.2	38.9	28.6	20.5	-	-	-	-	-	-	-	-	-	-	-	-	-
1957	39.7	27.9	20.3	10.9	4.0	-	-	-	-	-	-	-	-	-	-	-	-
1958	53.7	35.1	19.0	9.7	2.8	1.5	0.8	-	-	-	-	-	-	-	-	-	-
1959	877.3	630.9	437.1	303.2	204.3	128.6	61.0	38.7	20.5	-	-	-	-	-	-	-	-
1960	741.0	545.5	402.6	294.1	212.4	149.1	104.0	76.0	54.2	36.7	-	-	-	-	-	-	-
1961	920.5	661.9	485.5	355.3	259.0	187.0	133.1	97.9	69.5	42.4	24.2	-	-	-	-	-	-
1962	-	429.5	316.9	227.3	165.4	119.8	85.2	56.1	39.6	20.3	11.2	5.0	-	-	-	-	-
1963	-	-	429.5	304.5	221.9	158.9	114.0	69.1	48.3	30.9	19.7	7.5	2.3	-	-	-	-
1964	-	-	-	542.2	392.3	278.7	185.4	96.7	66.0	42.4	23.5	13.7	6.6	2.8	-	-	-
1965	-	-	-	-	1212.9	873.6	618.8	395.0	228.1	143.7	75.6	35.0	16.6	6.8	3.0	-	-
1966	-	-	-	-	-	3165.3	2344.1	1670.8	1080.1	650.8	300.7	146.5	81.8	38.5	17.7	1.8	0.9
1967	-	-	-	-	-	-	7786.5	5617.3	3904.2	2413.8	1289.8	614.5	285.9	118.6	44.2	13.5	6.8
1968	-	-	-	-	-	-	-	3114.3	2300.1	1654.0	1111.7	664.1	326.8	145.9	63.2	17.4	8.7
1969	-	-	-	-	-	-	-	-	3244.9	2226.5	1387.1	803.8	395.0	194.2	85.3	28.8	14.4
1970	-	-	-	-	-	-	-	-	-	1657.5	1161.4	785.5	337.3	162.5	69.7	28.4	14.2
1971	-	-	-	-	-	-	-	-	-	-	1711.9	1248.9	682.2	277.8	118.6	43.3	21.7
1972	-	-	-	-	-	-	-	-	-	-	-	1212.6	759.4	354.1	164.1	48.6	24.4
1973	-	-	-	-	-	-	-	-	-	-	-	-	1981.2	1385.1	653.2	252.0	126.4
1974	-	-	-	-	-	-	-	-	-	-	-	-	-	(2360.0)	1428.6	760.9	452.4
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(810.0)	589.4	408.3
1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(415.0)	305.6
1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		(415.0)
Stock size (age 1+)																	
Total(10^6)	2791.8	2434.4	2178.8	2067.7	2675.0	5062.5	11432.9	11231.9	11055.5	8919.0	7116.8	5537.1	4875.1	5046.3	3457.6	2199.1	1798.8
Wt(10^3tons)[1]	626.7	584.9	582.2	577.3	674.9	886.7	2150.3	2404.2	2285.6	2161.3	2099.5	1522.1	1186.5	964.1	702.2	524.4	468.6
Spawning stock (50% age 2, 100% age 3+)																	
Total(10^6)	1500.8	1674.0	1590.9	1373.3	1266.0	1460.0	2474.4	5309.0	6660.6	6148.3	4824.2	3700.1	2514.2	1993.8	1933.3	1489.4	1231.0
Wt(10^3tons)[1]	461.4	491.0	517.8	501.6	517.1	512.6	920.2	1505.8	1802.1	1829.9	1811.7	1300.8	931.6	635.6	519.3	434.7	402.5

[1]Adjusted using ratio of observed to calculated weights in Table 3.

Table 11. Catch per tow (number) of age 1 and 2 mackerel from USA spring bottom trawl surveys (strata 1-25, 61-76) and year-class size (millions of fish) at age 1 and 2 from cohort analysis.

Year-class	Age 1		Age 2	
	Spring survey	Cohort analysis	Spring survey	Cohort analysis
1966	-	3165.3	21.661	2344.1
1967	197.993	7786.5	1.190[1]	5617.3
1968	.299[1]	3114.3	12.435	2300.1
1969	6.208	3244.9	13.390	2226.5
1970	2.954	1657.5	5.545	1161.4
1971	12.093	1711.9	6.683	1248.9
1972	1.949	1212.6	.749	759.4
1973	2.067	1981.2	1.101	1385.1
1974	5.330	(2103.9)[2]	4.928	(1488.3)[2]
1975	.447	(915.3)[2]	.254	(651.8)[2]
1976	.043	(416.9)[2]	-	-

[1]Not used.

[2]Calculated.

Table 12. Catch per tow (number) of age 0 mackerel from USA autumn bottom trawl surveys (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26) and year-class size (millions of fish) at age 1 from cohort analysis.

Year-class	Autumn survey age 0	Cohort analysis age 1
1963	.087	429.5
1964	.022	542.2
1965	.134	1212.9
1966	.170	3165.3
1967	15.709	7786.5
1968	.215	3114.3
1969[1]	38.504	3244.9
1970	.027	1657.5
1971	.517	1711.9
1972	.119	1212.6
1973	.339	1981.2
1974	.648	(2515.6)[2]
1975	.012	(614.3)[2]
1976	.000	(0)[2]

[1]Not used.

[2]Calculated.

Table 13. Percentage of fishing mortality (F) at ages 1 and 2 compared to mean F at age 3 and older (partial recruitment).

Year	Age 1	Age 2
1962	78.9	15.8
1963	9.5	23.8
1964	112.8	82.1
1965	46.2	32.7
1966	46.7	70.0
1967	0.9	40.5
1968	17.4	25.2
1969	2.1	44.4
1970	41.6	16.2
1971	20.9	64.6
1972	4.7	28.8
1973	37.3	67.6
1974	11.3	89.9
1975	38.0	85.0
1976	2.4	44.3
1977	1.5	17.2

Table 14. Summary of parameters used in the mackerel assessment.

Parameter		Value
Fishing mortality in 1977(4+)		0.39
Recruitment at age 1:	1974 year-class	$2{,}360.0 \times 10^6$
	1975 year-class	810.0×10^6
	1976 year-class	415.0×10^6
	1977 year-class	415.0×10^6
Partial recruitment in 1978 (%):	Age 1	9
	Age 2	39
	Age 3+	100
1978 projection: Spawning stock (10^3 tons)		402.5

Table 15. Projected mackerel catch in SA 3-6 in 1978 with fishing mortality ranging from 0.0 to 0.7, and the resulting spawning stock in 1979 and the percentage change from 1978.

Fishing mortality (F)	Total mortality (Z)	Catch in 1978 (10^3 tons)	Spawning stock in 1979 (10^3 tons)	% change in spawning stock from 1978(by weight)
0.00	0.30	0.0	428.0	+6.3
0.05	0.35	16.9	409.6	+1.8
0.07	0.37	23.5	402.5	0.0
0.10	0.40	33.0	392.6	-2.5
0.15	0.45	48.5	376.3	-6.5
0.20	0.50	63.2	360.8	-10.4
0.25	0.55	77.3	346.0	-14.0
0.30	0.60	90.8	331.9	-17.5
0.35	0.65	103.7	318.5	-20.9
0.40	0.70	116.0	305.6	-24.1
0.45	0.75	127.8	293.4	-27.1
0.50	0.80	139.0	281.7	-30.0
0.55	0.85	149.8	270.6	-32.8
0.60	0.90	160.1	260.0	-35.4
0.65	0.95	170.0	249.8	-37.9
0.70	1.00	179.5	240.1	-40.3

Figures 1 & 2 missing from original.

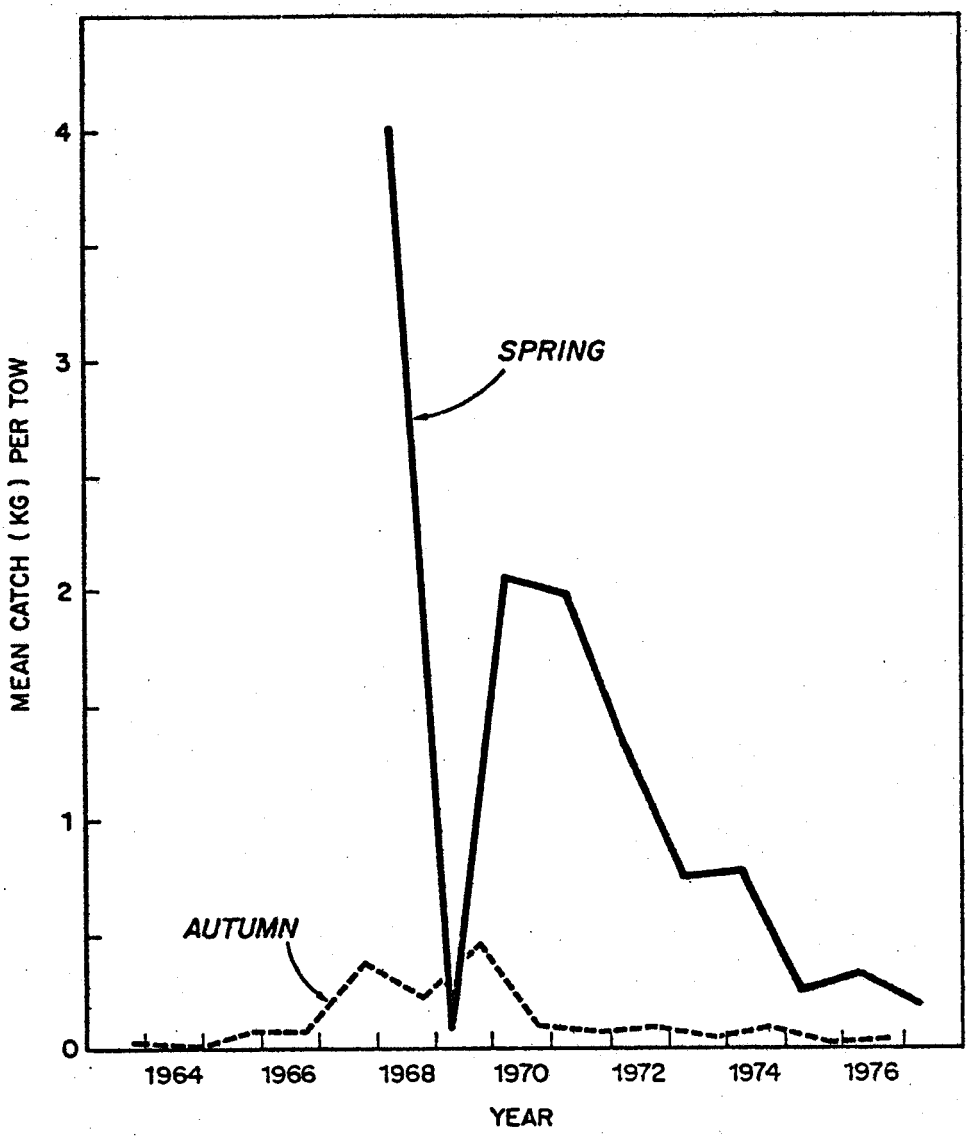

Figure 3. Stratified mean catch (kg) per tow of mackerel from USA spring (1968-77) and autumn (1963-76) bottom trawl surveys.

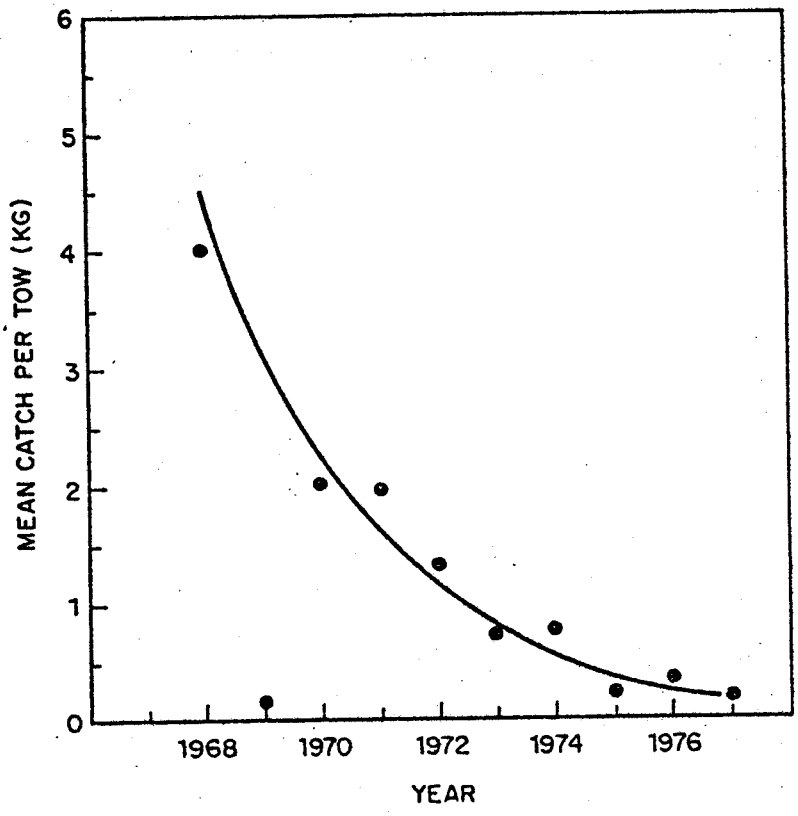

Figure 4. Exponential curve calculated through 1968-77 time-series (1969 point omitted from calculation of curve) of spring survey catch-per-tow (kg) indices for mackerel.

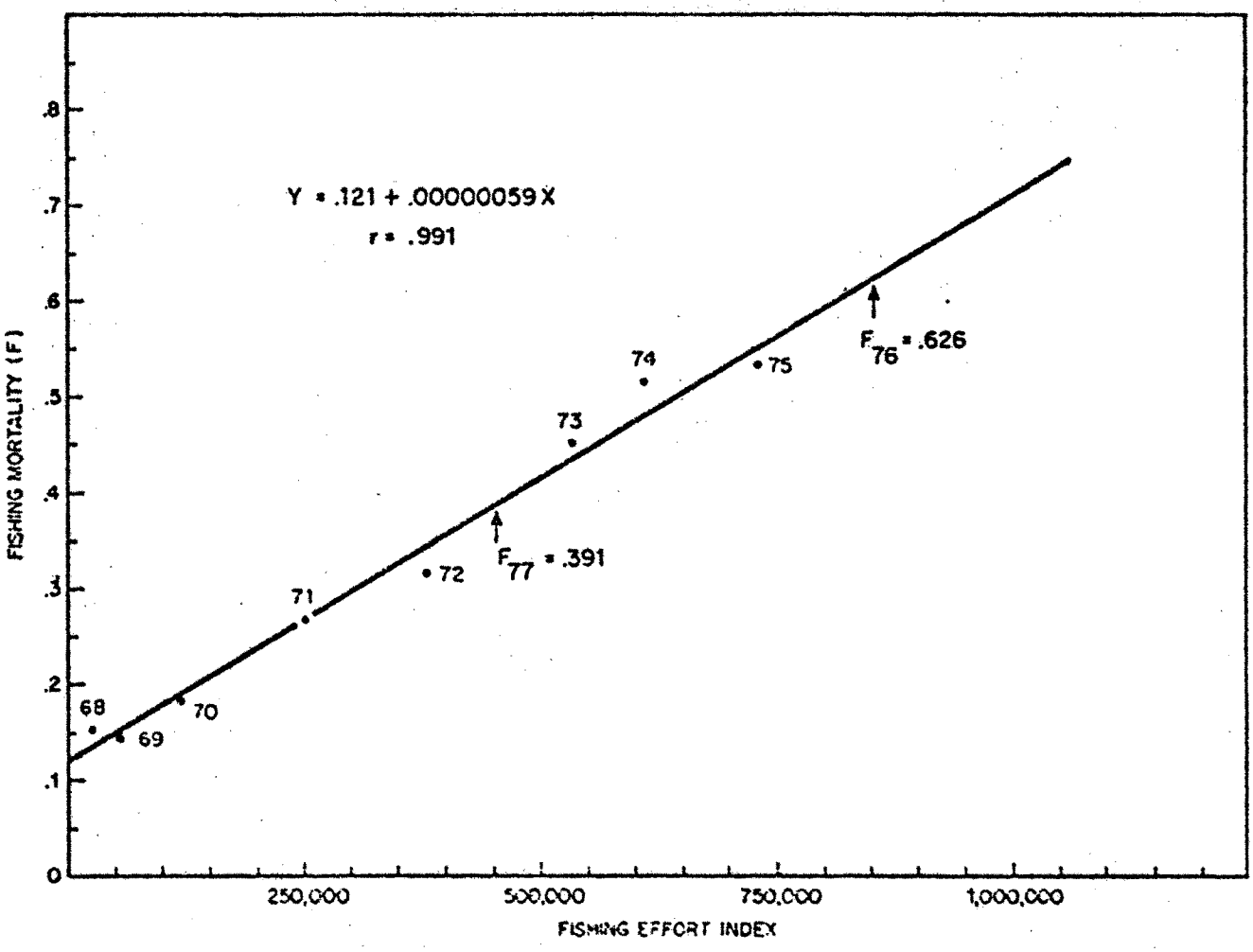

Figure 5. Relationship between fishing mortality from cohort analysis and fishing effort derived from spring survey catch-per-tow and total catch.

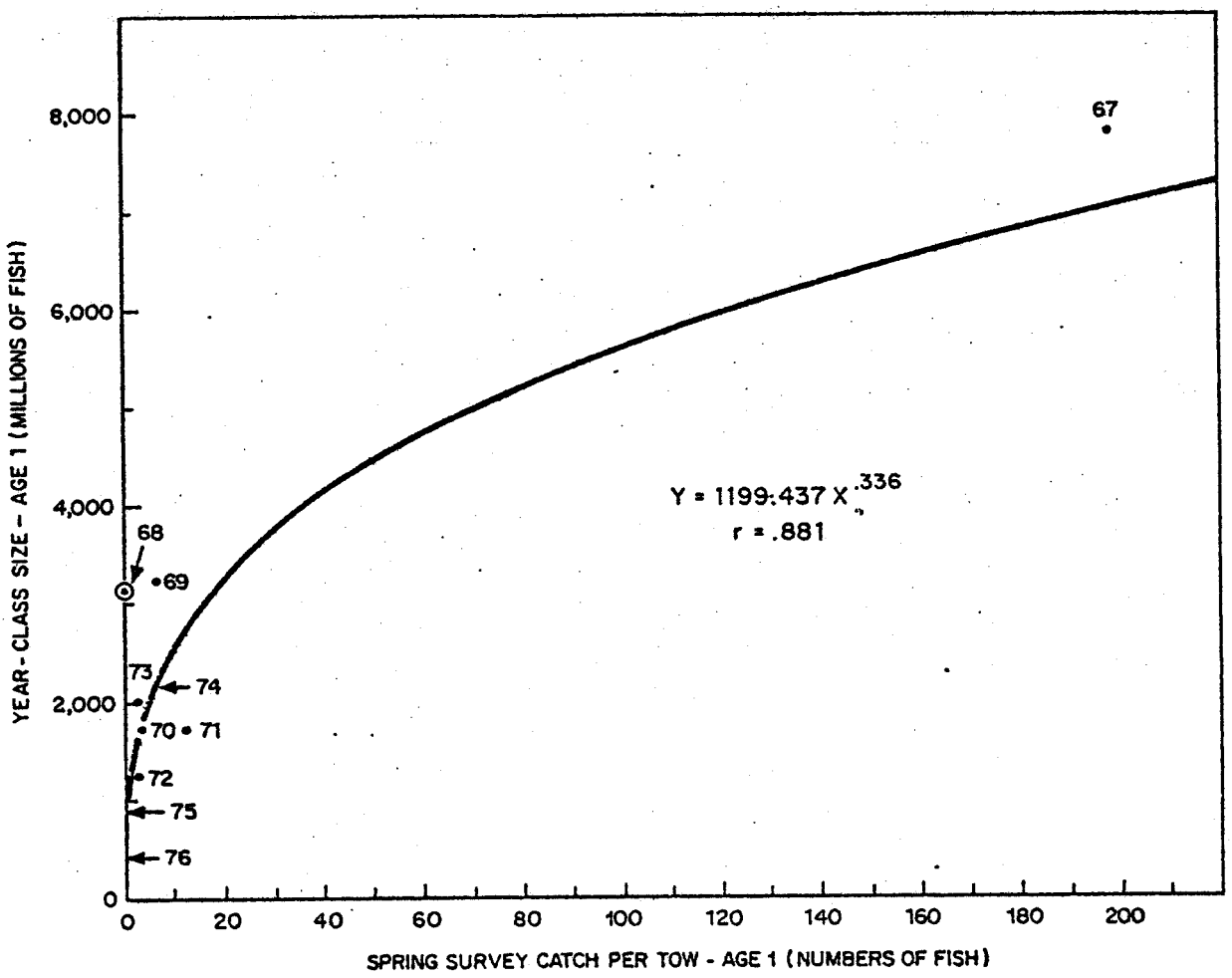

Figure 6. Power curve relationship between mackerel year-class size at age 1 and spring survey catch-per-tow at age 1. The 1968 point was not used in calculating the curve.

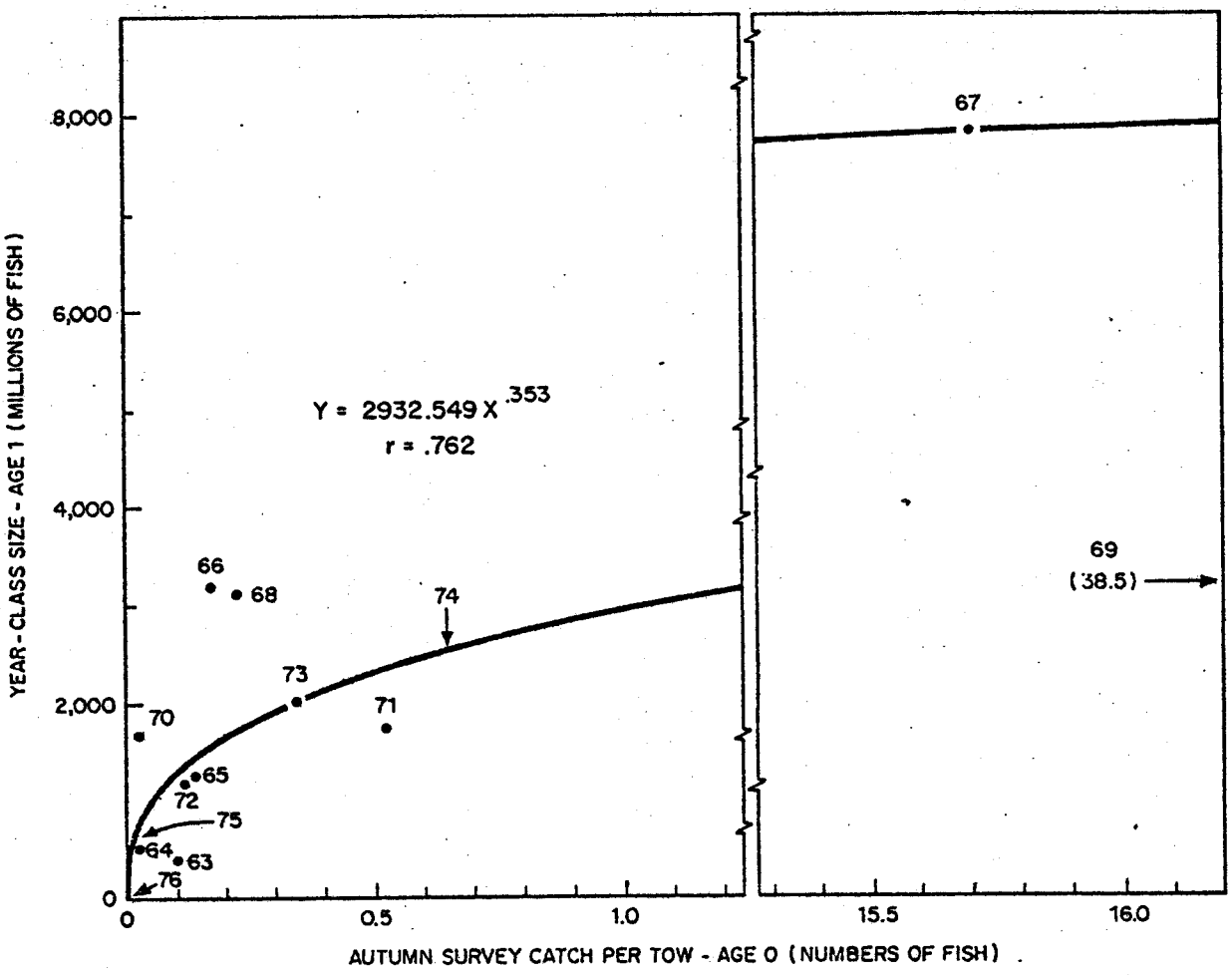

Figure 7. Power curve relationship between mackerel year-class size at age 1 and autumn survey catch-per-tow at age 0. The 1969 point was not used in calculating the curve.

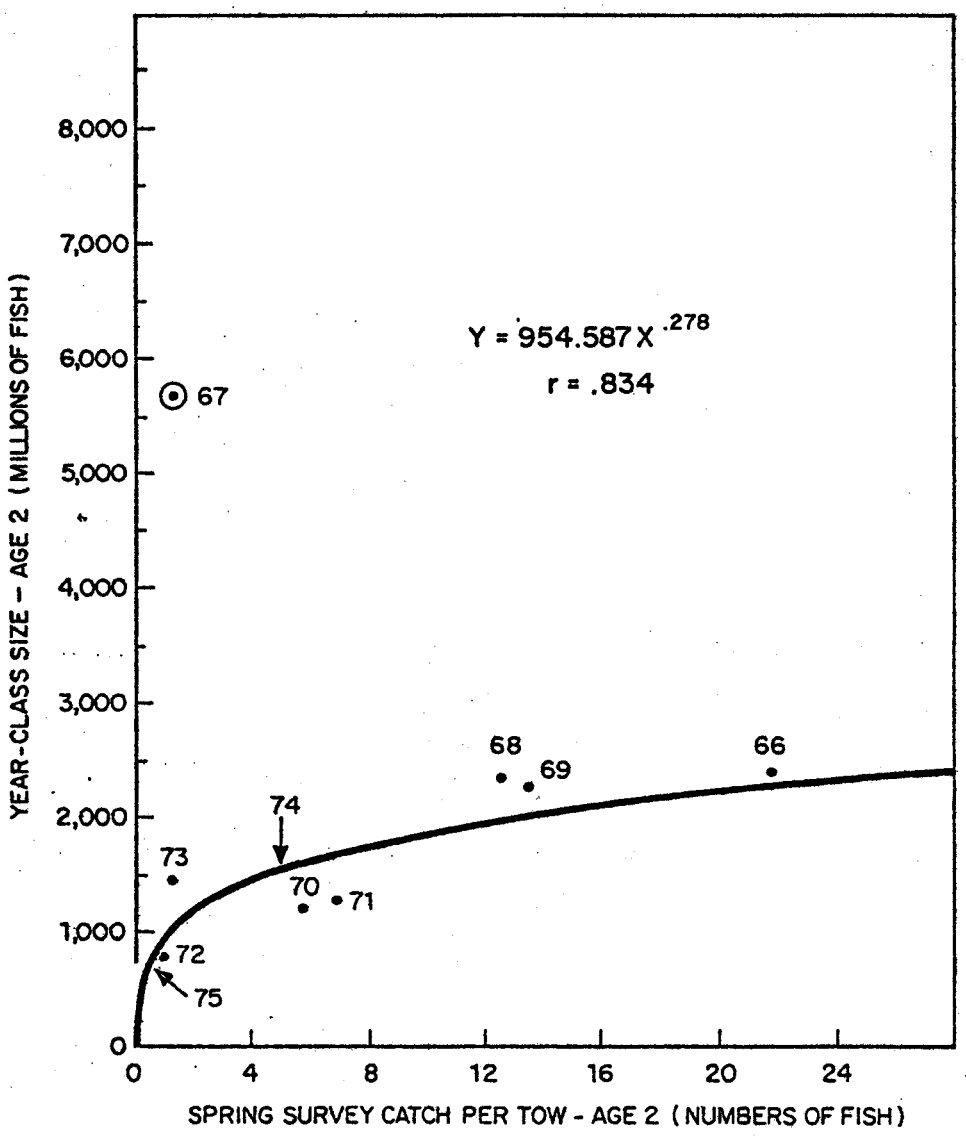

Figure 8. Power curve relationship between mackerel year-class size at age 2 and spring survey catch-per-tow at age 2. The 1967 point was not used in calculating the curve.

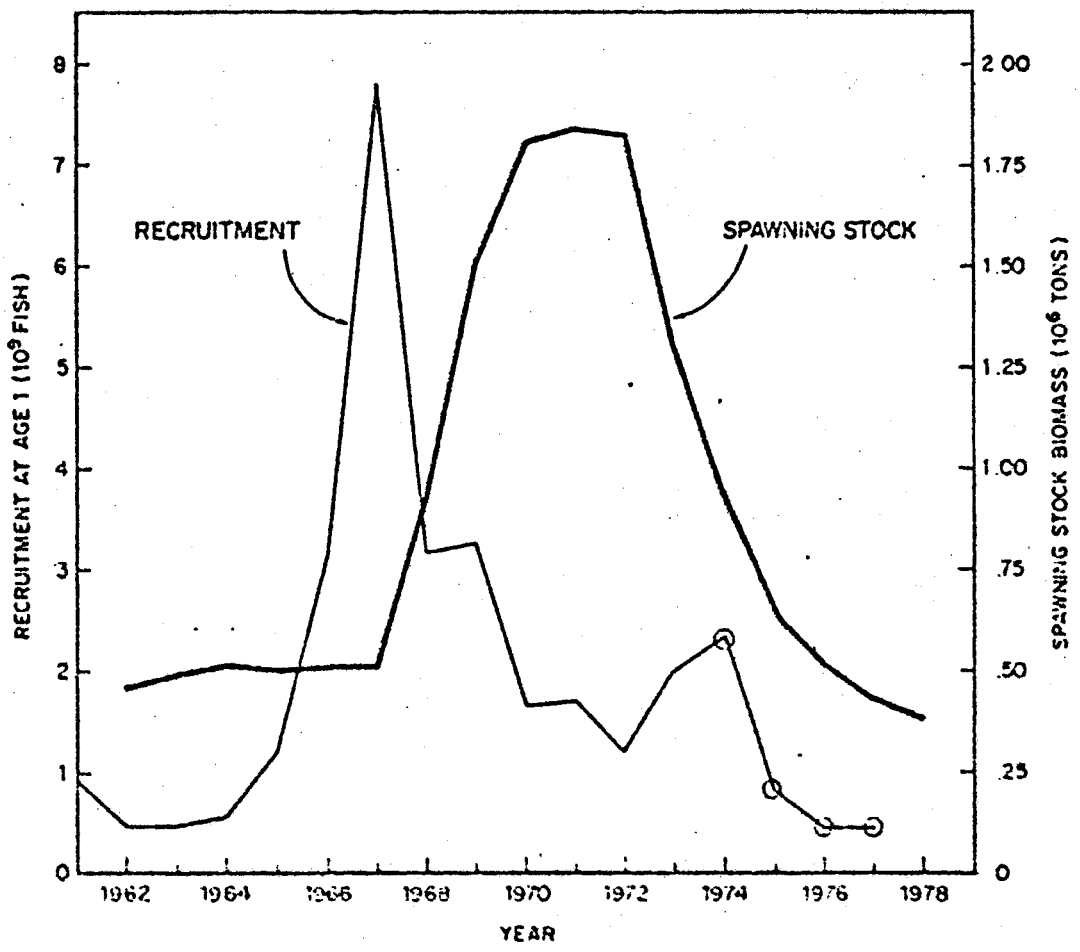

Figure 9. Mackerel spawning stock biomass in 1962-77 and abundance at age 1 of the 1961-77 year-classes. (Open circles indicate estimated year-class sizes.)