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Status of the Northwest Atlantic Mackerel Stock-1978

by

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INTRODUCTION

The following report presents an analysis of the status of the Northwest Atlantic mackerel (*Scomber scombrus*) stock distributed within ICNAF Subareas 3, 4, and 5 and Statistical Area 6 (SA 3-6) (Figure 1). This analysis is an update of an earlier assessment by Anderson (1977) and includes 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 1979 under various levels of catch in 1978 with resulting spawning stock biomasses in 1980.

CATCH

Mackerel catches for 1960-77 by the USA, Canada, and other countries in SA 3-6 are listed in Table 1. These data are similar to those given by Anderson (1977) except for the addition of data for 1960 and corrections and revisions made to catches in 1973 and 1975-77. The USA recreational catch estimates for 1975-76 were revised slightly as a result of final tabulation and analysis of data collected from NMFS, NEFC mackerel angler surveys in the Mid-Atlantic area. For the previous assessment (Anderson 1977), the USA recreational catch for 1977 was assumed to be 5,000 tons. Based on an NEFC mackerel angler survey conducted in 1977, the 1977 recreational catch was estimated to be only 522 tons. The international commercial catch in 1977 was assumed for the previous assessment to be 87,000 tons; however, provisional statistics indicate a commercial catch of 77,598 tons (Table 2). Therefore, the present assessment is based on a total 1977 catch of 78,120 tons compared to 92,000 tons assumed previously.

USA commercial catches ranged from 938 to 4,364 tons during 1960-77 and averaged 2,200 tons per year; the 1977 catch was only 1,376 tons. Estimated USA recreational catches ranged from 522 to 33,303 tons and averaged 13,600 tons annually. Canadian catches varied from 5,459 to 22,477 tons (1977) and averaged 12,800 tons each year. The total international catch increased from 12,310 tons in 1960 to a high of 431,606 tons in 1972, decreased to 245,935 tons in 1976, and then dropped sharply to 78,120 tons in 1977.

Catch statistics for 1978 are incomplete. The USA recreational catch, based on data obtained from a NMFS mackerel angler survey in Delaware, New Jersey, and New York during April-June, was estimated to be 6,200 tons for the area from Virginia to Maine (Christensen[1]). A comparison of January-July statistics for 1977 and 1978 suggests a USA commercial catch for 1978 of only about 1,300 tons. Distant-water-fleet catches in SA 5-6 for January-September total only about 250 tons and in SA 3-4 for January-July about 240 tons. The largest component of the mackerel fishery in SA 3-6 in 1978 is Canadian. Statistics available from ICNAF indicate a catch of 3,896 tons during January-July 1978 compared to 4,097 tons for the same period in 1977. A projection based on a comparison between 1977 and 1978 catches, assuming comparable fishing patterns in the two years, implies a total Canadian catch of 21,400 tons for 1978. This may be an underestimate in view of reports of a possible expansion of the Canadian mackerel fishery in 1978. However, considering the above estimates and projections for the various components of the mackerel fishery, the total 1978 catch, at a minimum, may be expected to be about 29,400 tons.

CATCH COMPOSITION

The international mackerel catch in numbers at age during 1962-77 (Table 3) is as given by Anderson (1977) except for changes made to the 1973 and 1975-77 data as a result of revised catch statistics. The 1977 results were further modified by the availability of numbers at

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

age for the Canadian catch calculated by Hunt[2] and Dawson[3]. The numbers at age calculated for the January-March commercial catch in SA 5-6, as described by Anderson (1977), were raised to include the balance of the commercial catch in SA 3-6 (less the Canadian catch). These were combined with the Canadian numbers and raised to include the USA recreational catch.

The 1974 year class at age 3 was predominant in the 1977 catch, comprising 45% by number of the total. The 1973 year class (age 4) was next in importance at 24%, followed by the 1975 year class at 12%. The average age of the 1977 catch was 3.8 years, compared with an average of 3.6 years for 1962-76.

MEAN WEIGHTS AT AGE

Mean weights at age adopted by ICNAF (1974) were utilized in the present assessment (Table 4). The numbers of fish caught at each age (Table 3) were multiplied by the appropriate mean weight, with the products summed by calendar year to obtain calculated catches (tons). Ratios between observed and calculated catches ranged from 0.906 to 1.302 (Table 3) and averaged 1.020. The mean weight values were also multiplied by the stock size numbers at age calculated from cohort analysis, with the products summed by calendar year to obtain stock biomass values. The annual biomass values were corrected using the appropriate observed/calculated catch ratios. Projected catch and stock biomass levels for 1978-80 were not corrected.

STOCK ABUNDANCE INDICES

The USA spring and autumn research vessel bottom trawl survey catch-per-tow indices have indicated a steady downward decline in mackerel abundance since 1968-69 (Table 5, Figure 3). Surveys conducted since the previous assessment (Anderson 1977) indicate a decrease in mean catch per tow (kg, retransformed) during the autumn survey from 0.039 in 1976 to 0.027 in 1977, and an increase during the spring survey

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[2]Hunt, J. J. Department of Fisheries and Oceans, Fisheries and Marine Service, Marine Fish Division, Resource Branch, St. Andrews, New Brunswick E0G 2X0 Canada, personal communication.

[3]Dawson, M. F. Department of Fisheries and Oceans, Fisheries and Marine Service, Marine Fish Division, Resource Branch, St. John's, Newfoundland A1C 1A1 Canada, personal communication.

from 0.199 in 1977 to 0.447 in 1978. The abrupt increase in the spring index in 1978 reflects the improved abundance and availability of mackerel at the time of the survey due to the absence of the international fishery. In previous years, an intensive international mackerel fishery was conducted in SA 5-6 during the late autumn and winter months. The average catch during November-March of 1971-72 to 1975-76 was over 232,000 tons.

Mean catch per tow in numbers from the spring survey also increased from 1977 (0.946) to 1978 (2.614) (Table 6).

The standardized USA commercial catch-per-day index (Table 7, Figure 4) has generally been consistent with survey indices of abundance and with stock biomass estimates from cohort analysis (Table 9). However, it increased sharply from 0.17 tons in 1974 to 0.53 tons in 1975 and remained relatively steady in 1976 (0.59 tons) and 1977 (0.52 tons) while the survey indices and stock biomass estimates continued to decline after 1974. As suggested previously (Anderson 1977), the USA commercial index may be limited as a measure of overall stock abundance, particularly in recent years (1970-77) since the catches on which the index is based have averaged only 0.2% of the total catch from the SA 3-6 stock per year. The increase in the index in 1975-77 may, therefore, reflect only localized improvements in abundance.

Distant-water-fleet catch-per-effort data appear to be unreliable as a relative measure of mackerel stock abundance. Anderson (1976) found dissimilar patterns of catch per hour among various distant-water-fleet country-tonnage classes during 1968-74 which were generally inconsistent with changes in stock biomass determined from cohort analysis, and suggested that learning, improvements in vessel efficiency through technological changes, or both occurred which essentially invalidated the catch rates as consistent measures of mackerel abundance. Anderson and Paciorkowski (1978) analyzed Bulgarian, GDR, Polish, and USSR catch statistics and also found substantial variability in catch-per-day trends among country-tonnage classes. The GDR and Polish stern trawler classes did exhibit declining catch rates after 1973 which varied from 12% per year (Polish B-418 vessel class) to 18% per year (GDR >1800 GT class). By contrast, the USA spring survey indices indicate a 29% decline per year during 1968-77 (Table 8, Figure 5), and results of cohort analysis (Table 9) indicate an average decrease of 23% per year in total stock biomass during 1972-77. Since the catch rates from the above distant-water-fleet vessel classes do not reflect the changes in mackerel abundance before 1973, it is uncertain how closely the declines in their catch rates after 1973 depict actual decreases in biomass. Data for the Polish B-29 and B-18 vessel classes do indicate, however, that catch per day during January-February decreased in 1977 to the lowest level observed for these classes during the period for which data are available (1970-77) (Anderson and Paciorkowski 1978).

NATURAL MORTALITY

Instantaneous natural mortality (M) was assumed to be 0.30 for all ages, as adopted earlier by ICNAF (1974).

FISHING MORTALITY

Instantaneous fishing mortality (F) in 1977 was estimated using the method proposed by Anderson et al. (1976) based on a linear relationship between mean annual F values (ages 3 and older) from cohort analysis and relative exploitation indices (international catch divided by spring survey catch per tow). This technique gave a predicted F for 1977 of 0.39 in the previous assessment (Anderson 1977). As a result of changes in the numbers-at-age catch data (Table 3), particularly for 1977, requiring a new cohort analysis, the F for 1977 was re-estimated to be 0.36 (Table 8, Figure 6).

Age-specific fishing mortality (F) rates for 1962-76 (Table 9) were generated from cohort analysis (Pope 1972) assuming F = 0.36 at ages 4 and older in 1977. Mean annual F values for ages 3 and older increased from 0.04 in 1962-64 to a peak of 0.84 in 1976 (Figure 12).

RECRUITMENT

The sizes of the 1961-73 year classes at age 1, estimated from cohort analysis, ranged from 428 million (1962 and 1963 year classes) to 7,791 million fish (1967 year class) (Table 9, Figure 12), with a mean size of 2,089 million and a median of 1,616 million.

Power curve relationships, fitted by least squares, between (1) autumn survey catch per tow (numbers) at age 0 and year-class size at age 1 estimated from cohort analysis for 1963-73 (Table 10, Figure 7),

(2) spring survey catch per tow at age 1 and year-class size at age 1 for 1967-73 (Table 10, Figure 8), and (3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-73 (Table 10, Figure 9) were used to estimate the sizes of the 1974-77 year classes.

The 1974 year class was estimated to be 2,488 and 2,059 million fish at age 1 based on the autumn (age 0) and spring (age 1) survey catch-per-tow indices, respectively, and 1,460 million at age 2 based on the spring age 2 index (Table 10, Figures 7-9). The catch (C_2) of 353.5 million fish at age 2 in 1976 (Table 3) and a year-class size (N_2) of 1,460 million fish implied, from the catch equation:

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

an F_2 of 0.326. A year-class size of 2,406 million at age 1 then followed from cohort analysis. Based on three estimates of its size at age 1 (2,488, 2,059, and 2,406 million fish), which averaged 2,318 million, the 1974 year-class size was considered to be 2,300 million at age 1.

Estimates obtained in the same manner for the 1975 year class at age 1 (606, 880, and 854 million) averaged 780 million; therefore, this year class at age 1 was chosen to be 800 million.

The 1976 year class was estimated to be 0 and 395 million fish at age 1 based on the autumn (age 0) and spring (age 1) survey catch-per-tow indices, respectively, and 686 million at age 2 based on the spring age 2 index (Table 10, Figures 7-9). The catch (C_1) of 2.0 million fish at age 1 in 1977 (Table 3) and a year-class size (N_2) of 686 million fish at age 2 in 1978 implied, from the following expression:

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

an F_1 of 0.0025. A year-class size of 929 million at age 1 (N_1) was then implied from Equation 1. Based on the estimates of 395 and 929 million at age 1 (the estimate of 0 from the autumn survey was not considered), which averaged 662 million, the 1976 year-class size at age 1 was set at 700 million fish.

The 1977 year class was estimated to be 774 and 661 million fish at age 1 based on the autumn (age 0) and spring (age 1) survey catch-per-tow indices, respectively (Table 10, Figures 7-8). Since the mean of these two estimates was 718 million, this year class was assumed to be 700 million fish at age 1 or equal in size to the 1976 year class.

For the purpose of the catch and stock size projections in this assessment and lacking any information, the 1978 year class was arbitrarily set equal to the 1976-77 year classes (700 million fish at age 1).

Based on the above estimates, the 1974 year class appears to be the strongest observed since the 1969 year class, and the 1975-77 year classes all appear to be poor in comparison to those observed during 1965-74. The results of the 1978 USA spring survey, from which estimates of the sizes of the 1976 and 1977 year classes were determined (Table 10), are supported by data from a bottom trawl survey conducted during January-March 1978 in SA 5-6 by the USSR R/V Argus. The relatively low mean catch-per-tow values from the USA survey for ages 1 and 2 mackerel in comparison to older ages (Table 6) are in close agreement with the corresponding values from the USSR survey. Both surveys indicated a predominance of 1974 year-class fish (USA-31%; USSR-38%) followed by 1973 year-class fish (USA-18%; USSR-22%).

PARTIAL RECRUITMENT

Partial recruitment of an age group to the fishery in a given 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 9), mackerel appear to have generally become fully recruited to the fishery at age 3. Partial recruitment coefficients calculated for ages 1 and 2 during 1962-77 are given in Table 11. These values differ very little, if any, from those calculated by Anderson (1977).

Partial recruitment coefficients for 1978-79 were assumed to be 9% at age 1 and 39% at age 2, with 100% at ages 3 and older (Table 12), the same as assumed in the previous assessment (Anderson 1977) based on average values for selected years.

YIELD PER RECRUIT

A Beverton and Holt (1957) yield-per-recruit curve for mackerel, based on von Bertalanffy (1938) growth parameters of W_∞ = 735 gm,

$K = 0.250$, and $t_o = -1.900$ yr adopted by ICNAF (1973) and additional parameters of $t_r = 0$ yr, $t_c = 2$ yr, $t_\lambda = 12$ yr, and $M = 0.30$, is shown in Figure 10. The curve is virtually asymptotic with $F_{max} = 1.55$ and $F_{0.1} = 0.40$. Yield per recruit at $F_{0.1}$ is about 88% of that at F_{max}.

An equilibrium-yield curve, based on the assumption of a constant level of recruitment at age 1, partial recruitment of 9% at age 1 and 39% at age 2, 100% recruitment at ages 3 and older, and mean weights at age in Table 4 (ICNAF 1974), is shown in Figure 11. This curve, nearly identical to the Beverton and Holt curve in Figure 10, has an F_{max} of 1.08 and an $F_{0.1}$ of 0.40. The equilibrium yield at $F_{0.1}$ is about 90% of that at F_{max}.

STOCK SIZE

Age-specific stock size estimates generated from cohort analysis and annual biomass values determined by applying mean weights at age to these estimates are given in Table 9. Total stock biomass (ages 1 and older) increased from around 600,000 tons during 1962-66 to 2.4 million tons in 1969 (Figure 12) and then dropped steadily to an estimated 517,600 tons at the beginning of 1978. Spawning stock biomass, defined as 50% of the age 2 fish and 100% of ages 3 and older according to recent work by Isakov (1976) and Moores (1976), increased from about 500,000 tons during 1962-67 to 1.8 million tons in 1970-72 and then declined to an estimated 405,900 tons at the beginning of 1978.

CATCH AND STOCK SIZE PROJECTIONS

Projections of spawning stock biomass available at the beginning of 1979 were made (Table 13) assuming various levels of catch in 1978. The minimum level of catch was assumed to be 29,400 tons which was the amount projected based on the most current statistics available (USA commercial = 1,300 tons; USA recreational = 6,200 tons; Canada = 21,400 tons; and others = 500 tons). Three different levels of catch (33,000, 58,000, and 108,000 tons) were assumed based on catches of 7,500 tons by the USA, 500 tons by distant-water fleets (others), and 25,000, 50,000, and 100,000 tons by Canada. Three additional levels (40,500, 65,500, and 115,500 tons) were based on catches of 14,300 tons by the USA (USA capacity as stated in the NMFS preliminary fishery management plan for mackerel), 1,200 tons by others (the total allowable level of foreign fishing in SA 5-6 as specified in the NMFS management plan), and 25,000, 50,000, and 100,000 tons by Canada. The estimated amount of catch which can be taken in 1978 and still maintain the same spawning stock biomass in 1979 as in 1978 (405,900 tons) would be 61,900 tons (USA commercial = 1,300 tons; USA recreational = 6,200 tons; Canada = 53,900 tons; and others = 500 tons). Fishing mortality (F) estimated to generate these catches will range from 0.088 (29,400 tons) to 0.392 (115,500 tons). Resultant spawning stock biomass levels at the beginning of 1979 will vary from an estimates 440,100 tons (8.4% increase from 1978) to 349,700 tons (13.8% decrease from 1978).

Projected options for catch in 1979 and resultant levels of spawning stock biomass available at the beginning of 1980 were made (Table 14) assuming various levels of catch in 1978. If the 1978 catch is at the minimum projected amount of 29,400 tons, then a 1979 catch as high as 88,000 tons could be taken and keep the spawning stock biomass in 1980 at the 1978 level, or as high as 55,000 tons and maintain the spawning biomass in 1980 at the 1979 level. If the catch in 1978 is greater than 29,400 tons, then the projected catch for 1979 which would maintain or increase the spawning stock in 1980 at or above the 1978 or 1979 levels would be less than the above estimates of 88,000 and 55,000 tons as indicated in Table 14.

If the management objective would be to set fishing mortality at the $F_{0.1}$ (0.40) level in 1979, then the catch would range between 127,000 and 101,000 tons, given a range of catch in 1978 between 29,400 and 115,500 tons, and spawning stock biomass in 1980 would decrease 9.9-23.3% from 1978 and 16.9-11.0% from 1979 (Table 14).

Since spawning stock size for mackerel appears to bear little, if any, relationship to recruitment (Anderson 1977), there is presently no biological basis for establishing a level of catch for 1979. However, since estimated stock size has steadily decreased to the lowest level (1978) observed during 1962-78 (Table 9, Figure 12) and recent year classes appear to be weak, there is cause for concern if the spawning stock decreases further.

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Table 1. **Mackerel catches (MT) from SA 3-6 during 1960-1977.**

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[2]	522[1]	22,477[2]	53,745[2]	78,120[2]

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

[2]Provisional.

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

Country	Total
Bulgaria	3,110
Canada	22,477
Cuba	917
FRG	190
GDR	7,981
Italy	366
Japan	16
Poland	17,186
Romania	1,070
Spain	67
USSR	22,842
USA (comm.)	1,376
USA (rec.)	522
Total	78,120

Table 3. Mackerel commercial and recreational catch at age (millions of fish) from ICNAF SA 3-6 during 1962-1977.

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

[1] Thousands of tons.

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

Table 4. 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 5. 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.

Year	Spring[1] Linear	Spring[1] Ln	Spring[1] Retransformed	Autumn[2] Linear	Autumn[2] Ln	Autumn[2] 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	-	-	-

[1] Based on catches with No. 41 trawl; 1968-1972 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 1973-78 USA spring bottom trawl surveys in SA 5-6, strata 1-25, 61-76.

	Number by year class 1977	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
1978	.194	.358	.400	.801	.465	.202	.063	.014	.014	-	.068	.035	-	-	-	2.614

Table 7. 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

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

Year	Spring survey catch/tow: Actual[1]	Spring survey catch/tow: Calculated[2]	Catch[3] (tons)	Relative exploitation index[4]	Mean F[5] age 3+
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	.319
1973	.748	.804	429,286	533,938	.460
1974	.769	.569	347,220	610,228	.529
1975	.255	.403	293,205	727,556	.553
1976	.317	.285	245,935	862,930	(.652)[6,7]
1977	.199	.202	78,120	386,733	(.357)[6]

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

[2] Values predicted from exponential curve calculated using actual values for 1968-1977 (except 1969). See Figure 5.

[3] Includes commercial and recreational catch.

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

[5] Obtained from cohort analysis assuming F = 0.36 in 1977.

[6] Calculated from regression of relative exploitation index on mean F for 1968-1975: Y = 0.118 + 0.000000620X, r = 0.991.

[7] Actual value calculated from cohort analysis was 0.345, assuming F = 0.36 in 1977.

Table 9. Fishing mortality rates (F) and stock size by age (millions of fish) for mackerel in ICNAF SA 3-6 derived from cohort analysis assuming M = 0.30 and F = 0.36 at ages 4 and older in 1977.

Fishing mortality

Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Mean[1]
1962	.030	.006	.030	.126	.051	.050	.043	.073	.090	.031	(.038)[2]	.038
1963	.004	.010	.004	.067	.312	.017	.006	.006	.019	(.043)[2]	(.043)[2]	.043
1964	.044	.032	.012	.014	.066	.372	.321	.033	(.039)[2]	(.039)[2]	-	.039
1965	.024	.017	.018	.016	.025	.095	.938	.713	(.052)[2]	-	-	.052
1966	.028	.042	.034	.023	.026	.054	.163	.288	(.060)[2]	-	-	.060
1967	<.001	.045	.108	.032	.041	.040	.060	.446	.350	-	-	.112
1968	.027	.038	.149	.353	.201	.119	.007	.013	.156	(.151)[2]	-	.151
1969	.003	.064	.136	.251	.082	.059	.049	.043	.039	.336	-	.144
1970	.078	.030	.181	.205	.163	.142	.145	.371	.196	.090	(.185)[2]	.185
1971	.057	.176	.098	.326	.468	.345	.292	.150	.293	.264	(.268)[2]	.268
1972	.016	.094	.250	.218	.441	.414	.476	.241	.674	.506	(.319)[2]	.319
1973	.169	.310	.568	.420	.416	.464	.278	.459	.432	.904	(.460)[2]	.460
1974	.061	.468	.615	.459	.424	.520	.578	.443	.619	.588	(.529)[2]	.529
1975	(.208)[3]	.487	.477	.577	.609	.553	.560	.680	.456	.537	(.553)[2]	.553
1976	(.018)[3]	(.348)[3]	.764	.968	.789	.745	.899	1.120	.885	1.803	(.845)[2]	.845
1977	(.003)[3]	(.055)[3]	(.174)[3]	.360	.360	.360	.360	.360	.360	.360	.360	.360[4]

Stock size (10^6)

Year	Age 1	2	3	4	5	6	7	8	9	10	11+	Age 1+ Total	Age 1+ Wt(10^3 tons)[6]	Spawning stock[5] Total	Spawning stock[5] Wt(10^3 tons)[6]	Mean age
1962	916.6	741.0	877.3	53.7	39.7	55.2	57.8	18.1	8.3	7.8	12.4	2787.9	626.3	1500.8	461.4	3.3
1963	427.9	659.0	545.5	630.9	35.1	27.9	38.9	41.0	12.5	5.6	5.6	2429.9	584.2	1672.5	490.7	3.6
1964	428.4	315.7	483.4	402.6	437.1	19.0	20.3	28.6	30.2	9.1	-	2174.6	581.4	1588.2	517.2	4.0
1965	540.6	303.8	226.5	353.7	294.1	303.2	9.7	10.9	20.5	-	-	2063.0	576.3	1370.5	500.8	4.4
1966	1207.9	391.1	221.4	164.8	257.8	212.4	204.3	2.8	4.0	-	-	2666.5	673.3	1263.1	516.1	4.6
1967	3178.8	869.9	277.8	158.5	119.3	186.1	149.1	128.6	1.6	-	-	5069.6	886.3	1455.8	511.2	4.2
1968	7790.7	2354.1	616.0	184.8	113.7	84.8	132.4	104.0	61.0	0.8	-	11442.3	2150.9	2474.6	919.1	3.4
1969	3084.6	5620.4	1678.3	393.0	96.2	68.9	55.8	97.4	76.0	38.7	-	11209.3	2402.1	5314.5	1506.6	2.9
1970	3208.6	2278.1	3906.5	1085.6	226.6	65.7	48.1	39.4	69.2	54.2	20.5	11002.5	2279.9	6654.8	1801.5	3.3
1971	1615.7	2199.6	1637.7	2415.5	654.9	142.6	42.2	30.8	20.1	42.1	36.7	8837.9	2150.3	6122.4	1824.8	3.7
1972	1688.0	1130.4	1367.2	1099.6	1291.1	303.7	74.8	23.3	19.7	11.1	24.0	7032.9	2082.1	4779.7	1799.8	4.0
1973	1203.5	1231.3	762.5	789.0	655.1	615.4	148.8	34.4	13.6	7.4	5.0	5466.0	1504.5	3646.8	1285.5	4.2
1974	1869.8	752.7	669.1	320.2	384.0	320.2	286.6	83.4	16.1	6.5	2.2	4710.8	1158.0	2464.6	914.3	4.4
1975	(2300.0)[7]	1302.6	349.1	268.1	149.8	186.1	141.0	119.1	39.7	6.4	2.7	4864.6	930.4	1913.3	613.8	4.0
1976	(800.0)[7]	1384.2	592.7	160.5	111.6	60.4	79.3	59.7	44.7	18.6	2.8	3314.5	667.3	1822.4	488.7	3.5
1977	(700.0)[7]	581.9	724.9	204.5	45.2	37.6	21.2	23.9	14.4	13.7	2.3	2369.6	553.8	1378.6	428.4	3.4
1978	(700.0)[7]	516.9	408.1	451.0	105.7	23.4	19.4	11.0	12.4	7.4	8.3	2263.6	517.6	1305.2	405.9	3.6

[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 3.

[7] Estimated.

Table 10. Stratified mean catch per tow (number) 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=0.36 at ages 4 and older in 1977.

Year-class	Autumn survey Age 0	Spring survey Age 1	Spring survey Age 2	Cohort analysis Age 1	Cohort analysis Age 2
1963	0.087	-	-	428.6	303.8
1964	0.022	-	-	540.6	391.1
1965	0.134	-	-	1207.9	869.9
1966	0.170	-	21.661[1]	3178.8	2354.1
1967	15.709	197.993[1]	1.190	7790.7	5620.4
1968	0.215	0.299	12.435	3084.6	2278.1
1969	38.504[1]	6.208	13.390	3208.6	2199.6
1970	0.027	2.954	5.545	1615.7	1130.4
1971	0.517	12.093	6.683	1688.0	1231.3
1972	0.119	1.949	0.749	1203.5	752.7
1973	0.339	2.067	1.101	1869.8	1302.6
1974	0.648	5.330	4.928	(2487.8)[2] (2058.9)[3]	(1460.3)[4]
1975	0.012	0.447	0.254	(605.9)[2] (880.5)[3]	(621.6)[4]
1976	0.000	0.043	0.358	(0)[2] (394.7)[3]	(686.2)[4]
1977	0.024	0.194	-	(774.4)[2] (661.1)[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 1963-1973 year-classes: $\ln Y = \ln 2900.920 + 0.354 \ln X$, $r = 0.764$.

[3]Calculated from power curve relationship between survey catch per tow at age 1 and year-class size at age 1 for 1967-1973 year-classes: $\ln Y = \ln 1160.313 + 0.343 \ln X$, $r = 0.888$.

[4]Calculated from power curve relationship between survey catch per tow at age 2 and year-class size at age 2 for 1966-1973 year-classes: $\ln Y = \ln 922.435 + 0.288 \ln X$, $r = 0.850$.

Table 11. Percentage of fishing mortality (F) at ages 1 and 2 compared to mean F at ages 3 and older (partial recruitment)

Year	Age 1	Age 2
1962	78.9	15.8
1963	9.5	23.8
1964	100.0	82.1
1965	46.2	32.7
1966	46.7	70.0
1967	0.9	40.5
1968	17.4	24.5
1969	2.1	44.4
1970	42.2	16.2
1971	21.3	65.7
1972	5.0	29.5
1973	36.7	67.4
1974	11.5	88.5
1975	37.6	88.1
1976	2.1	41.2
1977	0.8	15.3

Table 12. Summary of parameters used in projection of catch and stock size options for mackerel in SA 3-6.

Parameter		Value
Fishing mortality (F) in 1977 (ages 4 and older)		0.36
Recruitment at age 1:	1974 year class	2300×10^6 fish
	1975 year class	800×10^6 fish
	1976 year class	700×10^6 fish
	1977 year class	700×10^6 fish
	1978 year class	700×10^6 fish
Partial recruitment in 1978-79:	Age 1	9%
	Age 2	39%
	Ages 3 and older	100%
Total stock biomass at beginning of 1978		517,600 tons
Spawning stock biomass at beginning of 1978		405,900 tons

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Table 13. Various levels of catch of mackerel in SA 3-6 in 1978 and associated fishing mortality (F) with resulting spawning stock biomass in 1979 and its percentage change from 1978. Catch and stock are expressed as thousands of tons.

Stock in 1978	Catch[1] in 1978	F[2] in 1978	Stock in 1979	% change in stock from 1978
405.9	29.4	0.088	440.1	+ 8.4
405.9	33.0	0.099	436.3	+ 7.5
405.9	40.5	0.123	428.4	+ 5.5
405.9	58.0	0.181	409.9	+ 1.0
405.9	61.9	0.194	405.9	0.0
405.9	65.5	0.206	402.1	- 0.9
405.9	108.0	0.363	357.6	-11.9
405.9	115.5	0.392	349.7	-13.8

[1]See text or Table 14 for explanation of catch levels.

[2]Fishing mortality at ages 3 and older.

Table 14. Projected mackerel catch in SA 3-6 in 1979 with fishing mortality ranging from 0.05 to 0.50 assuming eight options of catch in 1978, and the resulting spawning stock biomass in 1980 and its percentage change from 1978 and 1979. Catch and stock are expressed as thousands of tons.

Fishing mortality (F)	Catch in 1979	Stock in 1980	% change in stock from 1978	% change in stock from 1979	Catch in 1979	Stock in 1980	% change in stock from 1978	% change in stock from 1979	Catch in 1979	Stock in 1980	% change in stock from 1978	% change in stock from 1977
	1978 catch = 29.4[1]				1978 catch = 33.0[2]				1978 catch = 40.5[3]			
0.05	18.4	478.5	+17.9	+8.7	18.3	475.3	+17.1	+8.9	17.9	468.8	+15.4	+9.4
0.10	36.1	460.1	+13.4	+4.5	35.7	457.0	+12.6	+4.7	35.1	450.6	+11.0	+5.2
0.15	52.9	442.5	+ 9.0	+0.5	52.5	439.6	+ 8.3	+0.8	51.5	433.5	+ 6.8	+1.2
0.20	69.1	425.7	+ 4.9	-3.3	68.5	422.9	+ 4.2	-3.1	67.2	417.2	+ 2.8	-2.6
0.25	84.5	409.7	+ 0.9	-6.9	83.8	407.0	+ 0.3	-6.7	82.2	401.5	- 1.1	-6.3
0.30	99.3	394.4	- 2.8	-10.4	98.4	391.9	- 3.4	-10.2	96.6	386.6	- 4.8	-9.8
0.35	113.4	379.8	- 6.4	-13.7	112.4	377.4	- 7.0	-13.5	110.4	372.4	- 8.3	-13.1
0.40[9]	127.0	365.8	- 9.9	-16.9	125.9	363.5	-10.4	-16.7	123.6	358.8	-11.6	-16.2
0.45	139.9	352.4	-13.2	-19.9	138.7	350.3	-13.7	-19.7	136.2	345.7	-14.8	-19.3
0.50	152.3	339.7	-16.3	-22.8	151.0	337.6	-16.8	-22.6	148.3	333.3	-17.9	-22.2
	1978 catch = 58.0[4]				1978 catch = 61.9[5]				1978 catch = 65.5[6]			
0.05	17.2	452.9	+11.6	+10.5	17.0	449.5	+10.7	+10.7	16.8	446.2	+ 9.9	+11.0
0.10	33.6	435.7	+ 7.3	+ 6.3	33.2	432.4	+ 6.5	+ 6.5	32.9	429.4	+ 5.8	+ 6.8
0.15	49.3	419.3	+ 3.3	+ 2.3	48.8	416.2	+ 2.5	+ 2.5	48.3	413.3	+ 1.8	+ 2.8
0.20	64.3	403.7	- 0.5	- 1.5	63.7	400.7	- 1.3	- 1.3	63.1	397.9	- 2.0	- 1.0
0.25	78.7	388.7	- 4.2	- 5.2	77.9	385.8	- 5.0	- 5.0	77.2	383.2	- 5.6	- 4.7
0.30	92.5	374.4	- 7.8	- 8.7	91.6	371.7	- 8.4	- 8.4	90.7	369.1	- 9.1	- 8.2
0.35	105.7	360.7	-11.1	-12.0	104.6	358.1	-11.8	-11.8	103.6	355.7	-12.4	-11.5
0.40[9]	118.3	347.7	-14.3	-15.2	117.1	345.2	-15.0	-15.0	116.0	342.9	-15.5	-14.7
0.45	130.4	335.2	-17.4	-18.2	129.1	332.8	-18.0	-18.0	127.9	330.6	-18.6	-17.8
0.50	142.0	323.2	-20.4	-21.2	140.6	321.0	-20.9	-20.9	139.3	318.9	-21.4	-20.7
	1978 catch = 108.0[7]				1978 catch = 115.5[8]							
0.05	15.0	408.4	+ 0.6	+14.2	14.6	401.7	- 1.0	+14.9				
0.10	29.3	393.3	- 3.1	+10.0	28.6	386.9	- 4.7	+10.6				
0.15	43.0	378.9	- 6.7	+ 6.0	42.0	372.9	- 8.1	+ 6.6				
0.20	56.1	365.2	-10.0	+ 2.1	54.9	359.4	-11.5	+ 2.8				
0.25	68.7	352.0	-13.3	- 1.6	67.2	346.5	-14.6	- 0.9				
0.30	80.7	339.5	-16.4	- 5.1	78.9	334.2	-17.7	- 4.4				
0.35	92.2	327.5	-19.3	- 8.4	90.2	322.5	-20.5	- 7.8				
0.40[9]	103.3	316.0	-22.1	-11.6	101.0	311.2	-23.3	-11.0				
0.45	113.8	305.0	-24.9	-14.7	111.4	300.5	-26.0	-14.1				
0.50	124.0	294.5	-27.4	-17.6	121.3	290.2	-28.5	-17.0				

[1]USA commercial = 1.3; USA recreational = 6.2; Canada = 21.4; others = 0.5.

[2]USA commercial = 1.3; USA recreational = 6.2; Canada = 25.0; others = 0.5.

[3]USA commercial and recreational = 14.3; Canada = 25.0; others = 1.2.

[4]USA commercial = 1.3; USA recreational = 6.2; Canada = 50.0; others = 0.5.

[5]USA commercial = 1.3; USA recreational = 6.2; Canada = 53.9; others = 0.5.

[6]USA commercial and recreational = 14.3; Canada = 50.0; others = 1.2.

[7]USA commercial = 1.3; USA recreational = 6.2; Canada 100.0; others = 0.5.

[8]USA commercial and recreational = 14.3; Canada = 100.0; others = 1.2.

[9]$F_{0.1}$.

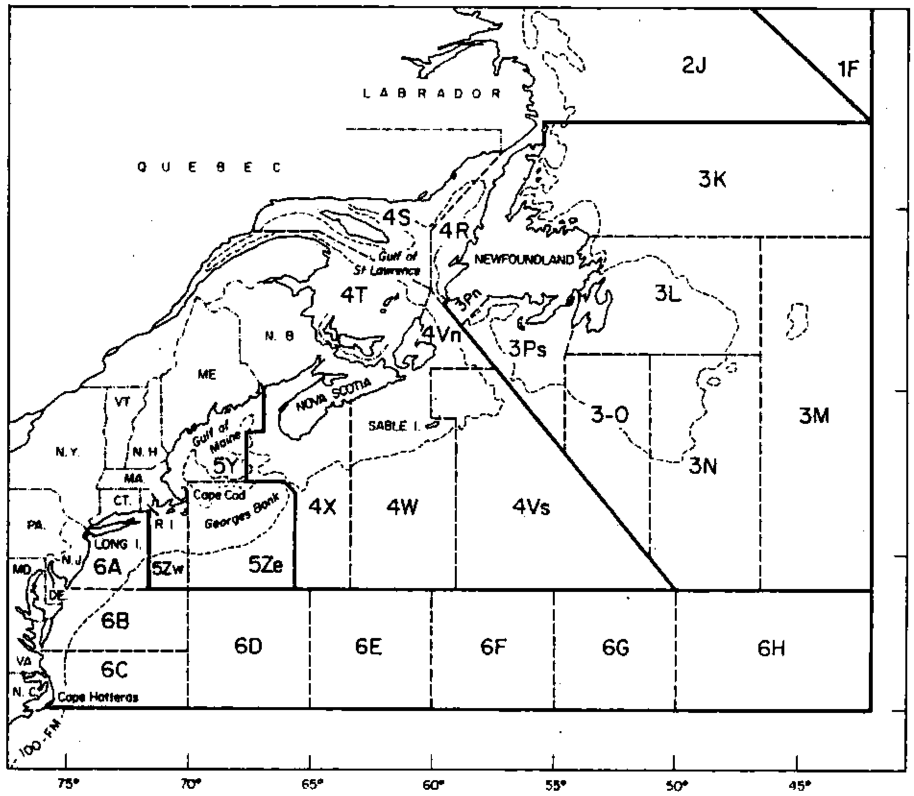

Figure 1. Northwest Atlantic from North Carolina to Labrador showing ICNAF SA 3-6.

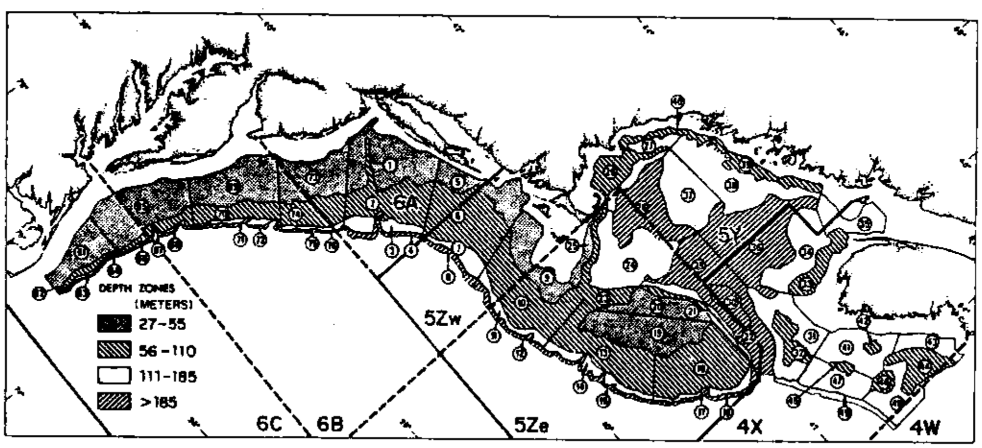

Figure 2. USA bottom trawl survey sampling strata in the Northwest Atlantic between Cape Hatteras and Nova Scotia.

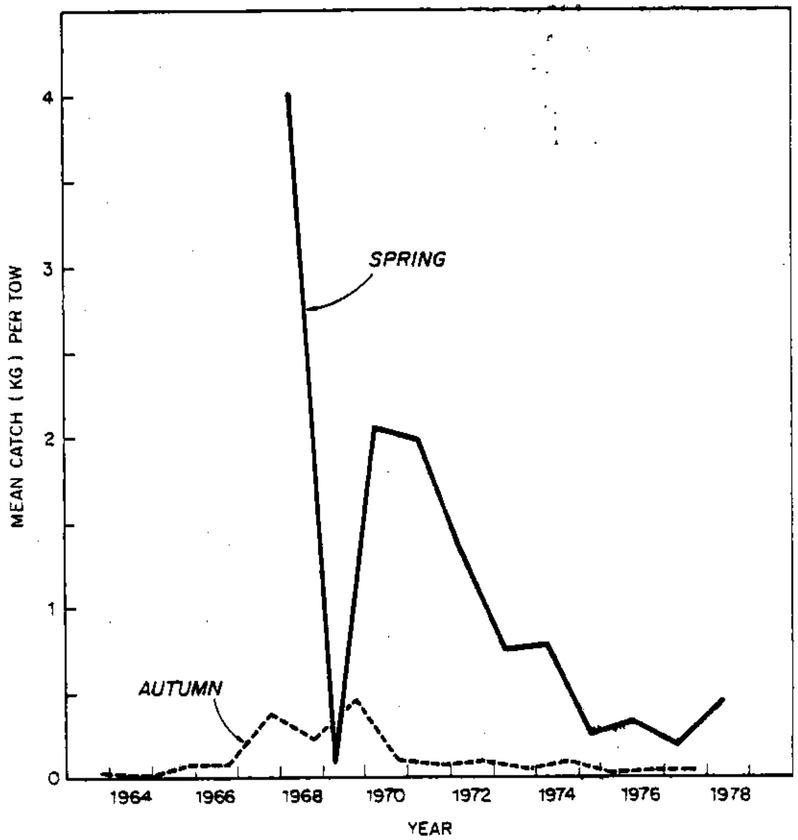

Figure 3. Stratified mean catch per tow (kg-retransformed) of mackerel from USA spring (1968-1977) and autumn (1963-1977) bottom trawl surveys in ICNAF SA 5-6.

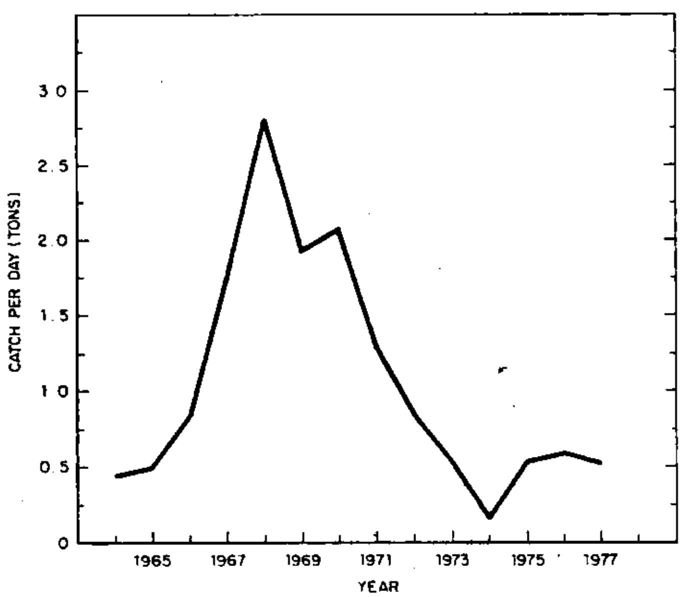

Figure 4. Catch per standardized day fished for the USA commercial mackerel fishery in ICNAF SA 5-6.

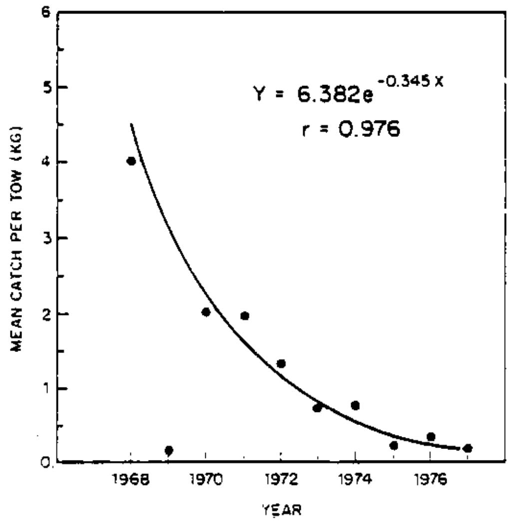

Figure 5. Exponential curve fitted to the 1968-1977 (1969 value omitted from calculation) catch-per-tow values for mackerel (retransformed) from the USA spring bottom trawl survey.

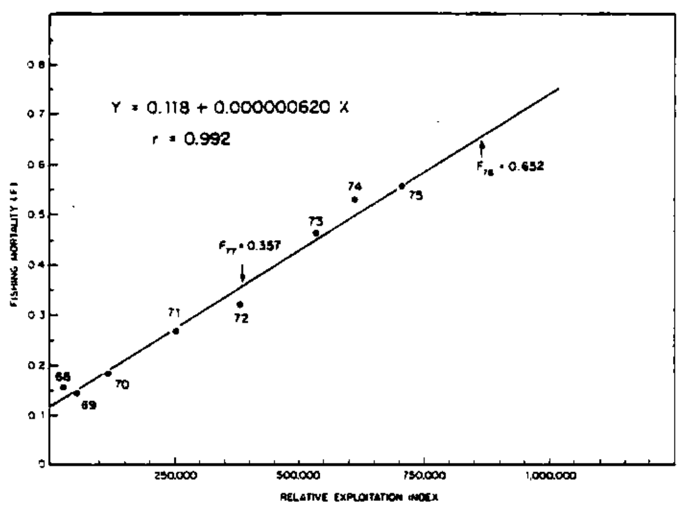

Figure 6. Relationship between fishing mortality from cohort analysis assuming F = 0.36 at ages 4 and older in 1977 and a relative exploitation index derived from USA spring survey catch per tow and total catch of mackerel.

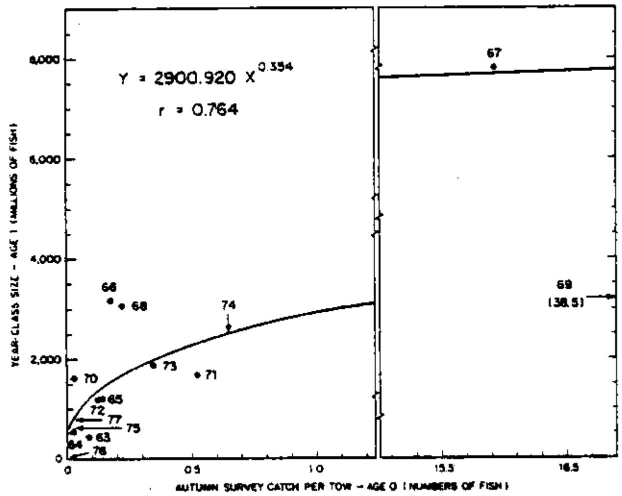

Figure 7. Power curve relationship between mackerel year-class size at age 1 from cohort analysis assuming F = 0.36 at ages 4 and older in 1977 and autumn survey catch per tow at age 0 (1969 value omitted from calculation).

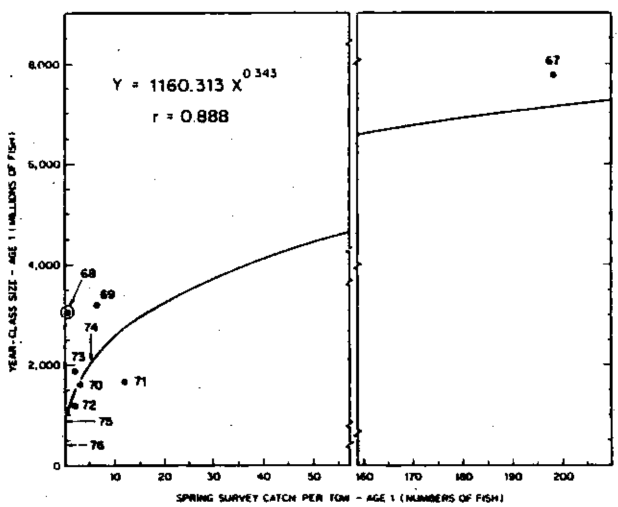

Figure 8. Power curve relationship between mackerel year-class size at age 1 from cohort analysis assuming F = 0.36 at ages 4 and older in 1977 and spring survey catch per tow at age 1 (1968 value omitted from calculation).

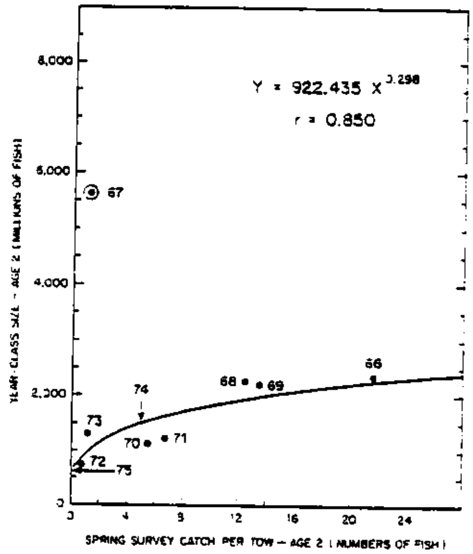

Figure 9. Power curve relationship between mackerel year-class size at age 2 from cohort analysis assuming F = 0.36 at ages 4 and older in 1977 and spring survey catch per tow at age 2 (1967 value omitted from calculation).

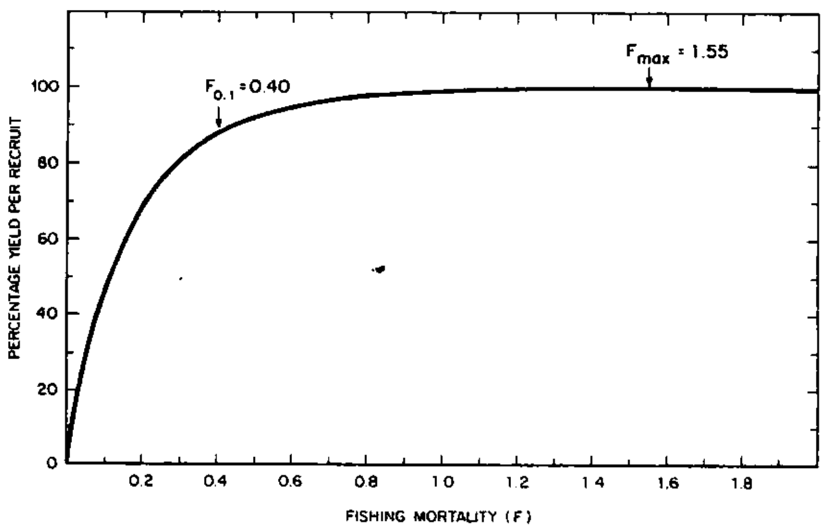

Figure 10. Beverton and Holt (1957) yield-per-recruit curve for mackerel (see text for parameters), with yield per recruit expressed as a percentage of the maximum.

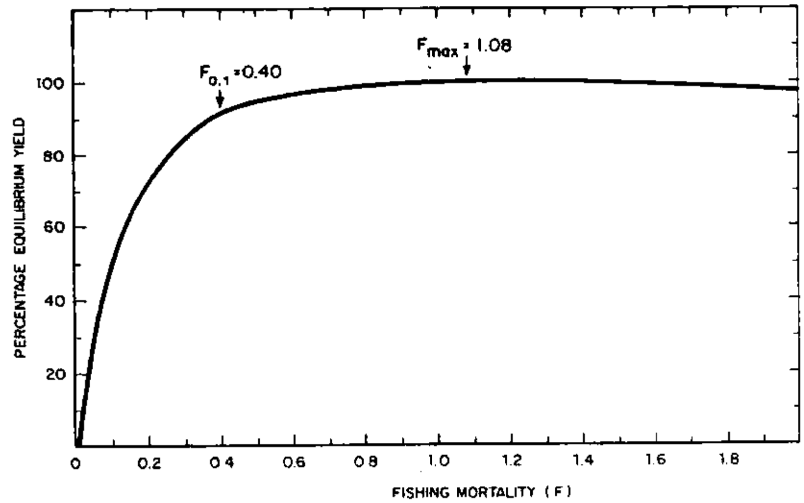

Figure 11. Curve of equilibrium yield for mackerel (see text for parameters), with yield expressed as a percentage of the maximum.

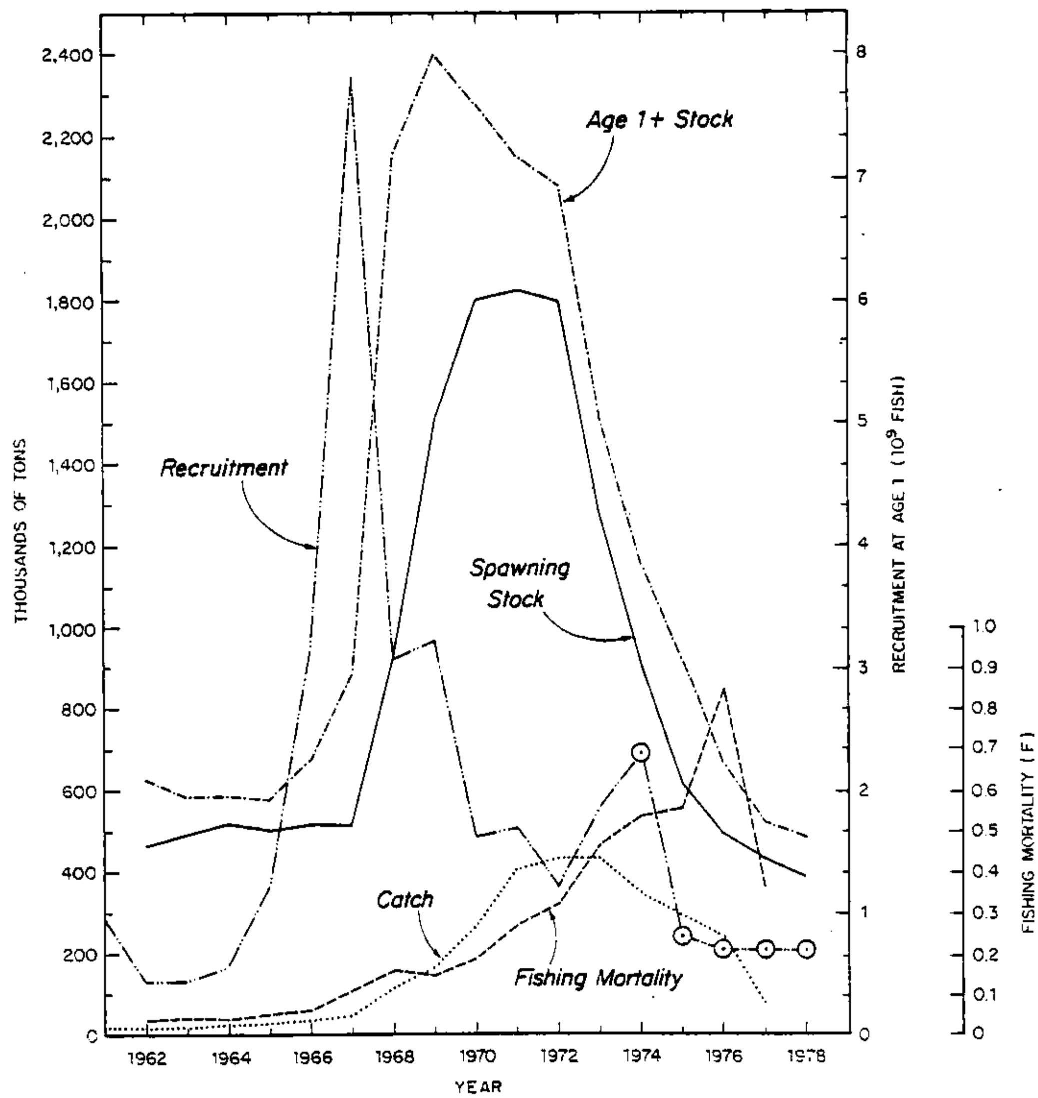

Figure 12. Mackerel stock biomass (ages 1 and older and spawners) during 1962-1978 from cohort analysis assuming F = 0.36 at ages 4 and older in 1977, abundance at age 1 of the 1961-1977 year classes (open circles represent estimated year-class sizes; others determined from cohort analysis), total international catch (commercial and recreational) during 1961-1977, and fishing mortality (mean for ages 3 and older) during 1962-1977 in ICNAF SA 5-6.

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