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Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

Emory D. Anderson

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U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

The status of the Atlantic mackerel, *Scomber scombrus*, stock in the International Commission for the Northwest Atlantic Fisheries (ICNAF) convention area is analyzed in this paper. Total catch declined from a high of 431,606 t in 1972 to an estimated 92,000 t in 1977. The U.S. spring bottom trawl survey has shown a continuous decrease in Atlantic mackerel abundance since 1968. Fishing mortality (F) in 1977 was estimated at 0.39, nearly one-half of the 1976 level and the lowest since 1972. The 1974 year class appears to be the strongest since 1969, whereas the 1975 and 1976 year classes appear to be very weak. Spawning stock biomass decreased from 1.8 million t in 1970-72 to an estimated 402,500 t at the beginning of 1978, which is slightly below the 1962-67 level when catches averaged only about 25,000 t. A zero catch in 1978 would increase the 1979 spawning stock by 6%; a catch of 23,500 t (F = 0.07) would maintain the spawning stock at the 1978 level.

INTRODUCTION

The following report analyzes the status of the Northwest Atlantic mackerel, *Scomber scombrus*, stock inhabiting the waters from Cape Hatteras, N.C., to Newfoundland, which is the area included in ICNAF (International Commission for the Northwest Atlantic Fisheries) Subareas 3, 4, and 5 and Statistical Area 6 (SA 3-6) (Fig. 1). This assessment provided the basis for establishing the allowable level of catch in 1978 in the southern part of this area (SA 5-6) and was used by the National Marine Fisheries Service for its environmental impact statement/preliminary fishery management plan for the Atlantic mackerel fishery and by the Mid-Atlantic Fishery Management Council for its environmental impact statement/fishery management plan for this fishery.

In previous years, this stock was managed through ICNAF, and assessments were completed jointly by scientists from various member nations within the ICNAF Assessments Subcommittee. The last such assessment, on which the 1977 total allowable catch (TAC) was based, was made at the time of the Ninth Special Meeting of ICNAF held at Puerto de la Cruz, Tenerife, Canary Islands, Spain, in November-December 1976 (ICNAF 1977). Separate assessments submitted by Anderson et al.,[2] Isakov et al.,[3] and Ivanov[4] provided the basis for the 1976 assessment. In addition to this paper, catch projections for 1978 were provided by Isakov[5] and several unpublished Canadian reports (Hunt[6]; Lett and Hunt[7]; and Lett and Marshall[8]).

Data utilized here include international commercial and U.S. recreational catch statistics for 1961-77 and U.S. research vessel bottom trawl survey results for 1963-77. Results include estimates of fishing mortality, stock size, recruitment, and projected catch options for 1978, with the resulting spawning stock biomass levels for 1979.

METHODS

International commercial Atlantic mackerel catches for 1961-76 were obtained from *ICNAF Statistical Bulletins* published in 1963-77 (volumes 11-26), provisional catches for January-March 1977 were obtained from *ICNAF Circular Letters*, and catches for the remainder of 1977 were estimated.

Various marine angler surveys provided estimates of the 1960, 1965, 1970, 1974, and 1976 U.S. recreational catches of Atlantic mackerel (Clark 1962; Deuel and Clark 1968; Deuel 1973; Deuel[9]; Christensen et al.[10]).

[1]Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

[2]Anderson, E. D., P. W. Wood, B. B. Ackerman, and F. P. Almeida. 1976. Assessment of the mackerel stock in ICNAF Subareas 3-6. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/137, Ser. No. 4033 (mimeogr.), 21 p.

[3]Isakov, V. I., L. Ivanov, P. Kolarov, W. Mahnke, A. Paciorkowski, V. A. Rikhter, S. Ucinski, and B. Vaske. 1976. Reassessment of the mackerel stock in the ICNAF area. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/169, Ser. No. 4065 (mimeogr.), 10 p.

[4]Ivanov, L.S. 1976. Relative assessment of mackerel stock in the ICNAF area and forecast of the possible catch in 1977. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/135, Ser. No. 4030 (mimeogr.), 7 p.

[5]Isakov, V. I. 1977. Estimation of stock and total allowable catch of mackerel in the Northwest Atlantic for 1977-78. Int. Comm. Northwest Atl. Fish. Res. Doc. 77/VI/41, Ser. No. 5066 (mimeogr.), 6 p.

[6]Hunt, J. J. 1977. Data tables mackerel — Subareas 3-6. Can. Atl. Fish. Sci. Adv. Comm., Working Pap. 77/6, 3 p. CAFSAC, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2.

[7]Lett, P. F., and J. J. Hunt. 1977. A preliminary study of some biological factors related to the assessment of mackerel. Can. Atl. Fish. Sci. Adv. Comm., Working Pap. 77/19, 16 p.

[8]Lett, P. F., and W. H. Marshall. An interpretation of biological factors important in the management of the northwestern Atlantic mackerel stock. Department of Fisheries and Environment, Fisheries and Marine Service, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2. Unpubl. manuscr., 37 p.

[9]D. G. Deuel, Northeast Fisheries Center, Narragansett Laboratory, Natl. Mar. Fish. Serv., NOAA, Narragansett, R.I., pers. commun. September 1976.

[10]Christensen, D. J., B. L. Freeman, and S. E. Turner. 1976. The

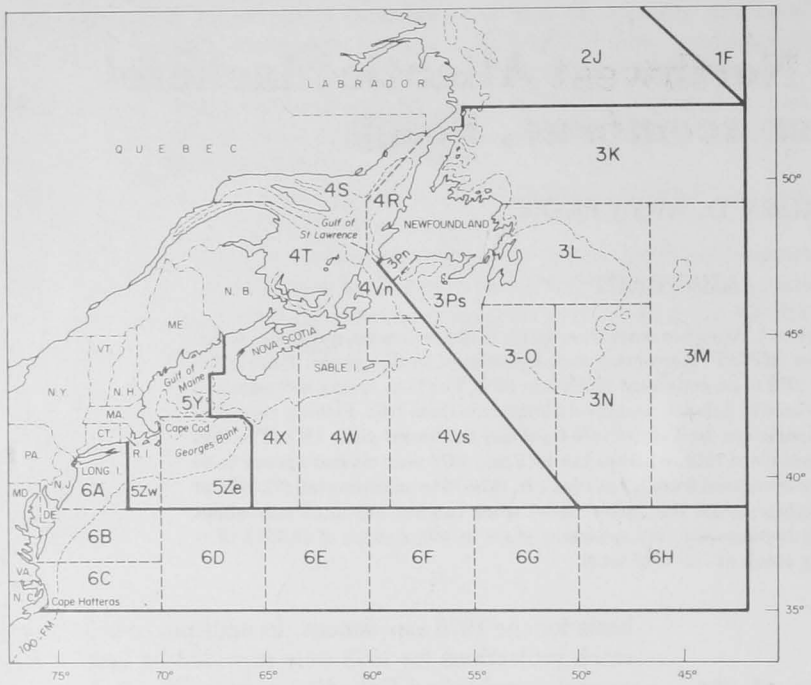

Figure 1.—Northwest Atlantic from North Carolina to Labrador showing ICNAF Subareas 3, 4, and 5 and Statistical Area 6.

Catches in the intervening years were estimated by assuming that the ratio between catch and stock biomass from cohort analysis using only commercial data (ICNAF 1977) in each of the above years was the same in the preceding and succeeding 2 yrs, with the exception that the mean of the 1970 and 1974 ratios was used for 1972, and the mean of 1974 and 1976 was used for 1975.

The 1962-75 numbers at age from the commercial catch were taken from Anderson et al. (see footnote 2). The 1976 numbers at age were revised from those used in the last ICNAF 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, since significant differences were evident among age-length keys submitted by various countries for 1976 (Anderson et al.[11]), it was decided to combine country age-length keys by quarter. The procedure used was to: 1) determine numbers at length by country by month from available length frequencies and corresponding catches, 2) combine the numbers at length by quarter 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 U.S. recreational catches.

Mean weights at age (Table 1) adopted by ICNAF (1974) and used in previous assessments were employed in the present analysis. These values were applied to the numbers-at-age catch data for 1962-77 to obtain calculated catches which were compared with the observed catches. These values were also applied to the stock size numbers at age calculated from cohort analysis to obtain stock biomass values. The summed biomass values for each year were adjusted using the appropriate observed/calculated catch ratios. The mean weights at age were used unadjusted in the projections of catch and stock biomass for 1978-79.

Table 1.—Mean weights at age (kilograms) for Atlantic mackerel (ICNAF 1974).

Age	Mean weight	Age	Mean weight
1	0.095	6	0.506
2	0.175	7	0.564
3	0.266	8	0.615
4	0.350	9	0.659
5	0.432	10+	0.693

Stratified mean catch-per-tow (kilograms) indices for Atlantic mackerel were calculated from U.S. research vessel spring (1968-77) and autumn (1963-76) bottom trawl surveys conducted in SA 5-6 in which sampling is based on a stratified random design (Cochran 1953) and strata (Fig. 2) constitute different depth zones and areas (Grosslein 1969). Survey methods, procedures, and gear

United States recreational fishery for Atlantic mackerel. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/142, Ser. No. 4038 (mimeogr.), 7 p.

[11]Anderson, E. D., C. F. Cole, and P. W. Wood. 1976. Variability in mackerel age data reported to ICNAF. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/146, Ser. No. 4042 (mimeogr.), 13 p.

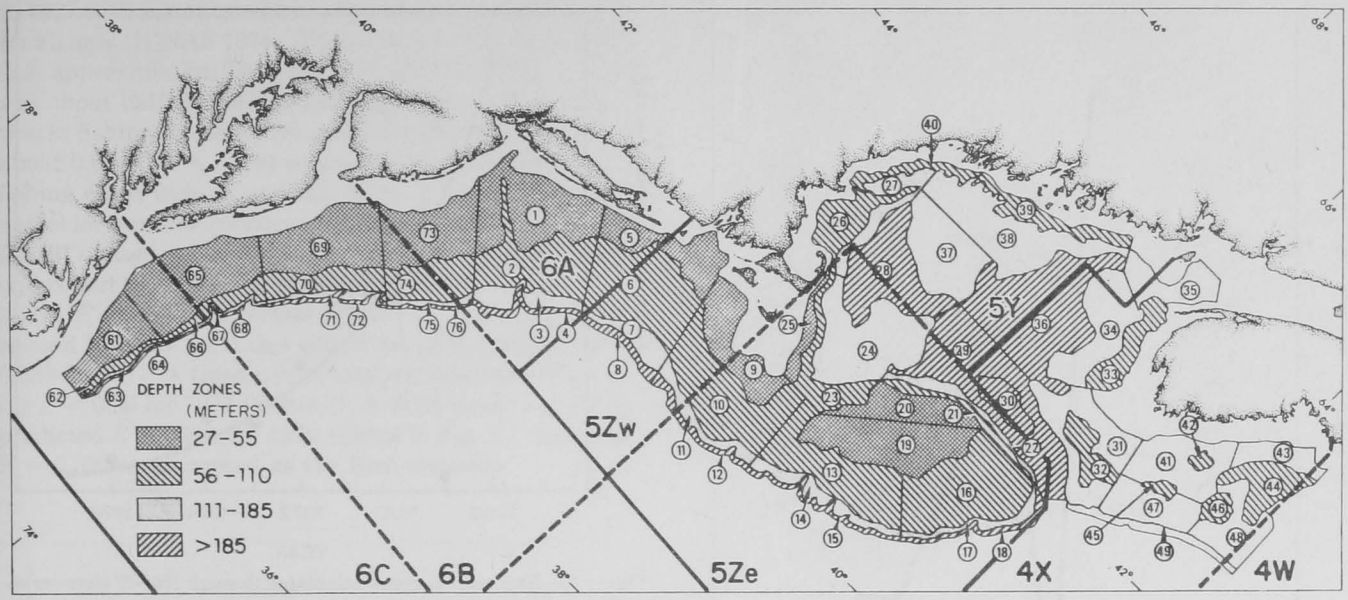

Figure 2.—Northwest Atlantic off the U.S. coast showing bottom trawl survey sampling strata and ICNAF Subarea 5 and Statistical Area 6.

were described by Grosslein.[12] Spring indices were calculated from catches in strata 1-25 and 61-76, and autumn indices from catches in strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, and 25-26 (Fig. 2). All autumn catches and the 1968-72 spring catches were made with a No. 36 Yankee trawl, and the 1973-77 spring catches were made with a larger No. 41 trawl. The 1968-72 spring catches were adjusted upwards to equivalent No. 41 trawl catches using a 3.25:1 ratio between the No. 41 and No. 36 trawls (Anderson 1976) to establish a standardized time-series of catches. A ln $(x + 1)$ transformation of the station catches (kilograms) was made before calculation of the mean catch-per-tow indices. The ln indices were then retransformed to the original scale for compatibility with other data used in the assessment. Retransformation was accomplished by the method described by Finney (1941) using the equation:

$$\bar{y} = \exp(\bar{x} + \frac{S^2}{2}) - 1 \qquad (1)$$

where $\bar{y}$ = retransformed catch per tow, $\bar{x}$ = ln catch per tow, and S^2 = population variance (ln scale).

Stratified mean catch per tow (numbers) by age for the 1973-77 spring surveys was determined by applying age-length keys to the length frequency of the stratified mean catch per tow (Anderson et al. see footnote 2). Since age samples were not taken prior to the 1973 spring survey, only the mean catch per tow for ages 0, 1, and 2 was determined prior to 1973. From the 1968-72 spring surveys, age 1 fish were defined as those measuring 22 cm and less (fork length) and age 2 fish were defined as those measuring 23-29 cm. Age 0 fish from the autumn surveys were defined as those measuring 23 cm or less.

[12]Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Mass., USA. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/96, Ser. No. 3332 (mimeogr.), 27 p.

Standardized U.S. commerical catch per day (metric tons) was calculated for 1964-76 as described by Anderson (1976).

Instantaneous fishing mortality (F) in 1977 was estimated using a technique developed by Anderson et al. (see footnote 2) which assumes a linear relationship between fishing effort and fishing mortality. The lack of an adequate measure of fishing effort or catch per effort was circumvented by calculating, as an index of fishing effort, the quotient of total catch divided by the spring survey catch per tow (Table 2). Because of the aberrant 1969 spring value (Anderson 1976; Anderson and Almeida 1977) and the year-to-year fluctuations in the remaining values, the 1968-77 time-series (Fig. 3) was smoothed by

Table 2.—Estimation of fishing mortality (F) in 1977 for the ICNAF Subareas 3, 4, and 5 and Statistical Area 6 Atlantic mackerel fishery.

Year	Spring survey catch/tow: Actual[1]	Spring survey catch/tow: Calculated[2]	Catch[3] (t)	Fishing effort index[4]	Mean F[5] age 3+
1968	3.998	4.518	109,940	24,334	0.155
1969	0.065	3.199	165,113	51,614	0.144
1970	2.039	2.265	262,681	115,974	0.185
1971	1.969	1.604	403,675	251,668	0.268
1972	1.332	1.135	431,606	380,270	0.316
1973	0.748	0.804	429,250	533,893	0.451
1974	0.769	0.569	347,220	610,228	0.515
1975	0.255	0.403	293,740	728,883	0.532
1976	0.317	0.285	243,033	852,747	[6,7](0.626)
1977	0.199	0.202	92,000	455,446	[6](0.391)

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

[2]Values predicted from exponential curve calculated using actual values for 1968-77 (except 1969). See Figure 4.

[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.

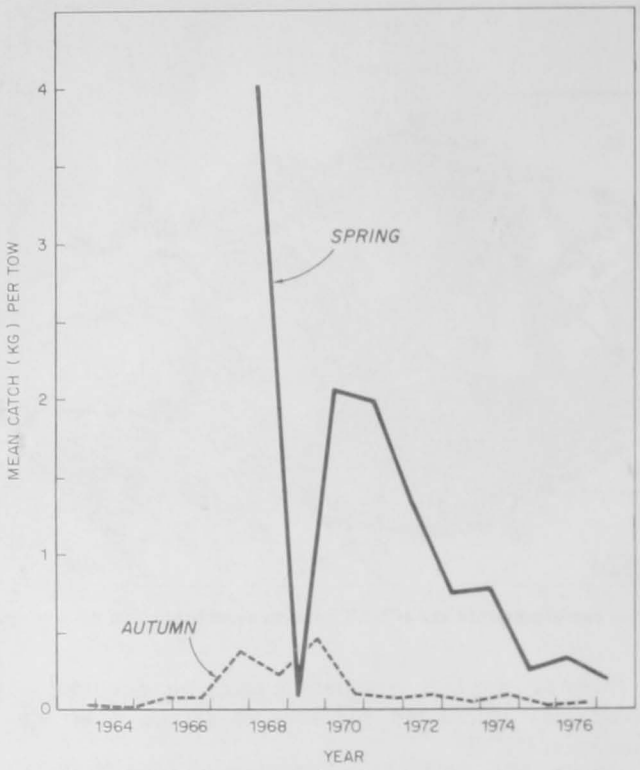

Figure 3.—Stratified mean catch (kilograms) per tow of Atlantic mackerel from the U.S. spring (1968-77) and autumn (1963-76) bottom trawl surveys.

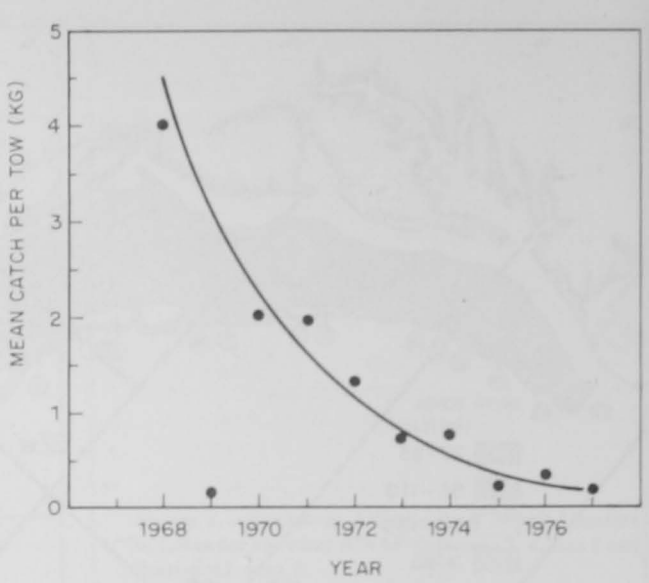

Figure 4.—Exponential curve calculated through 1968-77 time-series (1969 point omitted from calculation of curve) of spring survey catch-per-tow (kilograms) indices for Atlantic mackerel. Equation for the curve is: $Y = 6.382 \exp(-0.345 X)$, $r = 0.976$.

fitting an exponential curve by least squares to the data points (Fig. 4), and the predicted values calculated from the curve were used in place of the original values to determine the fishing effort index. Cohort analysis (Pope 1972) was performed using $F = 0.30$ for ages 4 and older

Table 3.—Fishing mortality rates (F) for Atlantic mackerel in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 derived from cohort analysis with natural mortality (M) = 0.30.

Year class	Year 1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	[1](.038)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	.030	[1](.042)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	.088	[1](.042)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	.073	.019	[1](.039)	—	—	—	—	—	—	—	—	—	—	—	—	—
1955	.043	.006	[1](.039)	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	.050	.006	.033	[1](.052)	—	—	—	—	—	—	—	—	—	—	—	—
1957	.051	.017	.321	.713	[1](.060)	—	—	—	—	—	—	—	—	—	—	—
1958	.127	.313	.374	.946	.288	.357	[1](.155)	—	—	—	—	—	—	—	—	—
1959	.030	.067	.066	.095	.163	.446	.156	.336	[1](.185)	—	—	—	—	—	—	—
1960	.006	.004	.014	.025	.054	.060	.013	.039	.090	[1](.268)	—	—	—	—	—	—
1961	.030	.010	.012	.016	.026	.040	.007	.042	.195	.262	[1](.316)	—	—	—	—	—
1962	—	.004	.032	.018	.023	.041	.119	.049	.369	.291	.500	[1](.451)	—	—	—	—
1963	—	—	.044	.017	.034	.032	.200	.059	.145	.150	.670	.892	[1](.515)	—	—	—
1964	—	—	—	.024	.042	.107	.351	.081	.142	.290	.239	.426	.575	[1](.532)	—	—
1965	—	—	—	—	.028	.045	.149	.249	.162	.342	.470	.449	.596	.503	[1](.745)	—
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	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].202	[2].330	[2].220
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].018	[2].067
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].006
$\bar{F}$ (age 3+)[3]	.038	.042	.039	.052	.060	.111	.155	.144	.185	.268	.316	.451	.515	.532	.745	[4].390

[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 12.
[4]Age 4+.

in 1977 with instantaneous natural mortality (M) = 0.30 for all ages (ICNAF 1974). This level of F was chosen as a first approximation since the fishing effort index in 1977 was about half 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 F values 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 performed 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 cohort analysis was performed using F = 0.39 for 1977 (Table 3). A third linear regression predicted F = 0.391 for 1977 (Table 2, Fig. 5); therefore, F = 0.39 was accepted as the best estimate.

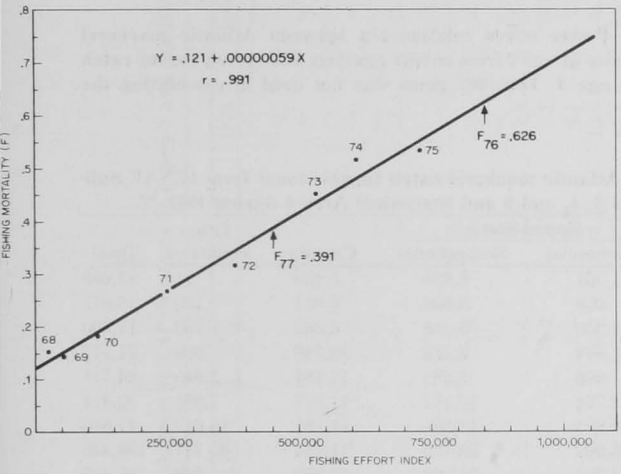

Figure 5.—Relationship between fishing mortality for Atlantic mackerel from cohort analysis and fishing effort derived from spring survey catch per tow and total catch.

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 determined from cohort analysis for 1963-73 (Table 4, Fig. 6), 2) spring survey catch per tow at age 1 and year-class size at age 1 for 1967-73 (Table 5, Fig. 7), and 3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-73 (Table 5, Fig. 8) were used to estimate the sizes of the 1974-76 year classes.

For age groups incompletely recruited to the fishery, the ratio of fishing mortality at each such age to fishing mortality of fully recruited ages (the latter considered here to be the mean F for ages 3 and older) was used as a measure of partial recruitment to the fishery. Partial recruitment coefficients were calculated for ages 1 and 2 for calendar years 1962-77.

Age-specific F and stock size (N) values were determined for 1962-77 using cohort analysis. The value for N at each age in 1978 was calculated using the relationship:

$$N_{i+1} = N_i \, e^{-z_i} \qquad (2)$$

Table 4.—Catch per tow (number) of age 0 Atlantic mackerel from the U.S. 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	0.087	429.5
1964	0.022	542.2
1965	0.134	1,212.9
1966	0.170	3,165.3
1967	15.709	7,786.5
1968	0.215	3,114.3
[1]1969	38.504	3,244.9
1970	0.027	1,657.5
1971	0.517	1,711.9
1972	0.119	1,212.6
1973	0.339	1,981.2
1974	0.648	[2](2,515.6)
1975	0.012	[2](614.3)
1976	0.000	[2](0)

[1]Not used.
[2]Calculated.

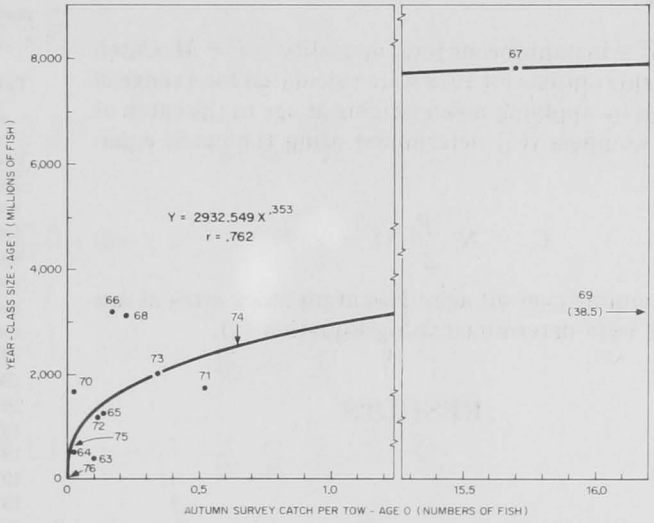

Figure 6.—Power curve relationship between Atlantic mackerel year-class size at age 1 from cohort analysis and autumn survey catch per tow at age 0. The 1969 point was not used in calculating the curve.

Table 5.—Catch per tow (number) of age 1 and 2 Atlantic mackerel from the U.S. spring bottom trawl surveys (strata 1-25, 61-76) and year-class size (millions of fish) at ages 1 and 2 from cohort analysis.

	Age 1		Age 2	
Year class	Spring survey	Cohort analysis	Spring survey	Cohort analysis
1966	—	3,165.3	21.661	2,344.1
1967	197.993	7,786.5	[1]1.190	5,617.3
1968	[1]0.299	3,114.3	12.435	2,300.1
1969	6.208	3,244.9	13.390	2,226.5
1970	2.954	1,657.5	5.545	1,161.4
1971	12.093	1,711.9	6.683	1,248.9
1972	1.949	1,212.6	0.749	759.4
1973	2.067	1,981.2	1.101	1,385.1
1974	5.330	[2](2,103.9)	4.928	[2](1,488.3)
1975	0.447	[2](915.3)	0.254	[2](651.8)
1976	0.043	[2](416.9)	—	—

[1]Not used.
[2]Calculated.

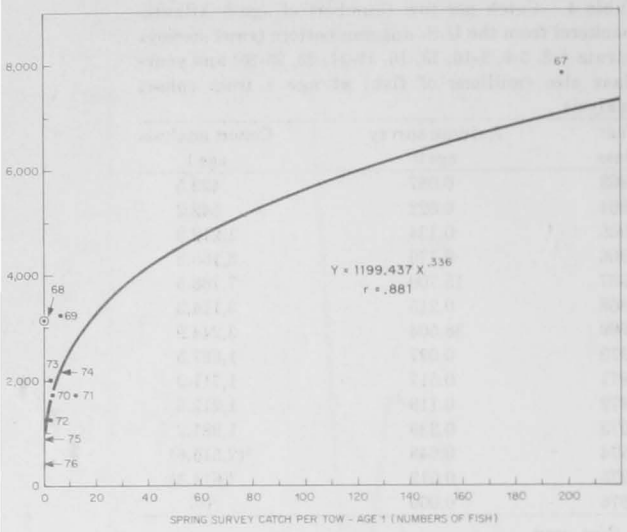

Figure 7.—Power curve relationship between Atlantic mackerel year-class size at age 1 from cohort analysis and spring survey catch per tow at age 1. The 1968 point was not used in calculating the curve.

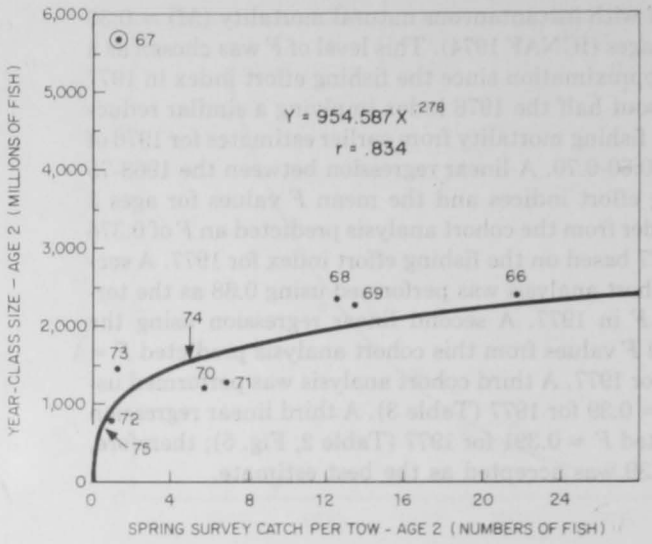

Figure 8.—Power curve relationship between Atlantic mackerel year-class size at age 2 from cohort analysis and spring survey catch per tow at age 2. The 1967 point was not used in calculating the curve.

where Z = instantaneous total mortality = $F + M$. Catch (in weight) options for 1978 were calculated for a range of F values by applying mean weights at age to the catch at age in numbers (C_i) determined using the catch equation:

$$C_i = N_i \frac{F_i}{Z_i} (1 - e^{-Z_i}) \quad (3)$$

and summing over all ages. Resultant stock sizes at age in 1979 were determined using Equation (2).

RESULTS

Catch

Table 6 contains a summary of annual Atlantic mackerel catches by the United States, Canada, and other countries during 1961-77. International catches increased from 13,700 t in 1961 to 431,600 t in 1972 and then declined to 243,000 t in 1976. United States commercial catches varied from 900 to 4,400 t during this period and averaged 2,300 t/yr. Estimated U.S. recreational catches increased from 6,800 t in 1961 to a high of 33,300 t in 1969 and then declined to 5,000 t in 1976; the yearly average for the period was about 15,000 t. Canadian catches ranged between 5,500 and 21,200 t and averaged 12,600 t.

A total allowable catch (TAC) of 105,000 t was allocated by ICNAF for the international commercial fishery in 1977. The provisional reported catch for January-March was 52,114 t (Table 7). Because of the considerable reduction in TAC from 1976 (310,000 t) and the high demand for Atlantic mackerel by the distant-water fleets, it was assumed that all countries, except Canada, the United States, and "Others," would harvest their full catch allocations during the remainder of 1977. Based on past performance, the Canadian catch was con-

Table 6.—Atlantic mackerel catch (metric tons) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 during 1961-77.

Year	United States		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	[1]8,583	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	[1]32,078	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	[1]7,640	16,701	321,837	347,220
1975	1,974	6,503	13,544	271,719	293,740
[2]1976	2,345	[1]4,947	15,744	219,997	243,033
[3]1977	3,000	5,000	20,000	64,000	92,000

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

Table 7.—Estimated Atlantic mackerel catches (metric tons) in 1977 by country from ICNAF Subareas 3, 4, and 5 and Statistical Area 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
F.R.G.	—	1,100	1,100	1,100
G.D.R.	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	—
U.S.S.R.	22,586	214	22,800	22,800
U.S.A. (comm.)	527	2,473	3,000	6,000
U.S.A. (rec.)	—	5,000	5,000	—
Others	—	90	90	5,100
Total	52,114	39,886	92,000	105,000

Table 8 —Atlantic mackerel catch (commercial and recreational) (millions of fish) from ICNAF Subareas 3, 4, and 5 and Statistical Area 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. wt.	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
Mean age	2.8	3.9	3.8	4.7	3.9	4.8	2.3	2.8	3.0	3.6	4.2	3.6	3.8	2.8	3.5	3.8

[1]Thousands of tons.

[2]Using mean weights at age from Table 1.

sidered to be 20,000 t (30,000 t allocated), and the U.S. commercial catch 3,000 t (6,000 t allocated). The catch by countries without specific allocations ("Others") which were expected to take some Atlantic mackerel as by-catch was chosen as 100 t (5,100 t allocated) because of severe catch restrictions for many other species. The U.S. recreational catch was arbitrarily considered to be the same in 1977 as in 1976 (5,000 t). The total catch in 1977 was, therefore, taken to be 92,000 t for the purpose of this assessment.

Catch Composition

Table 8 contains estimates of the Atlantic mackerel catch in numbers at age during 1962-77. Ages ranged between 0 and 10+. Average age of the catch during the period was 3.6 yr, with annual mean ages ranging between 2.3 and 4.8 yr. In 1977, 45% of the catch in numbers was age 3 fish, with a mean age of 3.8 yr. Predominant age groups in the catches have varied, generally reflecting the passage of dominant year classes through the fishery.

Abundance Indices

United States research vessel bottom trawl survey catch-per-tow data (Table 9) indicate a continued decline in Atlantic mackerel abundance. The spring survey catch-per-tow (kilograms) index decreased 37% from 1976 to 1977. Both the spring and autumn indices have demonstrated a continuous biomass decline since 1968-69 (Fig. 3). The spring survey mean catch per tow in numbers has also declined continuously (Table 10) and has shown a marked decrease in the number of age 1 Atlantic mackerel in 1976 and 1977.

The standardized U.S. commercial catch-per-day index (Table 11) has generally been consistent with estimates of abundance from survey data and with stock biomass estimates obtained from cohort analysis (Table 12), although it increased in 1975 and 1976 while the other indices continued to decrease. The U.S. commercial index may be limited as a measure of overall stock abundance because it has been based on small inshore catches, and particularly since these catches have comprised an increasingly smaller proportion of the total catch in recent years. The U.S. Atlantic mackerel catch from directed effort averaged 3.6% of the international catch each year during 1964-67, 1.4% in 1968-69, 0.2% during 1970-76, and <0.1% in 1974-75. The increase in the index in 1975-76 may reflect only localized improvements in abundance.

Distant-water fleet catch-per-effort data are considered to be unreliable as a measure of Atlantic mackerel abundance. Previous analysis of distant-water fleet statistics by Anderson (1976) indicated that various country-vessel tonnage classes experienced different patterns of catch per hour fished during 1968-74, most of which were not in agreement with the change in stock biomass determined by cohort analysis. Total stock biomass peaked in 1969 (Table 12) and then declined sharply, whereas distant-water fleet catch per effort generally increased or was erratic in year-to-year changes. Anderson (1976) suggested that learning, improvements in vessel efficiency through technological changes, or both occurred in varying degrees for nearly all country-tonnage classes engaged in the Atlantic mackerel fishery which invalidates their catch rates as consistent measures of stock abundance. In view of the previous inconsistency in these data, it is difficult to interpret the current catch rates. Although 1977 data are not available, 1976 data indicated increases in catch per effort for certain Bulgarian, German Democratic Republic, and Polish vessel classes and decreases for some U.S.S.R. vessels. The difficulty in interpreting distant-water fleet catch rates was recognized at the time of the last ICNAF assessment (ICNAF 1977), and it was also felt that a schooling species such as Atlantic mackerel was subject to continued accessibility to fishing gear even at low levels of abundance.

Table 9.—Stratified mean catch (kilograms) per tow (ln and retransformed) of Atlantic mackerel from United States 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).

	Spring[1]		Autumn[2]	
Year	ln	Retransformed	ln	Retransformed
1963	—	—	.013	.016
1964	—	—	<.001	<.001
1965	—	—	.046	.073
1966	—	—	.057	.085
1967	—	—	.195	.372
1968	.575	3.998	.117	.217
1969	.029	0.065	.154	.459
1970	.471	2.039	.068	.099
1971	.425	1.969	.052	.073
1972	.354	1.332	.070	.107
1973	.228	0.748	.034	.043
1974	.277	0.769	.046	.108
1975	.121	0.255	.010	.016
1976	.144	0.317	.028	.039
1977	.118	0.199	—	—

[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 11.—Atlantic mackerel catch per standardized U.S. day fished.

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

Table 10.—Stratified mean catch (number) per tow of Atlantic mackerel by year class from the 1973-76 U.S. spring bottom trawl surveys in ICNAF Subarea 5 and Statistical Area 6, strata 1-25, 61-76.

	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	0.365	0.574	68.094
1974	—	—	—	2.067	0.749	1.347	0.185	0.492	0.249	1.401	0.440	0.237	0.107	—	7.274
1975	—	—	5.330	1.101	0.141	0.128	0.030	0.028	0.020	0.014	0.001	—	—	—	6.793
1976	—	0.447	4.928	0.365	0.070	0.014	0.006	0.009	—	0.004	—	—	—	—	5.843
1977	0.043	0.254	0.340	0.153	0.050	0.017	0.010	0.024	0.011	0.018	0.007	0.019	—	—	0.946

Table 12.—Atlantic mackerel stock size by age in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 (millions of fish) derived from cohort analysis assuming natural mortality (M) = 0.30 and fishing mortality (F) = 0.39 at ages 4 and older in 1977. Values in parentheses estimated.

Year class	Year																
	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	—	—	—	—	1,212.9	873.6	618.8	395.0	228.1	143.7	75.6	35.0	16.6	6.8	3.0	—	—
1966	—	—	—	—	—	3,165.3	2,344.1	1,670.8	1,080.1	650.8	300.7	146.5	81.8	38.5	17.7	1.8	0.9
1967	—	—	—	—	—	—	7,786.5	5,617.3	3,904.2	2,413.8	1,289.8	614.5	285.9	118.6	44.2	13.5	6.8
1968	—	—	—	—	—	—	—	3,114.3	2,300.1	1,654.0	1,111.7	664.1	326.8	145.9	63.2	17.4	8.7
1969	—	—	—	—	—	—	—	—	3,244.9	2,226.5	1,387.1	803.8	395.0	194.2	85.3	28.8	14.4
1970	—	—	—	—	—	—	—	—	—	1,657.5	1,161.4	785.5	337.3	162.5	69.7	28.4	14.2
1971	—	—	—	—	—	—	—	—	—	—	1,711.9	1,248.9	682.2	277.8	118.6	43.3	21.7
1972	—	—	—	—	—	—	—	—	—	—	—	1,212.6	759.4	354.1	164.1	48.6	24.4
1973	—	—	—	—	—	—	—	—	—	—	—	—	1,981.2	1,385.1	653.2	252.0	126.4
1974	—	—	—	—	—	—	—	—	—	—	—	—	—	(2,360.0)	1,428.6	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)	2,791.8	2,434.4	2,178.8	2,067.7	2,675.0	5,062.5	11,432.9	11,231.9	11,055.5	8,919.0	7,116.8	5,537.1	4,875.1	5,046.3	3,457.6	2,199.1	1,798.8
Wt (10^3 tons)[1]	626.7	584.9	582.2	577.3	674.9	886.7	2,150.3	2,404.2	2,285.6	2,161.3	2,099.5	1,522.1	1,186.5	964.1	702.2	524.4	468.6
Spawning stock (50% age 2, 100% age 3+)																	
Total (10^6)	1,500.8	1,674.0	1,590.9	1,373.3	1,266.0	1,460.0	2,474.4	5,309.0	6,660.6	6,148.3	4,824.2	3,700.1	2,514.2	1,993.8	1,933.3	1,489.4	1,231.0
Wt (10^3 tons)[1]	461.4	491.0	517.8	501.6	517.1	512.6	920.2	1,505.8	1,802.1	1,829.9	1,811.7	1,300.8	931.6	635.6	519.3	434.7	402.5

[1]Adjusted using ratio of observed to calculated weights in Table 8.

Fishing Mortality

Instantaneous fishing mortality (F) for ages 4 and older in 1977 was estimated to be 0.39 (see section on Methods). Age-specific F values computed from cohort analysis, assuming instantaneous natural mortality (M) = 0.30, for 1962-76 are given in Table 3. Mean annual F values for ages 3 and older were stable during 1962-64, averaging 0.04, and then increased steadily to a peak of 0.74 in 1976.

Recruitment

The estimated sizes of the 1961-73 year classes at age 1, computed by cohort analysis, are given in Table 12 and plotted in Figure 9. Sizes ranged between 430 million fish (1962 and 1963 year classes) and 7,786 million fish (1967 year class) and averaged 2,108 million. Only 4 of these 13 year classes were above the mean. The median size was 1,658 million.

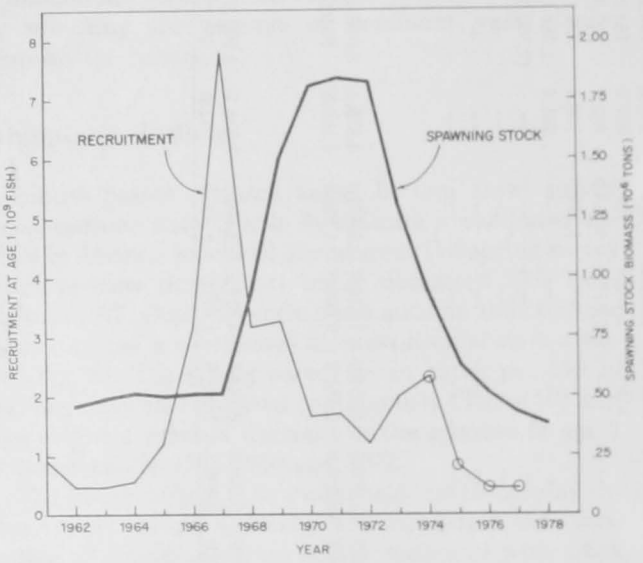

Figure 9.—Atlantic mackerel spawning stock biomass (metric tons) in 1962-77 and abundance at age 1 of the 1961-77 year classes from cohort analysis. Open circles indicate estimated year-class sizes.

The 1974 year class at age 1 was estimated to be 2,516 million fish based on the autumn survey age 0 index (Table 4, Fig. 6) and 2,104 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year class was estimated to be 1,488 million fish based on the spring survey age 2 index (Table 5, Fig. 8). The corresponding catch of 349.5 million fish at age 2 in 1976 (Table 8) implies, using Equation (3), an F of 0.314. It then follows that the size of this year class at age 1 (from cohort analysis) would be 2,447 million fish. The mean of the above three estimates at age 1 was 2,356 million fish. The catch of 375.4 million fish at age 1 in 1975 (Table 8) and the year-class estimates of 2,516 and 2,104 million fish at age 1 result, using Equations (2) and (3), in year-class estimates at age 2 of 1,543 and 1,238 million fish, respectively. The mean of these two estimates and the other estimate of 1,488 million at age 2 was 1,423 million fish. The reported catch of 349.5 million at age 2 from a year-class size of 1,423 million fish requires, from Equation (3), an F of 0.331. Cohort analysis, using this F at age 2 in 1976, results in a year-class size of 2,358 million fish at age 1 in 1975. Given this estimate and the mean (2,356 million) of the three other 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 (Table 4, Fig. 6) and 915 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year class was estimated to be 652 million fish based on the spring survey age 2 index (Table 5, Fig. 8). The catch of 33.0 million fish at age 2 in 1977 (Table 8) implies, from Equation (3), an F of 0.060, which then infers (from cohort analysis) a year-class size of 898 million fish at age 1 in 1976. The mean of the above three estimates at age 1 was 809 million fish. The catch of 12.3 million fish at age 1 in 1976 (Table 8) and the year-class estimates of 614 and 915 million fish at age 1 result, from Equations (2) and (3), in year-class estimates at age 2 of 444 and 667 million fish, respectively. The mean of these two estimates and the other estimate of 652 million at age 2 was 588 million fish. The reported catch of 12.3 million fish at age 2 from a year-class size of 588 million fish requires an F of 0.067. Cohort analysis, using this F at age 2 in 1977, results in a year-class size of 809 million fish at age 1 in 1976. Given this estimate and the mean (809 million) of the three other estimates, the estimated size of the 1975 year class at age 1 was considered to be 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 (Table 5, Fig. 7). There were no fish from this year class caught at age 0 (Table 4) during the 1976 autumn survey. The survey catch-per-tow index for this year class at both ages 0 and 1 was lower than for any other year class during 1963-77 (Tables 4, 5). This indicates that this year class may be very weak. Previously the weakest year classes since 1961 appeared in 1962 and 1963 (430 million fish at age 1). Based on the single estimate from the 1977 spring survey data, the size of the 1976 year class at age 1 was set at 415 million fish.

There are no estimates of the size of the 1977 year class available. Since the contribution of age 1 fish to the 1978 catch is expected to be low, 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 more detrimental to conservation management than of underestimating it. If the year class is underestimated, any unrealized catches at age 1 can be regained in later years since yield per recruit reaches a maximum at about age 4 (ICNAF 1973). However, if the year class is overestimated, the 1978 allowable catch may be set too high to achieve management objectives and the 1979 stock size would be less than projected. The 1977 year class at age 1 was, therefore, set at the minimum level of the weak 1976 year class.

Partial Recruitment

Atlantic mackerel appear to have been fully recruited to the fishery at age 3 and older in recent years, based on age-specific mortality rates (Table 3). Partial recruitment at ages 1 and 2 varied considerably during 1963-77 (Table 13). Partial recruitment at age 1 ranged from 1 to 100% and at age 2 from 16 to 90%. Values prior to 1968 are less precise than those since because the numbers-at-age data for 1962-67 are based on very limited sampling data and are not as reliable as later data (Anderson et al.

Table 13.—Percentage of fishing mortality (F) of Atlantic mackerel at ages 1 and 2 compared with mean F at ages 3 and older (partial recruitment).

Year	Age 1	Age 2	Year	Age 1	Age 2
1962	78.9	15.8	1970	41.6	16.2
1963	9.5	23.8	1971	20.9	64.6
1964	100.0	82.1	1972	4.7	28.8
1965	46.2	32.7	1973	37.3	67.6
1966	46.7	70.0	1974	11.3	89.9
1967	0.9	40.5	1975	38.0	85.0
1968	17.4	25.2	1976	2.4	44.3
1969	2.1	44.4	1977	1.5	17.2

see footnote 2). Partial recruitment at ages 1 (1.5%) and 2 (17.2%) in 1977 was near the low end of the range of values. In view of the wide fluctuations evident in previous years, the 1977 partial recruitment coefficients may not reflect the situation that would actually occur in 1978. An average of the 1968-77 values (except 1970, 1973, and 1975) was used for age 1 in 1978 (9%). The high values in 1970 and 1975 were excluded from this average because they occurred as a result of large catches taken from strong incoming year classes which does not represent the expected situation in 1978. The high 1973 value was also excluded because it resulted from a large harvest of age 1 fish from a year class of below-averge size. This catch reflected a shifting of intensive fishing effort onto younger age groups in an attempt to maintain high levels of catch at a time when older age groups exhibited a sharp drop in abundance.

An average of the 1968-77 values (except 1974-75) was used for age 2 in 1978 (39%). The 1974-75 values were excluded because they were unusually high and do not represent the expected situation for 1978. Such high values may have resulted from: 1) large catches being taken from strong year classes, and 2) apparent diversion of fishing effort onto that age group from older age groups in an attempt to maintain high levels of catch. Partial recruitment in 1978 was, therefore, predicted to be 9% at age 1, 39% at age 2, and 100% at ages 3 and older (Table 14).

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

Parameter		Value
Fishing mortality in 1977 (age 4+)		0.39
Recruitment at age 1:	1974 year class	$2{,}360.0\times10^6$
	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 spawning stock (10^3 tons) projection		402.5

Stock Size

Age-specific stock size estimates generated from cohort analysis and summed biomass values determined by applying mean weights at age to these estimates are given in Table 12. Total stock biomass (age 1 and older) increased from about 600,000 t in 1962-66 to a peak of 2.4 million t in 1969 and then declined steadily to an estimated 524,400 t in 1977. Spawning stock biomass, consisting of 50% of the age 2 fish and 100% of the age 3 and older fish (Isakov[13]; Moores [14]), increased from around 500,000 t during 1962-67 to 1.8 million t in 1970-72 before decreasing to 434,700 t in 1977 (Fig. 9).

Catch and Stock Size Projections

Under the assumption that the 1977 catch would be 92,000 t, the total stock biomass at the beginning of 1978 was estimated to be 468,600 t (11% decrease from 1977) with a spawning stock biomass of 402,500 t (7% decrease from 1977). Catch options for 1978 and resultant spawning stock biomass levels in 1979 were calculated for values of F ranging from 0 to 0.70 (Table 15). In the absence of any catch in 1978 (F = 0.00), the spawning stock biomass would increase about 6% from 1978 to 428,000 t in 1979. A catch of 23,500 t (F = 0.07) would maintain the spawning stock in 1979 at the 1978 level.

Table 15.—Projected Atlantic mackerel catch (metric tons) in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 in 1978 with fishing mortality ranging from 0.00 to 0.70, and the resulting spawning stock in 1979 and its 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

Equilibrium yield calculations, assuming a constant level of recruitment at age 1 and partial recruitment of 9, 39, and 100% at ages 1, 2, and 3+, respectively, indicate that $F_{0.1}$ = 0.40. The $F_{0.1}$ level, defined as the level of F at which the change in yield per recruit with respect to the change in F is only 10% of that which would occur if the fishery began on the virgin stock (Gulland and Boerema 1973), has been used recently within ICNAF as a basis for setting catch quotas. Fishing mortality at $F_{0.1}$ = 0.40 would result in a 1978 catch of 116,000 t and would reduce the spawning stock by 24% in 1979.

An assessment assuming a total catch of 110,000 t in 1977 (TAC of 105,000 plus 5,000 for the U.S. recreational catch) instead of 92,000 t has no significant effect on the

[13]Isakov, V. I. 1976. On some results of biological studies on mackerel from the Northwest Atlantic. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/52, Ser. No. 3838 (mimeogr.), 14 p.

[14]Moores, J. A. 1976. Mackerel research in the Newfoundland area during 1975. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/18, Ser. No. 3798 (mimeogr.), 10 p.

catch projections for 1978. The fishing mortality estimate for 1977 would be 0.435 instead of 0.39 and the projected spawning stock biomass in 1978 would be about 390,000 t instead of 402,500 t. A catch of about 25,000 t, instead of 23,500 t, could be taken in 1978 and still maintain the spawning stock in 1979 at the 1978 level.

DISCUSSION

The accuracy of the projected catch options for 1978 and the resultant spawning stock biomass levels in 1979 (Table 15) is dependent upon the accuracy of the data and parameters used in the analysis. The variability and bias associated with these data and parameters are evident.

The U.S. recreational catches (Table 6) are estimated and lack any measure of accuracy or reliability, and the validity of the international commercial statistics is uncertain. The numbers at age in the catch (Table 8) were generated from length and age samples contributed by various countries, and although ICNAF established recommended sampling procedures, the validity of the samples is unknown. Anderson et al. (see footnote 11) found significant differences in age interpretation and age-length keys between countries during 1970-76, particularly in 1976. As indicated earlier, country age-length keys for 1976 were combined in an attempt to modulate these differences. The procedure recommended by ICNAF specifies stratified age samples, whereas Kimura (1977) showed that random age samples are more accurate.

The U.S. bottom trawl survey data provided the basis for estimating the size of the recruiting year classes (Tables 4 and 5, Figs. 6-8) and also for predicting fishing mortality in 1977 (Table 2, Fig. 5). Although confidence limits were not given for any of these estimates, survey catch-per-tow data in general are subject to high variability (Grosslein 1971), and particularly so for Atlantic mackerel (Anderson 1976; Sissenwine 1978) since it is a pelagic schooling species. Therefore, even though the relationships using survey catch-per-tow data to predict year-class sizes and fishing mortality are statistically significant, the predicted values are necessarily somewhat imprecise.

The values for instantaneous natural mortality (M = 0.30) and partial recruitment coefficients, although having a basis for being chosen, introduce additional uncertainty to the final results.

In view of all the variability and uncertainty in the data, the results of this assessment must be treated with appropriate caution. Given the catch and stock size projections, fishery managers may set allowable catch levels for 1978 appropriate to management objectives which they have adopted. Since highly precise projections are currently not available, the decision process should include consideration of the acceptable level of risk of failing to achieve management objectives. If an objective is to rebuild the stock by a certain percentage from 1978 to 1979, it may be wise to set the catch in 1978 at a level corresponding to a greater percentage increase in stock size as a safety factor to guard against the probability that the predicted stock size and recruitment levels are, in fact, overestimated. According to the Fishery Conservation and Management Act of 1976 enacted by Congress, the level of catch must consider relevant economic, social, or ecological factors. Since economic and social factors are beyond the scope of this paper, only ecological or biological considerations will be discussed.

The historical relationship between Atlantic mackerel spawning stock and recruitment is shown in Figure 9. The spawning biomass estimated for 1978 is slightly below the 1962-67 level when, prior to the recent decade of intensive international fishing, catches averaged only about 25,000 t and stock size was relatively stable. The spawning biomass of about 500,000 t present in 1962-67 produced year classes ranging from the weakest (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 appears that for Atlantic mackerel, as for most species, spawning stock size alone exerts little influence on the size of a year class unless perhaps the spawning stock is reduced to extremely low levels. Lett and Kohler[15] found in population simulations of Atlantic herring, *Clupea harengus*, in the Gulf of St. Lawrence that recruitment was independent of spawning stock size over a fairly wide range, and that a stock-recruitment relationship emerged only when the stock was collapsing due to overfishing. Environmental factors are obviously a major influence on Atlantic mackerel year-class size, but the present state of knowledge concerning this influence 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 weak recruitment is likely. However, since spawning stock size has continued a steady decline and recent year classes (1975-76) appear to be as weak as any observed previously, there is reason for concluding that the spawning stock should not be allowed to fall much below the projected 1978 level.

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