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STATUS OF THE NORTHWEST ATLANTIC MACKEREL STOCK - 1983

by

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SUMMARY

The international catch (commercial and recreational) of Atlantic mackerel (Scomber scombrus) in the Northwest Atlantic decreased from 31,600 metric tons (mt) in 1981 to 30,400 mt in 1982. Canada and the United States (US) accounted for 54% and 24%, respectively, of the 1982 total. The international catch in 1983 was estimated to be 28,640 mt.

The 1980 year class was predominant in the 1982 catch comprising 21% of the total catch in numbers. The 1978 and 1974 year classes accounted for 18% and 17%, respectively, of the 1982 catch. Mean weights at age in 1982 continued to reflect an increase in growth rate which began in the mid 1970's.

Catch per tow (kg) from NEFC bottom trawl surveys (spring and autumn) declined sharply from 1982 to 1983. These changes appear to be the result of seasonal distributional changes causing a decrease in availability to the trawl survey and are also a reflection of the inherent variability of mackerel in survey catches. Marked changes in the timing of seasonal migrations and in the seasonal distribution of mackerel throughout their range have been observed in the last several years and appear to be related to water temperature. Catch per day (mt) of age 3 and older mackerel in the US commercial fishery increased from 1981 to 1982.

Mean annual fishing mortality (F) at ages 3 and older was estimated to be 0.11 in 1982 (M = 0.20) which was the same as in the previous four years (1978-81). Separable virtual population analysis (SVPA) was used to estimate the exploitation pattern (proportion of F at age relative to the mean F at ages 3 and older) for the fishery in 1982. Results of the SVPA indicated a dome-shaped pattern increasing from 53% at age 3 to 227% at age 6 and decreasing to 46% at age 12. This general pattern of F at age has been observed since 1978. The estimated catch of 28,640 mt in 1983 would result in a mean F of 0.08.

The 1975-83 year classes are all estimated to be below average (1961-83) in strength, with the 1982 year class appearing to be nearly twice as strong as any of the others (1975-83). The 1976, 1977, 1979, and 1983 year classes are extremely weak. Next to the 1982 year class, the 1980 and 1981 year classes are the strongest since the 1974 year class.

Total stock biomass increased from a recent low of 355,000 mt in 1980 to a projected level of 676,000 mt at the beginning of 1984. Spawning stock biomass improved from 297,000 mt in 1981 to an estimated 563,000 mt in 1984.

Yield-per-recruit calculations (M = 0.20) indicate an $F_{0.1}$ of 0.30 based on average 1981-82 (current) conditions in the fishery.

Assessment analyses indicate that the mackerel stock in the Northwest Atlantic has increased considerably in the last several years. Spawning stock biomass estimates increased 90% from 1981 to 1984 due to markedly improved recruitment from the 1980-82 year classes. If the international catch in 1984 remains at the relatively stable level taken during 1978-83 (average of 31,400 mt), mean annual fishing mortality at ages 3 and older will drop to about 0.06 (compared to 0.08 in 1983 and 0.11 in 1982) and spawning stock biomass in 1985 will increase about 20% from 1984. Fishing mortality at $F_{0.1}$ (0.30) in 1984 would result in a catch of 132,000 mt and leave a spawning stock biomass of 577,000 mt in 1985 (3% increase from 1984).

INTRODUCTION

This report presents an assessment of the status of Atlantic mackerel (Scomber scombrus) in Subareas 2-6 (SA 2-6) of the Northwest Atlantic Fisheries Organization (NAFO) (Figure 1). All mackerel in the Northwest Atlantic are treated herein as a unit stock. The assessment is based on catch, effort, and sampling data from fisheries conducted by the United States (US), Canada, and other countries and on data collected from Northeast Fisheries Center (NEFC) spring and autumn bottom trawl surveys. The data and analyses in this report are an update of those presented by Anderson (1982).

MANAGEMENT

Northwest Atlantic mackerel were managed by means of nationally-allocated catch quotas from 1973 until 1977 by the International Commission for the Northwest Atlantic Fisheries (ICNAF). Since 1 March 1977, mackerel in US waters have been managed by a Preliminary Management Plan (PMP) developed by the NMFS (until 21 February 1980) and the Atlantic Mackerel Fishery Management Plan (FMP) and its Amendments developed by the Mid-Atlantic Fishery Management Council. Management under the FMP has been on a 1 April - 31 March fishing year.

The Fishery Management Plan for the Atlantic Mackerel, Squid, and Butterfish Fisheries, which merged the three separate FMPs for the above species, was implemented on 30 September 1983. Amendment #1 to this FMP (MAFMC 1983), which provides for some modifications to the management scheme to account for a change in the natural mortality rate (M) from 0.30 to 0.20 (Anderson 1982), will be implemented on 7 February 1984.

The specification of optimum yield (OY), domestic annual harvest (DAH), domestic annual processing (DAP), and total allowable level of foreign fishing (TALFF) in Amendment #1 is contingent upon the level of spawning stock biomass (SSB).

If SSB for the year following the fishing year in question is projected to be less than or equal to 400,000 metric tons (mt), TALFF will equal 2% of the allocated silver hake TALFF plus 1% each of the allocated TALFFs for red hake, Illex squid, and Loligo squid. DAH will equal the estimated domestic annual harvest up to 30,000 mt minus TALFF, and OY will equal DAH plus TALFF but not exceed 30,000 mt.

If SSB for the year following the fishing year in question is greater than 400,000 mt, OY will be no greater than the catch (acceptable catch or AC) which, in conjunction with the anticipated catch in Canadian waters, would reduce the SSB to 400,000 mt or result in a fishing mortality rate not to exceed $F_{0.1}$. If the AC is less than 30,000 mt, TALFF will equal the by-catch percentages indicated above, DAH will equal AC minus TALFF, and OY will equal DAH plus TALFF. If AC is greater than or equal to 30,000 mt and DAH is less than 30,000 mt, TALFF will be as above and OY will equal 30,000 mt plus TALFF. If AC is greater than or equal to 30,000 mt and DAH is greater than or equal to 30,000 mt, OY will equal AC and initial DAH will equal the estimated domestic annual harvest. Under this option, if OY minus DAH is less than 10,000 mt, TALFF will equal OY minus DAH; if OY minus initial DAH is greater than or equal to 10,000 mt, half will be assigned to TALFF and half placed in reserve for allocation later in the year to DAH and/or TALFF.

CATCH

Commercial

The international commercial catch in SA 2-6 decreased about 5% from 27,596 mt in 1981 to 26,356 mt in 1982 (Table 1). The 1978-82 average catch was 27,977 mt, compared to the peak commercial catch of 419,714 mt in 1973.

About 62% of the total catch in 1982 was from Canadian waters, with nearly all of this coming from SA 4 (largely from Gulf of St. Lawrence area) (Table 2) mainly during the second and third quarters of the year. In US waters (SA 5-6), about 90% of the catch was from SA 6, with over 90% of the total taken during February-May.

The Canadian catch (62% of the total) has undergone a steady decline from a high of 30,244 mt in 1979 to 16,379 mt in 1982, the lowest level since 1976 (Table 1). There was a 96% decline in the catch by Newfoundland from 1981 (6,930 mt) to 1982 (308 mt) due to an apparent absence of mackerel in traditional areas around Newfoundland in 1982. The US catch, although much smaller than that by Canada, has increased steadily from 1,377 mt in 1977 to 3,330 mt in 1982. Catches by countries other than the US and Canada totalled 6,647 mt in 1982, approximately a 25% increase from 1981 and a 11-fold increase from the 1978-80 average. The sharp increase in 1981-82 was due primarily to Polish catches, which in 1982 were taken in a research fishery conducted in cooperation with the NEFC.

The international catch in 1983 was estimated to be about 24,640 mt, a 7% decrease from 1982. The US catch was estimated to be 3,500 mt, a slight increase from 1982. The Canadian catch was projected to be

15,000 mt, an 8% decline from 1982. The Canadian catch from the Maritimes and Quebec was estimated to be about 10,000 mt, a 38% drop from 1982, whereas the Newfoundland catch was estimated to be 5,000 mt, compared to 308 mt in 1982. Catches in 1983 by other countries were estimated to total 6,140 mt (including 4,341 mt by Poland in a research fishery in SA 5-6), an 8% decline from 1982.

Recreational

Estimates of the annual US recreational catch of mackerel between Maine and North Carolina since 1960 (Anderson 1981) are given in Table 1. Although the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) has been conducted since 1979, annual catch estimates are currently available only for 1979 (3,315 mt) and 1980 (1,696 mt). In the absence of estimates from the MRFSS for years after 1980, the catch in each of those years was assumed to be 4,000 mt.

Total

The total international catch in SA 2-6 decreased from 31,596 mt in 1981 to 30,356 mt in 1982 (Table 1). Catches during 1978-82 remained fairly stable averaging 31,900 mt annually, a level which is only 7% of the peak of 430,437 mt in 1973. Canada and the US accounted for 54% and 24%, respectively, of the 1982 total.

The total catch in 1983 was estimated to be 28,640 mt, a 6% decrease from 1982.

CATCH COMPOSITION

Length frequency samples from US commercial catches in 1982 were obtained during February (1), April (3), May (4), November (1), and December (1) from Div. 6A, during February (4) and April (4) from Div. 6B, during March (3), August (2), and September (1) from Subdiv. 5Zw, and during August (1) and November (1) from Div. 5Y. A total of 2,765 lengths was represented in these 26 samples; sampled catches were from otter trawls, pound nets, floating traps, and purse seines.

Length frequency samples collected by the NMFS Foreign Fisheries Observer Program in 1982 were obtained during January (1), February (4), March (17), October (4), November (13), and December (6). These samples (45) were taken aboard Italian (30), Spanish (9), and Japanese (6) vessels fishing in SA 5-6 and represented a total of 4,222 fish.

A total of 176 samples (30,779 lengths) was collected by NMFS and Polish scientists aboard two Polish vessels during a US-Poland research fishery for mackerel conducted during January-April 1982 in SA 6.

Age/length keys were prepared for the first and second quarters combined of 1982 using sampling data from Polish, Italian, Spanish, Japanese, US commercial, and NEFC spring bottom trawl survey catches, and for the fourth quarter using samples from Italian, Spanish, Japanese, US commercial, and NEFC autumn bottom trawl survey catches. Since there was an insufficient number of age-at-length observations available from US samples to construct an adequate age/length key for the third quarter, an age/length key based on Canadian Maritimes sampling data (all gears

combined) from the third quarter in SA 4 (Hunt[1]) was used. These keys were applied to the available length frequency data in the various months from both US and distant-water-fleet (DWF) catches to estimate numbers at age.

Numbers-at-age data from the 1982 SA 3-4 Canadian Newfoundland catch were obtained from Carscadden[2], and comparable data from the SA 4 Canadian Maritime catch were provided by Hunt (see footnote 1).

The disparity which existed between US and Canadian Maritimes age determinations in 1980 and 1981 samples (Anderson 1982, Dery and Anderson 1983) appeared to have diminished considerably in the 1982 samples based on a comparison of age/length keys for comparable time periods. The previous disagreement in ageing related primarily to the 1977 and 1978 year classes. A weak hyaline ring formed after the first annulus has been interpreted as a check by US readers and as an annulus by Canadian readers. Existing differences in interpretation now pertain mainly to the 1974 and 1975 year classes; in 1982 and also in earlier years, Canadian readers have consistently identified a much greater proportion of 1975 year-class fish relative to the 1974 year class than have US readers. Based on estimates of year-class size from virtual population analysis and from NEFC bottom trawl survey catch-per-tow indices (Anderson 1982, Tables 10

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

[2]James E. Carscadden, Fisheries and Oceans Canada, Fisheries Research Branch, St. John's, Newfoundland, personal communication.

and 11 in this report), the 1974 year class is considerably stronger than the 1975 year class. The US interpretation of the relative proportions of 1974 and 1975 year-class fish at given lengths tends to be more in agreement with the relative strengths of these two year classes than does the Canadian Maritime interpretation.

The percentage age composition of the US recreational catch in 1982 was assumed to be the same as the SA 3-6 commercial total (Table 3). Although length frequency data have been collected by the NMFS MRFSS since 1979, it has not been made available for analysis.

Numbers at age for the 1982 international catch are given in Table 3. The 1980 year class at age 2 comprised 21% of the catch in numbers, followed by the 1978 year class (age 4) with 18% and the 1974 year class (age 8) with 17%. Percentage compositions were fairly comparable between catches in SA 3-4 and SA 5-6 except at ages 2, 6, and 7. Age 2 fish comprised 28% of the catch in SA 5-6 but only 15% in SA 3-4. Age 6 and 7 fish accounted for 1% and 4%, respectively, of the SA 5-6 catch and 9% and 14%, respectively, of the SA 3-4 catch. The difference at age 2 was due to the large catch at that age (50%) by the US commercial fishery. The differences at ages 6 and 7 were due somewhat to dissimilar length compositions of sampled catches in the two areas but also to differences in age determination between US and Canadian Maritime readers.

The US commercial catch in 1982 was dominated by the 1980 year class at age 2 (50%) (Table 3). This year class at age 1 (61%) also dominated the 1981 US commercial catch. The 1982 US catch also included 18% age 4 fish (1978 year class) and 10% age 8 fish (1974 year class).

The non-US catch in SA 5-6 in 1982 (mainly from the Polish research fishery) included primarily age 8 (1974 year class - 21%) and age 4 (1978 year class - 20%), followed by age 2 (14%) and age 1 (11%) fish (Table 3).

In SA 3-4, age 4 (1978 year class) and age 8 (1974 year class) fish both contributed 17% of the Canadian Maritimes catch, followed by age 2 (16%) and age 7 (14%) fish (Table 3). The Newfoundland catch in 1982 was dominated by age 8 fish (24%), followed by age 14+ fish (14%).

The catch (4,341 mt) from the February-May 1983 research fishery conducted by Polish vessels in SA 5-6 consisted of 30% age 2 (1981 year class), 18% age 9 (1974 year class), 13% age 5 (1978 year class), and 10% age 1 (1982 year class) fish. Based on this as well as other information concerning year-class abundance, these year classes will likely contribute significantly to the total international catch in 1983.

The international numbers-at-age catch data for 1962-82 for SA 2-6 are presented in Table 4.

MEAN WEIGHTS AT AGE

Estimated mean weights for ages 1-14+ in the international catch from NAFO SA 2-6 during 1962-82 are given in Table 5. Mean weights at age for calculating stock biomass as of 1 January of each year are given in Table 6. Anderson (1982) described the procedures whereby these values were determined.

Mean weight at age has increased significantly since 1977. Values for 1982 were generally higher than for 1981. These increases are a reflection of changes in growth rate.

The 1981-82 average mean weights at age for catch (Table 5) and stock (Table 6) were used in calculating projected catches in 1983-84 and stock biomass in 1983-85.

STOCK BIOMASS INDICES

Research Vessel Survey Catch Per Tow

Indices of mackerel stock biomass have been calculated from catches made during NMFS, NEFC spring and autumn bottom trawl surveys. Spring catch-per-tow indices based on catches in sampling strata 1-25 and 61-76 (Figure 2) during 1968-83 and autumn indices based on catches in strata 1-42 and 49 during 1963-83 are given in Table 7 and Figure 3. Analysis of the data involves ln transformation of the catch (kg) at each trawl station, computation of stratified mean catch per tow (ln scale), and retransformation of the results to the linear scale (Anderson 1979, Anderson and Paciorkowski 1980).

Spring catch per tow rose sharply from 0.22 kg in 1979 to 1.84 kg in 1981, but then decreased in both 1982 (0.88 kg) and 1983 (0.27 kg) (Table 7, Figure 3). The values in 1981 and 1982 were both higher than any observed since 1972 and reflect the increase in stock biomass since 1980. The sharp drop in the spring 1983 index is not indicative of a decrease in biomass, but appears to be a result of year-to-year differences in the distribution of mackerel at the time the survey is conducted. In both 1981 and 1982, the largest catches of mackerel during the spring survey were obtained south of Hudson Canyon, whereas in 1983, most of the larger catches occurred farther north around Nantucket Shoals and Georges Bank. This difference suggests that the northward spring migration of mackerel was further advanced at the time of the survey in 1983 than in 1981-82 and that part of the stock may already have moved north out

of the survey area into Canadian waters, thus resulting in an unexpectedly low catch-per-tow index. Also in 1983, 90% of the spring survey catch-per-tow index (in numbers) was comprised of age 1 and 2 fish, much higher than in nearly every other year of the survey (1968-82 mean = 52%). Even though the 1981 and 1982 year classes are relatively strong compared to other year classes currently in the stock, their percentage contribution to the 1983 survey catch was much greater than would have been expected. Since older fish (generally ages 3 and older) typically migrate northward first, the predominance of age 1 and 2 fish in 1983 suggests that most of the older fish which would normally migrate to Canadian waters were unavailable to the spring survey by virtue of having advanced northward from the Mid-Atlantic area ahead of the survey (the spring survey is conducted from south to north during March-May).

Autumn catch per tow has exhibited the same general trends over time as has spring catch per tow, although catch per tow has averaged about 20 times smaller in the autumn than in the spring. After having increased from 0.02 kg in 1981 to 0.13 kg in 1982 (the highest since 1969), the 1983 index dropped to 0.05 kg per tow (Table 7, Figure 3). As with the spring index, year-to-year changes are reflective of both the variability in the timing of seasonal migrations and the inherent variability of mackerel catches in the NEFC bottom trawl survey. The drop in the 1983 index appears to be associated somewhat with a later southerly migration, relative to the timing of the autumn survey, than in 1982. In 1982, 85% of the autumn survey catch of mackerel was from sampling strata in southern New England waters (Figure 2), whereas in 1983, 91% of the autumn

catch was from more northerly waters (Georges Bank and Gulf of Maine). This difference suggests that some fish migrating south out of inshore waters along the coast of Maine or from Canadian waters may not have been available to the 1983 autumn survey.

US Commercial CPUE

The standardized US commercial catch-per-day index (all ages) (Anderson 1976), derived by standardizing effort from various gear-vessel tonnage categories to that of the floating trap, declined from 1.19 mt in 1981 to 0.86 mt in 1982 (Table 8, Figure 4). Although US CPUE declined in both 1981 and 1982 from a recent high of 1.42 mt in 1980, the values in all three years were higher than any observed since 1971 and are indicative of the increase in stock biomass since 1980.

Standardized US CPUE for ages 3 and older (Table 9, Figure 4) increased from 0.46 mt in 1981 to 0.57 mt in 1982. This index has generally followed the pattern of CPUE for all ages, except in 1980 and 1981 when about 60% of the CPUE for ages 1 and older was due to ages 1-2.

NATURAL MORTALITY

Instantaneous natural mortality (M) for mackerel in SA 2-6 was assumed to be 0.20 for all ages and years, as estimated by Anderson (1982).

FISHING MORTALITY

Instantaneous fishing mortality (F) for ages 3 and older in 1982 was estimated from a functional power curve regression between mean annual F derived from virtual population analysis (VPA) using M = 0.20 and international fishing effort expressed as equivalent US standardized days fished. F values for ages 3 and older from VPA were weighted by stock size at age (numbers) to obtain an annual mean F. Annual fishing effort directed towards ages 3 and older was determined by dividing the international catch (mt) at ages 3 and older by US standardized catch per day for ages 3 and older (Table 9).

Separable virtual population analysis (SVPA) was used to estimate the exploitation pattern (proportion of F at each age relative to the mean F at ages 3 and older) of the fishery in 1982. SVPA is a simple, rapid procedure developed by Pope and Shepherd (1982) to analyze a catch-at-age matrix in order to interpret the exploitation pattern. Fishing mortality at age can be separated into an age component common over years and a year component common over ages within the year, with the age component referred to as the exploitation pattern S(j) and the year component referred to as the fully exploited fishing mortality F(i) (Pope and Shepherd 1982). The method assumes that the exploitation pattern has remained relatively constant for a period of years (preferably the most recent years). SVPA applies a least squares minimization procedure to a matrix of log catch ratios (obtained from the catch-at-age matrix)

to calculate best estimates of F(i) and S(j). In addition to natural mortality (M), the only parameters which must be specified are F at a reference age in the last year (usually the age with the highest or close to the highest catch in number) and the selection factor (S) at the oldest age in the last year (ratio between F at the reference age and the oldest age). Further explanation of the procedures, use, and application of SVPA are provided elsewhere (Shepherd and Stevens 1983, Anonymous 1983).

A number of SVPA runs were made to determine the most appropriate range of ages and years to be used. The initial run included ages 1-11 during 1962-82 which resulted in a coefficient of variation (CV) of 63% and excessively high log catch ratio residuals at ages below 3 and above 10. Rerunning the SVPA with ages 3-10 during 1962-82 reduced the CV to 56% but resulted in high log catch ratio residuals at virtually all ages for years prior to 1969. Additional runs were made with incremental reductions in the number of years until the CV was reduced to only 17% for ages 3-10 during 1978-82, with a reference age for terminal F at 4 years and S = 1.0 at age 10. The assumption of a relatively constant exploitation pattern appears to be satisfied for 1978-82 which corresponds to a period when the fishery was conducted primarily by Canada and the US following extended jurisdiction and catches were much lower and quite stable relative to earlier years.

Given the exploitation pattern for 1982 estimated from SVPA, mean annual F values for ages 3 and older in 1964-81 were determined from conventional VPA using trial values of mean F at ages 3 and older in 1982. These estimates of mean annual F were regressed (functional power curve) against fishing effort for those years. The VPA-regression process was followed through several iterations until the mean F predicted by the regression for 1982 remained unchanged from the terminal mean F used in the previous VPA. Since SVPA extends the exploitation pattern which is calculated for a designated set of ages and years to all ages and years in the data set, terminal F values were thus selected for ages 11-13 in 1982 and for age 13 in 1978-81. F values at age 14+ in 1979-82 and at the oldest age in years prior to 1976 were assumed equal to the mean F at ages 3 and older in the respective year. A mean F of 0.107 was thus estimated for ages 3 and older in 1982 from a functional power curve regression having a correlation coefficient (r) of 0.892 (Table 9, Figure 5).

Age-specific F values estimated for 1962-82 are given in Table 10. Mean annual F for ages 3 and older increased from an average of 0.06 in 1962-64 to a high of 0.65 in 1976 before dropping to 0.10 in 1978. Mean F remained relatively constant during 1978-82 at an average of 0.10.

RECRUITMENT

The sizes of the 1961-79 year classes of age 1, estimated from VPA, ranged from 39 million (1977 year class) to 5,046 million fish (1967 year class) (Table 10), with a mean size of 1,066 million and a median size of 759 million. The estimates for the strongest (1967) and weakest (1977) year classes differed by a factor of 130. The 1975-79 year classes

were all below the mean and median level (range = 39-248 million, average = 134 million) with the 1978 being the strongest in that group.

Catch-per-tow indices for age 0 from NMFS, NEFC autumn bottom trawl surveys and for ages 1 and 2 from spring surveys (Table 11) were combined into a single age 1 index for each year class (Anderson 1982). These indices were regressed against year-class size at age 1 from VPA for the 1963-79 year classes, using a functional linear regression (r = 0.943) (Table 11, Figure 6), to provide a basis for predicting the size of the 1980-83 year classes.

The 1980 (590 million), 1981 (510 million), and 1982 (930 million) year classes at age 1 were all estimated to be stronger than the 1975-79 year classes. Even though the 1980-82 year classes are relatively strong compared to the 1975-79 year classes, they are all below the 1961-79 mean level and only the 1982 year class is above the long-term median level. The 1982 year class appears to be the strongest to appear since 1974 and is nearly twice the size of any others since 1974. The 1983 year class was estimated to be only 70 million fish at age 1, the poorest observed since 1977 (39 million), and the third poorest in the available time-series.

The 1978 year class at age 1, once considered to be as strong as the 1974 year class at that age (Anderson 1981), is now estimated to be only 16% of the size of the 1974 year class or 248 million fish, a further reduction from the estimated 400 million fish (27% of the 1974 year class) in the previous assessment (Anderson 1982). The present estimate of the 1979 year class (97 million at age 1) is about half of that in the previous assessment. The 1980 and 1981 year classes are approximately the same as estimated previously, whereas the current estimate of the 1982 year class is more than twice than before.

EXPLOITATION PATTERN

The exploitation pattern is defined here as the proportion of fishing mortality at each age in a given year relative to the mean F in that year at ages fully vulnerable to the fishery (considered here to be ages 3 and older). The exploitation patterns for the mackerel fishery during 1962-82 are presented in Table 12.

The exploitation pattern or selection factors for ages 3 and older in 1982 were determined by SVPA, with the factors in earlier years based on results from a conventional VPA. The selection factors at ages 1 and 2 in 1982 and age 1 in 1981 were based on F values derived from predicted year-class sizes and known catches. The exploitation pattern for 1982 was dome shaped increasing from 53% at age 3 (8% and 24% at ages 1 and 2, respectively) to 227% at age 6 and decreasing to 46% at age 12. This dome-shaped pattern was generally persistent during 1978-82.

During earlier years, particularly during the intensive distant-water-fleet fishery in SA 5-6 in 1968-77, a somewhat different exploitation pattern existed. During this time, selection factors were much higher at ages 1-4 and lower at ages 5 and older compared to 1978-82. This major difference was due to a greater proportion of younger fish in the catch during the earlier period because of a succession of above-average year classes (1966-74) entering the fishery. During the 1978-82 period, a succession of relatively weak year classes (1975-79) resulted in a greater reliance by the fishery on older fish from the stronger year classes.

Given the rather constant exploitation pattern which has persisted since 1978 corresponding to a period characterized by a relatively stable fishery with fairly constant and low catches and below average year classes, there is no reason to believe that this pattern will change in the next several years. For the purpose of projecting catches in 1983-84, the exploitation pattern for those two years was assumed to be equal to the mean of the patterns in 1981-82 (Table 12).

STOCK BIOMASS

Age-specific stock size estimates from VPA are given in Table 10. Annual stock biomass estimates for 1962-83 were obtained by applying the appropriate mean weights at age from Table 6 to the stock size estimates.

Total stock biomass (ages 1 and older) increased from around 300,000 mt during 1962-65 to 1.9 million mt in 1970-71 and then declined to a stable low level during 1978-81 ranging between 355,000 (1980) and 379,000 mt (1979) (Table 10, Figure 7). From a low in 1980, total stock biomass increased 65% to an estimated 587,000 mt at the beginning of 1983.

Spawning stock biomass, defined as 50% of the age 2 and 100% of the age 3 and older fish, increased from an average of 264,000 mt per year during 1962-67 to 1.6 million mt in 1971 and then decreased to 297,000 mt in 1981 (Table 10, Figure 7). Spawning biomass increased nearly 60% from 1981 to an estimated 473,000 mt in 1983.

YIELD PER RECRUIT

Yield-per-recruit analysis employing the Thompson and Bell (1934) method was performed to estimate the fishing mortality reference points of $F_{0.1}$ and F_{max}. Since the analysis was performed to obtain reference points applicable to conditions in the fishery in 1984, average catch mean weights at age for 1981-82 (Table 5) and the average exploitation pattern for 1981-82 (Table 12) were used. Results indicated that $F_{0.1}$ = 0.30 and F_{max} = 0.77. Both of these values are lower than those calculated in the previous assessment ($F_{0.1}$ = 0.40, F_{max} = 1.78) (Anderson 1982) because of the difference in the exploitation patterns used in the two analyses.

STOCK - RECRUITMENT

An examination was made of the relationship between year-class size at age 1 and the spawning stock biomass which produced that year class (Figure 8). The array of points in Figure 8 indicates a strong tendency for low spawning stock levels to produce poor year classes. During 1962-83, the estimated spawning biomass was 396,000 mt or less during 12 of those 22 years (averaging 302,000 mt per year) and only 33% (4 of 12) of the year classes produced were above median size (675 million fish at age 1). In the remaining 10 years, spawning stock biomass was 473,000 mt or higher (averaging 992,000 mt per year) and 70% (7 of 10) of the year classes produced were above median size.

As indicated in the previous assessment (Anderson 1982), there appears to be a recognizable stock-recruitment relationship for mackerel in the Northwest Atlantic even though environmental factors independent of spawning stock biomass strongly influence year class size. For the purpose of management, the minimum spawning stock biomass constraint of 400,000 mt adopted by the Mid-Atlantic Fishery Management Council (MAFMC 1983) in Amendment #1 to its FMP for mackerel appears justified based on the available stock-recruitment information.

CATCH AND STOCK BIOMASS PROJECTIONS

The estimated catch in 1983 of 28,640 mt will generate a mean F on ages 3 and older of 0.080 (compared to 0.107 in 1982). Total stock biomass at the beginning of 1984 was projected to be 676,000 mt, a 15% increase from 1983. Spawning stock biomass at the beginning of 1984 was estimated to be 563,000 mt, a 19% increase from 1983.

Projected catches in 1984 ranging from 20,000 mt to 132,000 mt (Table 13, Figure 9) would generate fishing mortality rates ranging from 0.04 to 0.30 and result in estimated spawning stock biomass levels at the beginning of 1985 varying from 686,000 mt (22% increase from 1984) to 577,000 mt (3% increase from 1984).

Fishing at the $F_{0.1}$ level (F = 0.30) would result in an estimated catch of 132,000 mt in 1984 and leave a spawning stock in 1985 of 577,000 mt. If catches in 1984 remain at the relatively stable level observed during 1978-83 (average = 31,400 mt), fishing mortality will decline to about 0.06 (compared to 0.08 in 1983 and 0.11 in 1982) and

spawning stock biomass would increase about 20% from 1984 to 1985. Catches in 1984 would total about 38,500 mt if fishing mortality equalled the 1983 rate and about 50,000 mt if F was at the 1982 level.

DISCUSSION

Results of this assessment indicate that the mackerel stock in the Northwest Atlantic has increased considerably in the last several years. Total stock biomass (ages 1 and older) increased about 90% from a low of 355,000 mt in 1980 to 676,000 mt in 1984. Similarly, spawning stock biomass increased 90% from 297,000 mt in 1981 to 563,000 mt in 1984. Stock rebuilding has been due to low catches, reduced fishing mortality, and improved recruitment. Catches and fishing mortality since 1978 have remained relatively low at an annual average (1978-83) of 31,400 mt and 0.10, respectively, compared to the high catches (average = 340,000 mt) and F levels (average = 0.42) during 1970-76. Although the 1975-83 year classes have all been below the long-term (1961-83) average, the 1980-82 year classes are considerably stronger than those in 1975-79. Growth rates since the mid-1970's have continued to improve which has also influenced the upward trend in stock biomass.

Although catches in Canadian waters have decreased about 50% in the past 5 years, catches in US waters have increased about 150% since 1978 due to both the US and distant-water fleets. Since catches by both the US and Canada have in the past been limited by economic factors, appropriate improvements in market conditions have the potential to

result in significant increases in catch by either country. Some of these improvements are now being observed in the US fishery by virtue of joint venture opportunities with European countries/companies. In addition, distant-water fleet catches in US waters will likely increase in the next several years as the TALFF becomes larger in response to the growing stock and the concomitant increased optimum yield as provided for by the present management scheme for mackerel (MAFMC 1983).

Projected catches in 1984 at realistic levels of fishing mortality (e.g. less than $F_{0.1} = 0.30$) result in continued rebuilding of the mackerel stock. Since current and projected levels of spawning stock biomass are well in excess of the minimum biomass constraint of 400,000 mt adopted as part of the management scheme for mackerel in US waters (MAFMC 1983), total catch (US and Canadian waters) can be as high as the level generated by fishing mortality at $F_{0.1} = 0.30$. The projected catch in 1984 corresponding to this level of F would be 132,000 mt.

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Table 1. Mackerel catch (mt) from NAFO SA 2-6 during 1960-82.

Year	US Commercial	US Recreational	Canada	Other countries	Commercial total	Grand total
1960	1,396	2,478	5,957	-	7,353	9,831
1961	1.361	3,022	5,459	11	6,831	9,853
1962	938	3,565	6,801	175	7,914	11,479
1963	1,320	3,981	6,363	1,299	8,982	12,963
1964	1,644	4,343	10,786	801	13,231	17,574
1965	1,998	4,292	11,185	2,945	16,128	20,420
1966	2,724	4,535	11,577	7,951	22,252	26,787
1967	3,891	4,498	11,181	19,047	34,119	38,617
1968	3,929	7,781	11,134	65,747	80,810	88,591
1969	4,364	13,050	13,257	114,189	131,810	144,860
1970	4,049	16,039	15,710	210,864	230,623	246,662
1971	2,406	16,426	14,942	355,892	373,240	389,666
1972	2,006	15,588	16,254	391,464	409,724	425,312
1973	1,336	10,723	21,619	396,759	419,714	430,437
1974	1,042	7,640	16,701	321,837	339,580	347,220
1975	1,974	5,190	13,544	271,719	287,237	292,427
1976	2,712	4,202	15,746	223,275	241,733	245,935
1977	1,377	522	20,362	56,067	77,806	78,328
1978	1,605	6,571	25,429	841	27,875	34,446
1979	1,990	3,315	30,244	440	32,674	35,989
1980	2,683	1,696	22,136	566	25,385	27,081
1981	2,941	4.000	19,294	5,361[1]	27,596	31,596
1982	3,330	4,000	16,379	6,647[2]	26,356	30,356

[1]Includes 3,979 mt taken by Poland.

[2]Includes 4,364 mt taken by Poland in a research fishery conducted with the NEFC.

Table 2. Mackerel catch (mt) in 1982 by country and subarea from NAFO SA 3-6.

	Subarea				
Country	3	4	5	6	Total
Canada (M)	-	12,588	-	-	12,588
Canada (N)	236	72	-	-	308
Canada (Q)	-	3,483	-	-	3,483
Italy	-	-	-	1,914	1,914
Japan	-	-	10	227	237
Poland	-	-	-	4,364[1]	4,364
Spain	-	-	2	127	129
US (comm)	-	-	1,013	2,317	3,330
USSR	-	3	-	-	3
Total	236	16,146	1,025	8,949	26,356
US (rec)					4,000
Grand total					30,356

[1]Taken in a research fishery in cooperation with the NEFC.

Table 3. Age composition (thousands of fish) of the 1982 mackerel catch from NAFO SA 3-6.

	SA 3-4			SA 5-6				
Age	Canada (N)	Canada (M+Q)[1]	Total	US (comm)	US (rec)[2]	Non-US	Total	SA 3-6 Total
0	-	-	-	-	1.8	12.1	13.9	13.9
1	-	1,984.8	1,984.8	77.0	525.7	1,401.8	2,004.5	3,989.2
2	4.0	3,920.4	3,924.4	3,901.1	1,443.2	1,683.8	7,028.1	10,952.6
3	14.6	1,608.5	1,623.1	500.6	396.5	488.6	1,385.7	3,008.7
4	25.5	4,261.6	4,287.1	1,374.8	1,228.8	2,434,8	5,038.4	9,325.5
5	10.9	686.4	697.3	122.8	167.8	285.7	576.3	1,273.6
6	12.1	2,314.9	2,327.0	65.1	387.3	159.9	612.3	2,939.2
7	27.0	3,480.9	3,507.9	206.7	638.4	492.0	1,337.1	4,845.1
8	87.8	4,317.8	4,405.6	774.7	1,175.8	2,566.9	4,517.4	8,922.9
9	33.1	1,248.3	1,281.4	285.3	382.6	954.1	1,622.0	2,903.4
10	34.6	464.6	499.2	157.4	183.6	552.9	893.9	1,393.1
11	22.5	182.1	204.6	78.8	82.7	261.8	423.3	627.9
12	13.4	108.0	121.4	36.2	49.1	165.8	251.1	372.4
13	29.4	237.7	267.1	103.7	108.0	341.0	552.7	819.9
14+	49.4	399.4	448.8	129.8	181.5	617.2	928.5	1,377.2
Total	364.2	25,215.3	25,579.5	7,814.0	6,952.8	12,418.4	27,185.2	52,764.6
Weight (mt)	308	16,074	16,382	3,330	4,000	6,644	13,974	30,356

[1] Includes 3 mt from USSR.

[2] Assumed same percentage age composition as SA 3-6 commercial total.

Table 4. Mackerel commercial and recreational catch at age (millions of fish) from NAFO SA 2-6 during 1962-82.

Year	Age 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total	Weight[1]	Mean age
1962	-	16.1	2.8	15.2	3.8	1.2	1.6	1.4	0.8	0.4	0.1	0.3	-	-	-	43.7	11.5	2.8
1963	-	1.1	4.2	1.3	26.3	6.0	0.3	0.2	0.2	0.2	0.1	0.1	-	-	-	40.0	13.0	4.1
1964	-	12.9	7.0	4.1	4.0	19.4	4.1	3.9	0.7	0.8	0.2	-	-	-	-	57.1	17.6	3.8
1965	-	9.0	3.6	2.9	4.0	5.2	19.5	4.2	4.0	0.7	-	-	-	-	-	53.1	20.4	4.7
1966	-	24.0	11.5	5.3	2.6	4.7	7.9	21.8	0.5	0.2	-	-	-	-	-	78.5	26.8	3.9
1967	1.8	0.8	26.7	19.8	3.5	3.3	5.1	6.1	32.3	0.3	-	-	-	-	-	99.7	38.6	4.3
1968	1.1	141.4	61.5	59.3	38.1	14.3	6.6	0.7	1.0	6.1	0.1	-	-	-	-	330.2	88.6	2.3
1969	4.0	7.1	262.1	160.7	65.8	5.7	3.0	2.0	3.1	2.2	8.3	-	-	-	-	524.0	144.9	2.8
1970	4.8	193.5	54.5	522.1	162.9	27.6	7.0	5.3	9.9	10.0	3.8	2.8	-	-	-	1,004.2	246.7	3.0
1971	2.4	74.6	294.2	127.4	558.9	203.5	34.6	8.9	3.6	4.3	8.1	7.2	-	-	-	1,327.7	389.7	3.6
1972	3.6	22.1	85.7	256.2	182.6	390.4	87.3	24.0	4.2	8.2	3.8	5.6	-	-	-	1,073.7	425.3	4.2
1973	4.0	161.8	283.2	285.1	233.6	192.4	197.2	31.2	11.0	4.1	3.8	1.6	-	-	-	1,409.0	430.4	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	-	-	-	1,075.8	347.2	3.8
1975	3.7	373.7	431.4	113.7	100.8	58.6	67.8	51.9	50.5	12.5	2.3	1.0	-	-	-	1,267.9	292.4	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	3.5
1977	-	2.0	27.0	101.0	54.0	12.0	9.9	5.6	6.3	3.8	3.6	0.3	0.3	-	-	225.8	78.3	3.8
1978	-	0.1	0.2	4.7	17.4	13.3	8.4	4.7	2.2	4.5	1.5	4.6	0.6	0.6	-	62.8	34.4	5.9
1979	-	0.4	0.6	1.3	7.1	18.6	13.1	6.2	2.6	2.2	2.2	0.6	1.8	0.5	0.9	58.1	36.0	6.2
1980	-	1.2	10.9	1.0	1.0	6.9	13.7	4.7	2.0	1.0	0.9	1.3	0.4	1.1	0.7	46.8	27.1	5.5
1981	+	10.1	4.7	8.4	1.9	2.7	7.7	12.6	5.4	2.6	0.9	0.4	0.3	0.7	0.8	59.2	31.6	5.1
1982	+	4.0	11.0	3.0	9.3	1.3	2.9	4.9	8.9	2.9	1.4	0.6	0.4	0.8	1.4	52.8	30.4	5.4

[1]Thousands of mt.

Table 5. Mean weight at age (kg) of the international mackerel catch from NAFO SA 2-6 during 1962-82.

Year	Age 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1962	-	.130	.208	.289	.365	.433	.491	.541	.581	.614	.641	.662	-	-	-
1963	-	.120	.192	.264	.334	.395	.448	.492	.529	.559	.583	.602	-	-	-
1964	-	.116	.188	.262	.332	.395	.450	.495	.533	.564	.588	-	-	-	-
1965	-	.123	.200	.278	.352	.419	.477	.525	.565	.598	-	-	-	-	-
1966	-	.128	.209	.294	.374	.447	.509	.562	.605	.641	-	-	-	-	-
1967	.057	.123	.202	.283	.360	.428	.489	.540	.581	.615	-	-	-	-	-
1968	.070	.148	.241	.335	.425	.506	.576	.634	.683	.722	.753	-	-	-	-
1969	.061	.131	.214	.300	.382	.456	.520	.574	.618	.654	.683	-	-	-	-
1970	.048	.107	.179	.253	.324	.389	.444	.491	.530	.562	.587	.608	-	-	-
1971	.050	.110	.181	.256	.327	.391	.446	.494	.532	.564	.589	.610	-	-	-
1972	.054	.123	.210	.300	.386	.464	.533	.590	.638	.677	.708	.733	-	-	-
1973	.051	.113	.189	.269	.345	.414	.473	.524	.565	.600	.628	.650	-	-	-
1974	.048	.111	.190	.273	.352	.425	.487	.541	.585	.621	.649	.673	-	-	-
1975	.045	.104	.176	.252	.326	.393	.451	.500	.540	.573	.600	.621	-	-	-
1976	-	.097	.168	.244	.316	.382	.440	.489	.530	.563	.590	.611	-	-	-
1977	-	.114	.198	.288	.375	.454	.524	.582	.631	.671	.703	.729	.749	-	-
1978	-	.192	.285	.425	.463	.509	.582	.625	.659	.673	.697	.717	.797	.705	-
1979	-	.190	.272	.531	.567	.579	.603	.652	.714	.752	.769	.822	.809	.842	.830
1980	-	.146	.376	.548	.609	.617	.635	.672	.705	.781	.743	.785	.773	.775	.778
1981	.072	.114	.315	.523	.577	.643	.660	.674	.707	.723	.756	.772	.812	.780	.801
1982	.065	.152	.340	.541	.606	.666	.743	.737	.722	.719	.740	.790	.811	.798	.829
1981-82[1]	.069	.133	.328	.532	.592	.655	.702	.706	.715	.721	.748	.781	.812	.789	.815

[1]Arithmetic mean

Table 6. Mean weight at age (kg) of the mackerel stock on 1 January in NAFO SA 2-6 during 1962-82.

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1962-77	.096	.177	.267	.355	.436	.508	.569	.620	.662	.696	.723	.745	-	-
1978	.141	.228	.359	.409	.462	.543	.594	.634	.657	.681	.706	.789	.699	-
1979	.132	.217	.438	.495	.527	.564	.619	.686	.730	.754	.809	.799	.834	.824
1980	.115	.307	.480	.545	.566	.596	.638	.679	.759	.729	.775	.766	.770	.774
1981	.093	.276	.461	.514	.589	.620	.645	.684	.706	.742	.762	.804	.774	.797
1982	.107	.285	.471	.551	.619	.698	.704	.700	.703	.728	.780	.802	.792	.824
1981-82[1]	.100	.281	.466	.533	.604	.659	.675	.692	.705	.735	.771	.803	.783	.811

[1]Arithmetic mean

Table 7. Stratified mean catch (kg) per tow of mackerel from NMFS, NEFC bottom trawl surveys in the spring (strata 1-25, 61-76) and autumn (strata 1-42, 49). See Figure 2 for location of sampling strata.

Year	Spring[1]	Autumn[2]
1963	-	.02
1964	-	<.01
1965	-	.03
1966	-	.04
1967	-	.15
1968	4.00	.10
1969	.06	.19
1970	2.04	.05
1971	1.97	.04
1972	1.33	.11
1973	.75	.05
1974	.77	.05
1975	.26	.01
1976	.32	.04
1977	.20	.04
1978	.45	.10
1979	.22	.06
1980	.35	.06
1981	1.84	.02
1982	.88	.13
1983	.27	.05

[1]Based on catches with No. 41 trawl; 1968-72 and 1982-83 catches were with No. 36 trawl and were adjusted to equivalent No. 41 catches using a 3.25:1 ratio (No. 41: No. 36).
[2]Based on catches with No. 36 trawl.

Table 8. Mackerel catch per standardized US day fished in NAFO SA 5-6.

Year	Catch per day (mt)
1964	.43
1965	.49
1966	.84
1967	1.75
1968	2.80
1969	1.92
1970	2.07
1971	1.29
1972	.84
1973	.53
1974	.17
1975	.53
1976	.59
1977	.52
1978	.48
1979	.69
1980	1.42
1981	1.19
1982	.86

Table 9. Data used in estimating fishing mortality (F) in 1982 for the NAFO SA 2-6 mackerel fishery. Catch per day, international catch, fishing effort, and F values apply to age 3 and older fish.

Year	US std. catch per day (mt)	International catch (thousands of mt)	Fishing effort[1] (thousands of days)	F[2]
1964	.36	14.8	41.0	.063
1965	.45	18.6	41.6	.080
1966	.67	21.3	31.9	.084
1967	1.50	33.0	22.0	.144
1968	1.67	52.8	31.6	.171
1969	1.16	87.7	75.5	.163
1970	1.81	216.0	119.2	.212
1971	1.09	328.2	301.9	.304
1972	.80	404.4	506.1	.344
1973	.44	358.4	812.7	.471
1974	(.44)[3]	290.5	655.8	.505
1975	.32	177.5	553.0	.451
1976	.44	185.3	417.3	.650
1977	.48	72.7	150.5	.258
1978	.43	34.3	79.8	.099
1979	.65	35.7	55.1	.115
1980	.57	22.8	40.0	.090
1981	.46	29.0	63.4	.109
1982	.57	26.0	45.5	(.107)[4]

[1]Expressed as equivalent US standardized days fished.

[2]Weighted mean fishing mortality for ages 3 and older obtained from virtual population analysis assuming F = 0.107 at ages 3 and older in 1982.

[3]Actual value of 0.14 replaced by 0.44 [see Anderson (1982) for explanation].

[4]Predicted from regression of fishing effort (f) on F for 1964-81:

$\ln F = -4.541 + 0.604 \ln f$, $r = 0.892$.

Table 10. Fishing mortality (F) and stock size (millions of fish) by age and year for mackerel in NAFO SA 3-6 derived from virtual population analysis (M = 0.20).

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Mean [1]
						Fishing mortality									
1962	.053	.011	.042	.142	.062	.086	.069	.145	.187	.050	.054	-	-	-	.054
1963	.007	.017	.006	.094	.346	.020	.014	.012	.049	.065	.065	-	-	-	.065
1964	.074	.053	.021	.025	.093	.423	.376	.061	.063	.063	-	-	-	-	.063
1965	.036	.026	.028	.026	.040	.127	1.054	.837	.080	-	-	-	-	-	.080
1966	.035	.059	.049	.032	.038	.079	.205	.322	.084	-	-	-	-	-	.084
1967	<.001	.050	.136	.042	.051	.053	.081	.525	.326	-	-	-	-	-	.144
1968	.031	.045	.151	.417	.238	.137	.009	.017	.175	.171	-	-	-	-	.171
1969	.004	.075	.157	.248	.100	.072	.056	.051	.047	.380	-	-	-	-	.163
1970	.094	.038	.209	.236	.156	.171	.174	.425	.231	.108	.212	-	-	-	.212
1971	.070	.202	.119	.362	.517	.299	.341	.172	.331	.296	.304	-	-	-	.304
1972	.019	.107	.272	.249	.464	.438	.349	.267	.729	.548	.344	-	-	-	.344
1973	.183	.352	.603	.427	.449	.452	.275	.267	.453	.929	.471	-	-	-	.471
1974	.073	.456	.653	.448	.383	.514	.484	.383	.245	.555	.505	-	-	-	.505
1975	.320	.534	.403	.562	.507	.413	.480	.438	.325	.130	.451	-	-	-	.451
1976	.061	.569	.783	.607	.649	.472	.466	.694	.358	.694	.109	-	-	-	.650
1977	.042	.181	.312	.342	.155	.239	.165	.121	.146	.088	.028	.031	-	-	.258
1978	.003	.005	.043	.081	.131	.155	.170	.090	.119	.079	.154	.072	.079	-	.099
1979	.002	.021	.043	.085	.116	.185	.164	.134	.122	.078	.041	.083	.079	.115	.115
1980	.014	.061	.044	.042	.111	.117	.093	.073	.070	.067	.060	.035	.067	.090	.090
1981	.019[2]	.069	.061	.111	.152	.174	.151	.147	.128	.083	.038	.018	.078	.109	.109
1982	.009[2]	.026[2]	.057	.089	.103	.243	.160	.151	.110	.094	.073	.049	.060	.107	.107

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Age 1+ Numbers	Age 1+ Weight[4]	Spawning stock[3] Numbers	Spawning stock[3] Weight[4]
						Stock size												
1962	345.3	275.9	411.4	31.7	22.1	21.5	23.3	6.5	2.6	2.2	6.3	-	-	-	1148.8	248.7	665.6	191.1
1963	182.5	268.3	223.4	323.2	22.5	17.0	16.1	17.8	4.6	1.8	1.8	-	-	-	1078.9	283.6	727.8	242.3
1964	199.7	148.5	215.9	181.8	240.9	13.0	13.7	13.0	14.4	3.6	-	-	-	-	1044.5	307.2	770.6	274.9
1965	281.0	151.9	115.3	173.1	145.3	179.7	7.0	7.7	10.0	-	-	-	-	-	1071.0	316.1	714.0	275.7
1966	759.0	222.0	121.1	91.8	138.1	114.3	129.6	2.0	2.7	-	-	-	-	-	1580.6	372.1	710.6	279.6
1967	1878.4	599.8	171.4	94.4	72.8	108.8	86.5	86.5	1.2	-	-	-	-	-	3099.7	556.4	921.4	323.0
1968	5045.9	1556.1	467.0	122.5	74.1	56.7	84.5	65.3	41.9	0.7	-	-	-	-	7514.6	1105.9	1690.6	483.8
1969	1947.6	4003.4	1218.7	329.0	66.1	47.8	40.4	68.6	52.6	28.8	-	-	-	-	7802.9	1511.2	3853.6	969.9
1970	2369.9	1591.5	3041.6	853.0	210.1	49.0	36.4	31.3	53.4	41.1	16.1	-	-	-	8293.4	1856.3	5127.8	1487.9
1971	1223.1	1765.9	1254.0	2020.3	551.8	147.2	33.8	25.1	16.8	34.7	30.2	-	-	-	7102.8	1889.2	4996.8	1615.5
1972	1301.3	934.2	1181.0	911.8	1152.3	269.5	89.4	19.7	17.3	9.9	21.1	-	-	-	5907.4	1665.2	4139.0	1457.6
1973	1062.6	1045.7	687.6	736.5	582.3	593.4	142.4	51.6	12.3	6.8	4.7	-	-	-	4926.1	1416.8	3340.6	1222.2
1974	1497.4	724.3	601.8	308.0	393.5	304.2	309.1	88.5	32.4	6.4	2.2	-	-	-	4267.8	1126.3	2408.2	918.4
1975	1498.3	1139.5	375.9	256.4	161.2	219.6	148.9	156.0	49.4	20.8	3.0	-	-	-	4029.0	949.5	1961.0	704.8
1976	233.0	890.9	546.7	205.7	119.7	79.5	119.0	75.4	82.4	29.2	14.9	-	-	-	2396.5	691.8	1718.0	590.6
1977	53.3	179.5	413.1	204.6	91.8	51.2	40.6	61.1	30.9	47.2	12.0	11.0	-	-	1196.1	416.9	1053.0	395.9
1978	38.9	41.8	122.6	247.5	119.0	64.3	33.0	28.2	44.3	21.8	35.4	9.5	8.7		815.2	370.2	775.4	360.0
1979	248.2	31.8	34.1	96.2	186.9	85.5	45.1	22.8	21.1	32.2	16.5	24.8	7.3	9.1	861.6	378.9	597.5	342.7
1980	96.7	202.8	25.5	26.8	72.3	136.3	58.2	31.3	16.3	15.3	24.4	13.0	18.7	9.0	746.6	354.6	548.5	312.4
1981	590.0[5]	78.1	156.2	20.0	21.0	53.0	99.2	43.4	23.9	12.5	11.7	18.8	10.3	8.5	1146.5	362.4	517.4	296.8
1982	510.0[5]	474.0	59.7	120.3	14.6	14.8	36.5	69.9	30.7	17.2	9.4	9.2	15.1	15.2	1396.6	451.4	649.6	329.3
1983	930.0[5]	413.9	378.1	46.2	90.1	10.8	9.5	25.5	49.2	22.5	12.8	7.2	7.2	22.8	2025.8	586.7	888.8	473.0

[1] Weighted mean F at ages 3 and older.

[2] Determined from predicted year-class size and known catch.

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

[4] Thousands of mt.

[5] Predicted.

Table 11. Stratified mean catch (numbers) per tow of age 0, 1, and 2 mackerel from NMFS, NEFC autumn and spring bottom trawl surveys, survey values adjusted to equivalent age 1 values on 1 January (see Anderson 1982), the geometric mean of the adjusted values, and year-class size at age 1 (millions of fish) from virtual population analysis (VPA) assuming F = 0.107 at ages 3 and older in 1982.

Year class	Mean catch per tow			Adjusted mean catch per tow				VPA
	Autumn age 0	Spring age 1	Spring age 2	Autumn age 0	Spring age 1	Spring age 2	Geometric mean	age 1
1963	.053	-	-	.473	-	-	.473	199.7
1964	.009	-	-	.082	-	-	.082	281.0
1965	.055	-	-	.482	-	-	.482	759.0
1966	.088	-	1.726	.773	-	1.822	1.187	1878.4
1967	.619	40.240	.198	5.482	42.290	.218	3.697	5045.9
1968	.039	.238	2.625	.345	.249	2.815	.623	1947.6
1969	.289	1.010	2.779	2.536	1.091	3.457	2.123	2369.9
1970	.023	.929	1.368	.200	1.002	1.626	.688	1223.1
1971	.068	1.894	.787	.591	2.008	.979	1.051	1301.3
1972	.076	.915	.383	.664	1.041	.629	.758	1062.6
1973	.236	.826	1.277	2.064	.907	1.975	1.546	1497.4
1974	.089	3.186	.787	.773	4.041	1.697	1.744	1498.3
1975	.009	.204	.109	.082	.224	.140	.137	233.0
1976	.012	.021	.221	.109	.023	.246	.085	53.3
1977	.045	.128	.009	.400	.136	.010	.082	38.9
1978	.264	.029	.406	2.300	.031	.432	.313	248.2
1979	.028	.066	.243	.245	.070	.267	.166	96.7
1980	.036	.647	.424	.318	.691	.461	.466	(594.9) [1]
1981	.013	.799	.598	.118	.845	.642	.400	(508.1) [1]
1982	.108	.526	-	.936	.554	-	.720	(929.0) [1]
1983	.007	-	-	.064	-	-	.064	(66.1) [1]

[1] Predicted from functional (geometric mean) regression between geometric mean of adjusted mean catch per tow and year-class size for the 1963-79 year classes: $Y = -18.061 + 1315.308\ X$, $r = 0.943$.

Table 12. Percentage of fishing mortality (F) at age relative to the weighted mean F at ages 3 and older for the mackerel fishery in NAFO SA 2-6 during 1962-82.

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1962	98	20	78	263	115	159	128	268	346	93	100	-	-	-
1963	11	26	9	145	532	31	22	18	75	100	100	-	-	-
1964	117	84	33	40	148	671	597	97	100	100	-	-	-	-
1965	45	33	35	33	50	159	1318	1046	100	-	-	-	-	-
1966	42	70	58	38	45	94	244	383	100	-	-	-	-	-
1967	<1	35	94	29	35	37	56	365	226	-	-	-	-	-
1968	18	26	88	244	139	80	5	10	102	100	-	-	-	-
1969	2	46	96	152	61	44	34	31	29	233	-	-	-	-
1970	44	18	99	111	74	81	82	200	109	51	100	-	-	-
1971	23	66	39	119	170	98	112	57	109	97	100	-	-	-
1972	6	31	79	72	135	127	101	78	212	159	100	-	-	-
1973	39	75	128	91	95	96	58	57	96	197	100	-	-	-
1974	14	90	129	89	76	102	96	76	49	110	100	-	-	-
1975	71	118	89	125	112	92	106	97	72	29	100	-	-	-
1976	9	88	120	93	100	73	72	107	55	107	17	-	-	-
1977	16	70	121	133	60	93	64	47	57	34	11	12	-	-
1978	3	5	43	82	132	157	172	91	120	80	156	73	80	-
1979	2	18	37	74	101	161	143	117	106	68	36	72	69	100
1980	16	68	49	47	123	130	103	81	78	74	67	39	74	100
1981	17	63	56	102	139	160	139	135	117	76	35	17	72	100
1982	8	24	53	83	96	227	150	141	103	88	68	46	56	100
1981-82[1]	12	44	54	92	118	194	144	138	110	82	52	32	64	100

[1]Arithmetic mean.

Table 13. Various levels of projected catch of mackerel in 1984 in NAFO SA 2-6 and associated mean fishing mortality (F) at ages 3 and older, with resulting spawning stock biomass in 1985 and the percentage change from 1984. These projections assume a 1983 catch of 28,640 mt (F = 0.080). Catch and stock biomass are expressed as thousands of mt.

Spawning stock in 1984	Catch in 1984	F in 1984	Spawning stock in 1985	% change in stock from 1984
562.6	20.0	.041	686.3	+ 22.0
562.6	30.0	.062	676.5	+ 20.2
562.6	38.5	.080[1]	668.2	+ 18.8
562.6	40.0	.083	666.8	+ 18.5
562.6	50.0	.105	657.1	+ 16.8
562.6	60.0	.127	647.3	+ 15.1
562.6	70.0	.149	637.6	+ 13.3
562.6	80.0	.172	627.9	+ 11.6
562.6	90.0	.196	618.1	+ 9.9
562.6	100.0	.220	608.4	+ 8.1
562.6	110.0	.244	598.6	+ 6.4
562.6	120.0	.269	588.8	+ 4.7
562.6	132.0	.300[2]	577.1	+ 2.6

[1] Level of F projected for 1983.

[2] $F_{0.1}$ applicable to average 1981-82 (current) conditions.

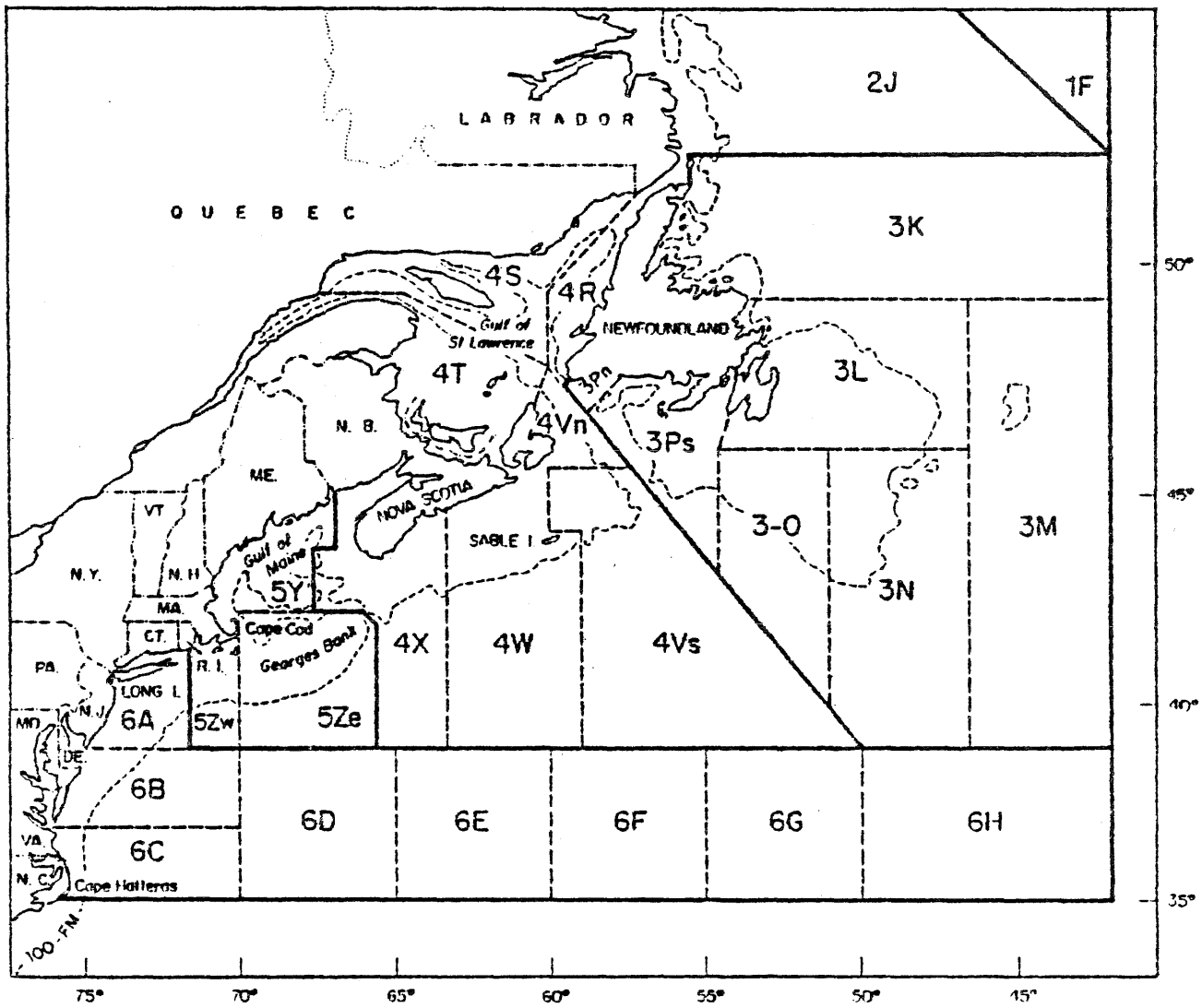

Figure 1. Northwest Atlantic from Labrador to North Carolina showing NAFO SA 2-6.

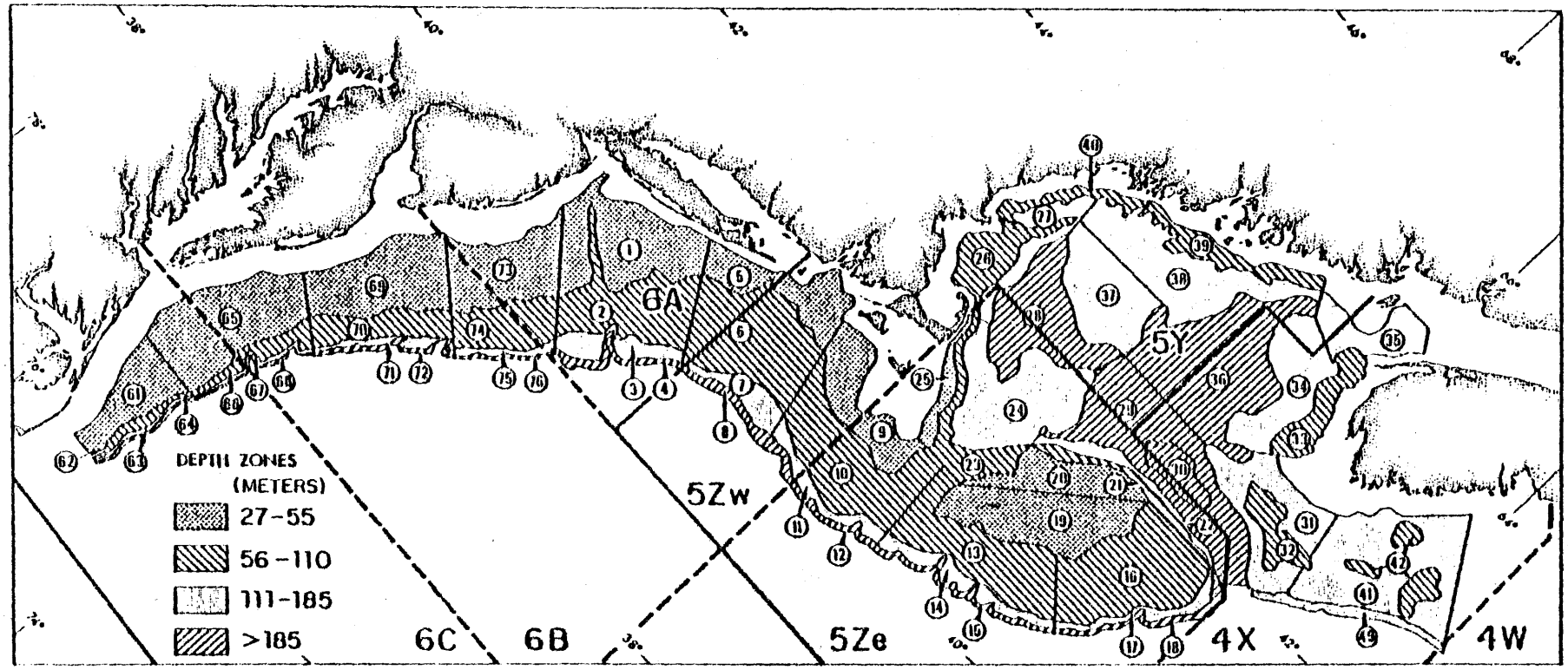

Figure 2. NMFS, NEFC bottom trawl survey sampling strata in the Northwest Atlantic between Cape Hatteras and Nova Scotia.

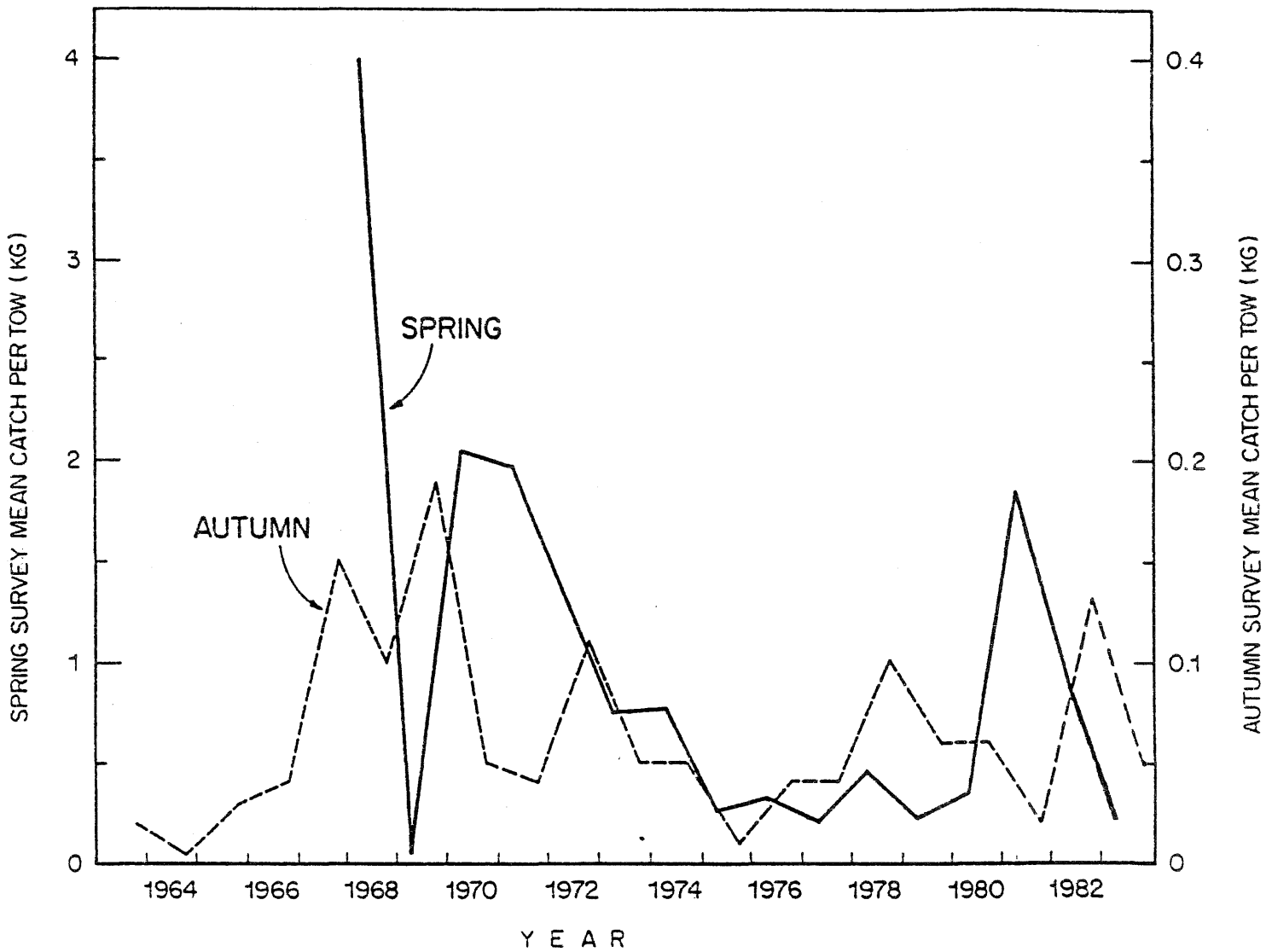

Figure 3. Mean catch per tow (kg) of mackerel from NMFS, NEFC spring (1968-83) and autumn (1963-83) bottom trawl surveys in NAFO SA 4-6.

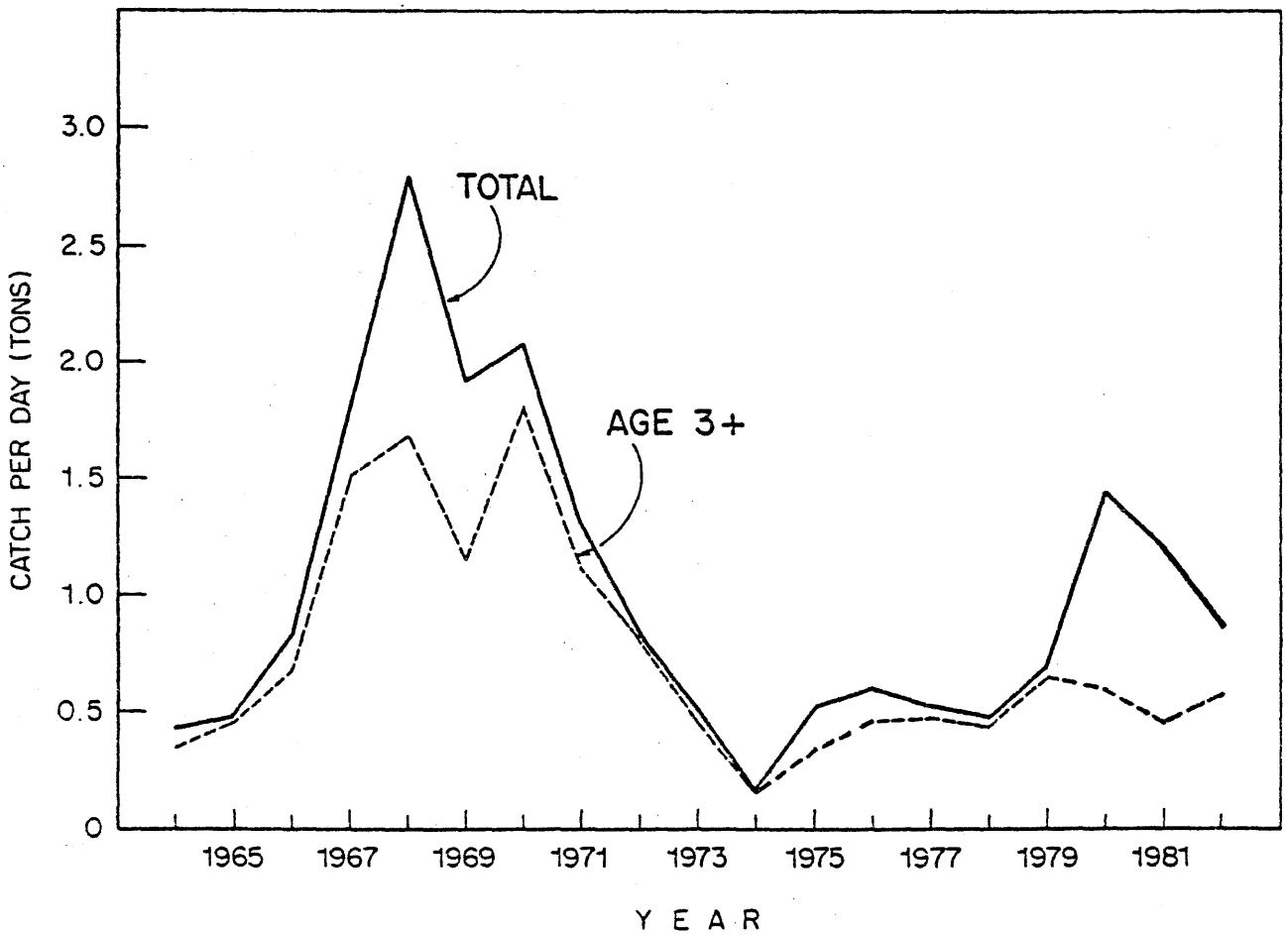

Figure 4. Catch per standardized day fished for (1) all ages (total) and (2) ages 3 and older in the US commercial mackerel fishery in NAFO SA 5-6.

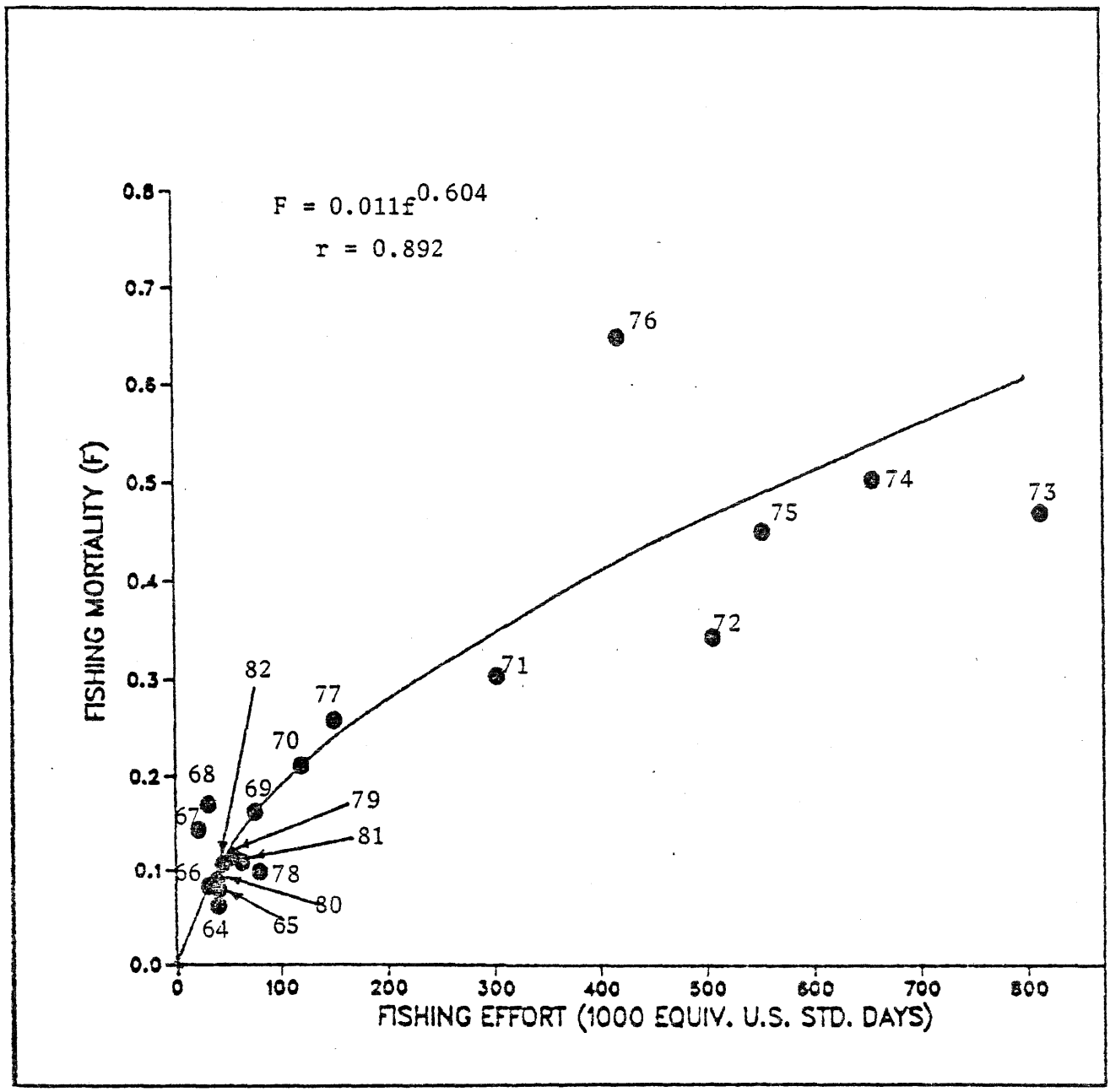

Figure 5. Relationship between mean fishing mortality for age 3 and older mackerel from VPA assuming mean F = 0.107 at ages 3 and older in 1982 (M = 0.20) and fishing effort directed towards ages 3 and older expressed as equivalent US standardized days fished.

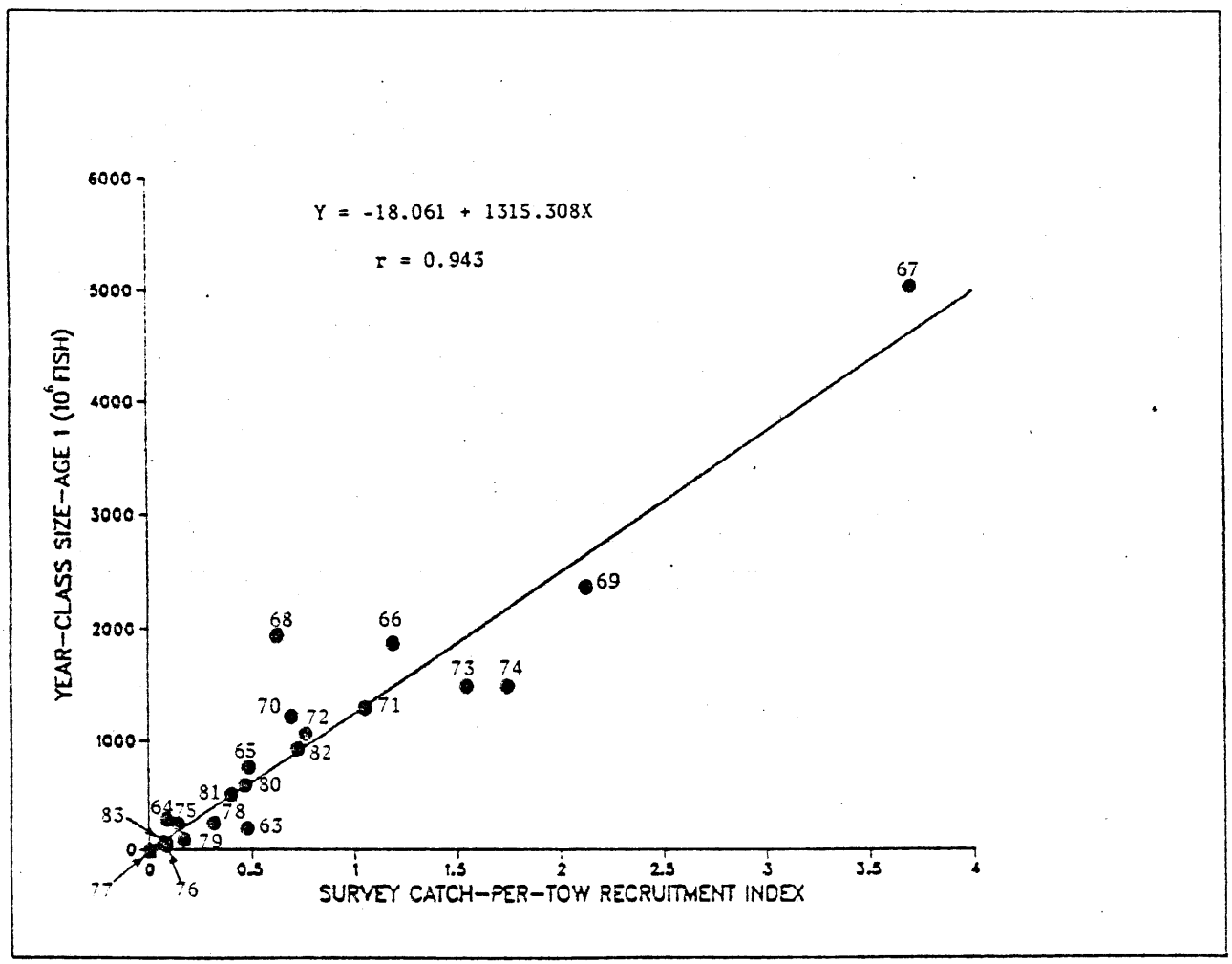

Figure 6. Relationship between mackerel year-class size at age 1 from VPA assuming mean F = 0.107 at ages 3 and older in 1982 (M = 0.20) and a catch-per-tow recruitment index from NMFS, NEFC autumn and spring bottom trawl surveys in NAFO SA 4-6.

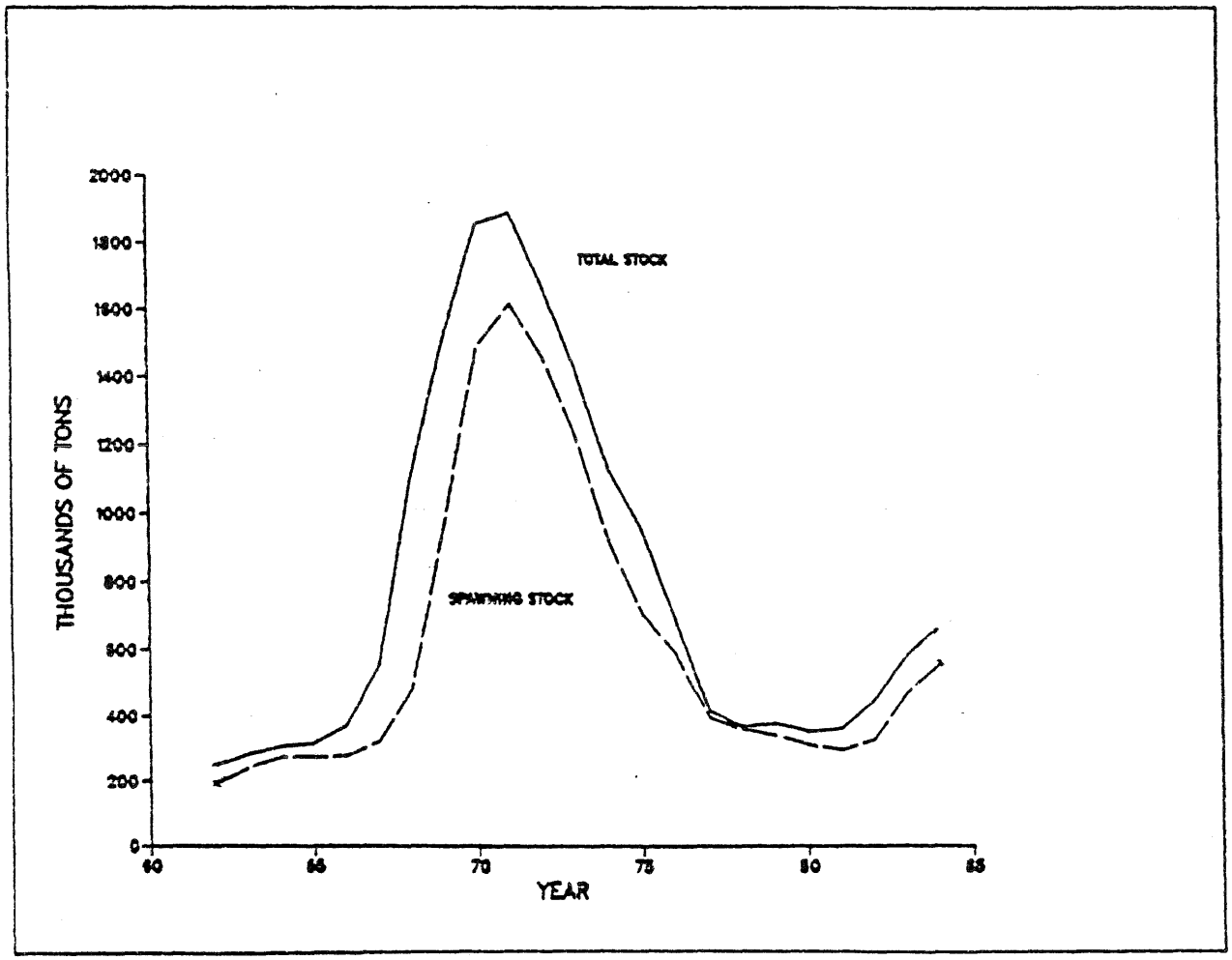

Figure 7. Total stock biomass (ages 1 and older) and spawning stock biomass (50% age 2 and 100% age 3 and older) of mackerel in NAFO SA 2-6 during 1962-84 estimated from VPA and biomass projections.

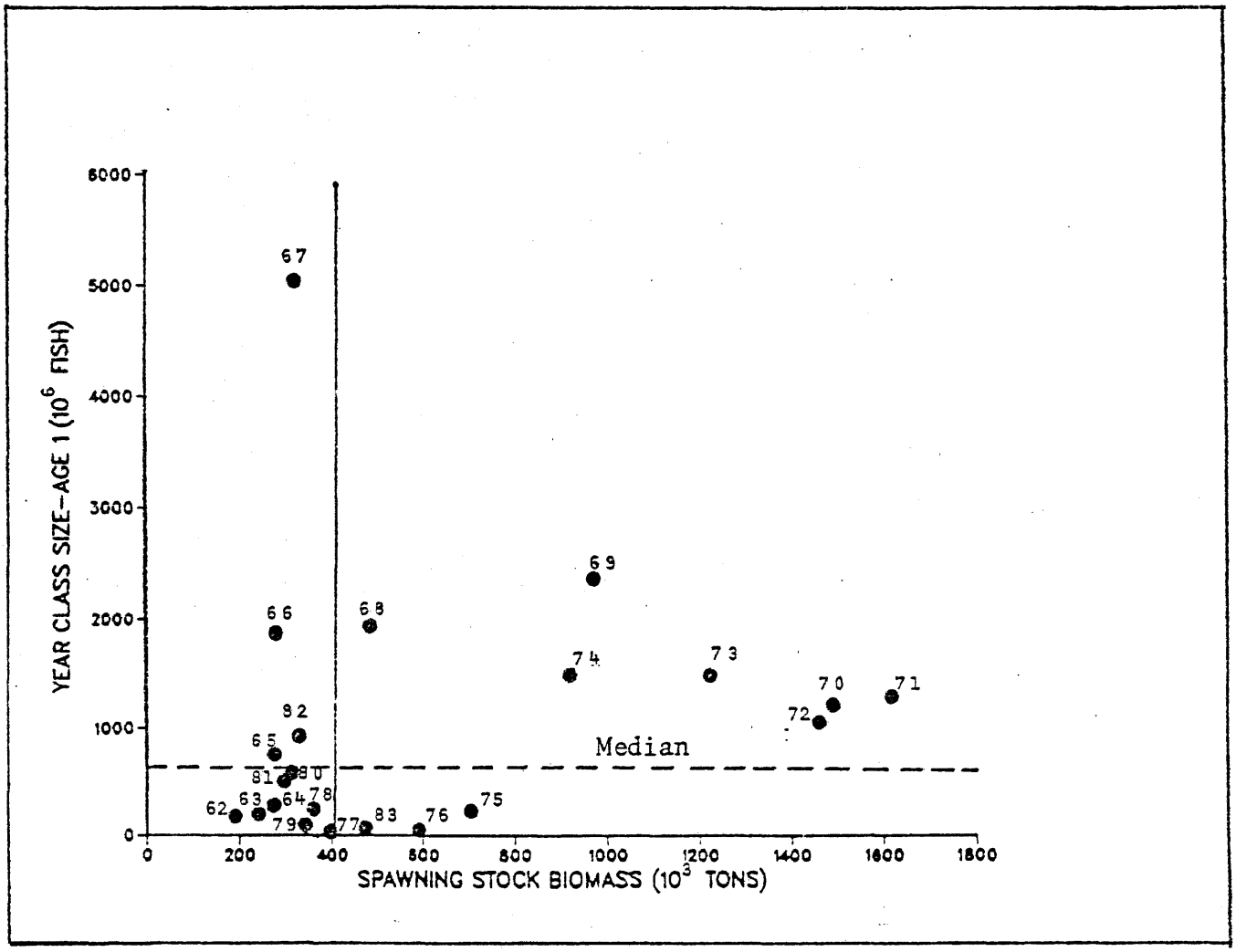

Figure 8. Relationship between mackerel year-class size at age 1 and the parental spawning stock biomass during 1962-83 in NAFO SA 2-6.

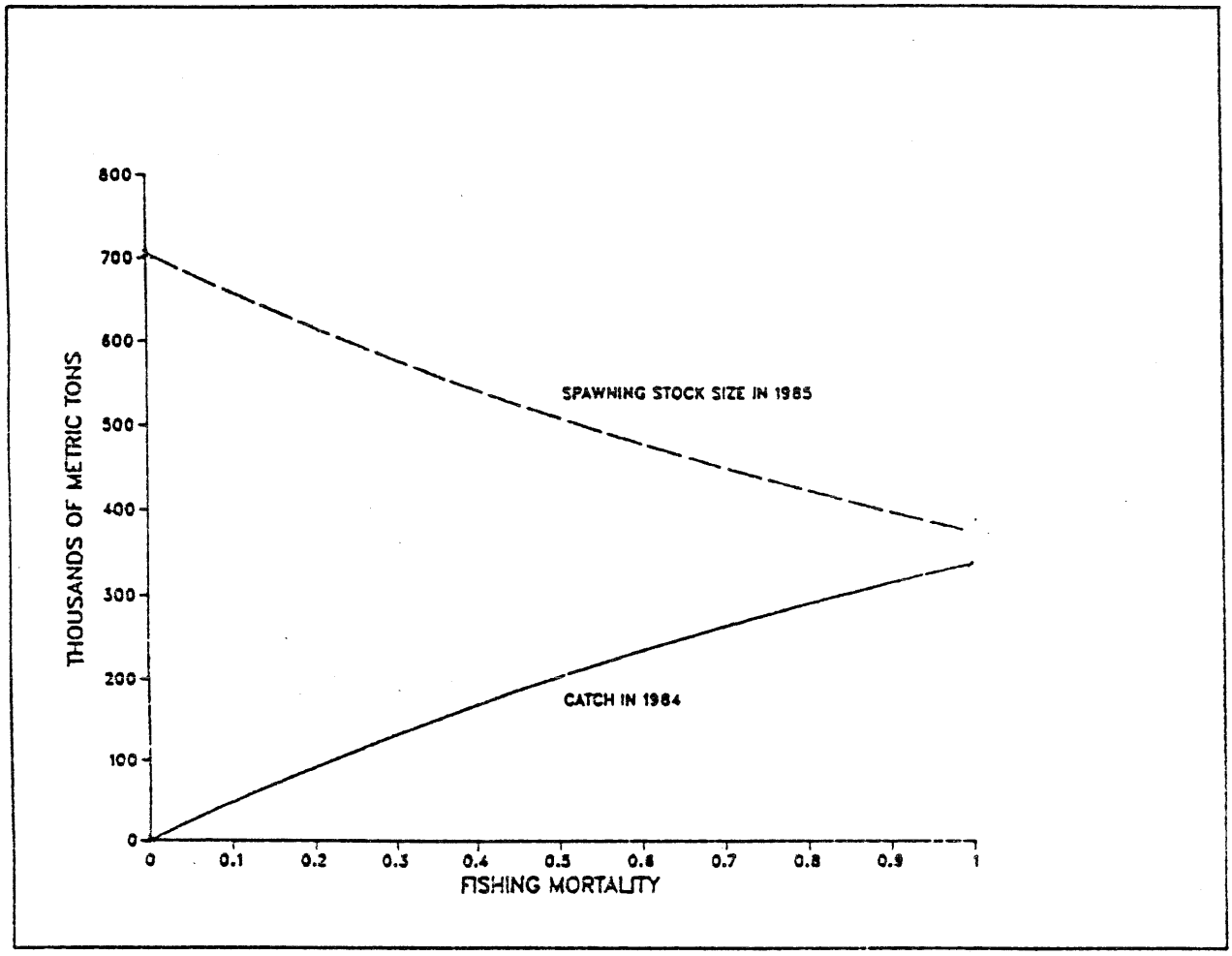

Figure 9. Projected catch in 1984 and resultant spawning stock in 1985 at variable levels of fishing mortality in 1984 (mean F at ages 3 and older) for the mackerel stock in NAFO SA 2-6. Projections assume a 1983 catch of 28,640 mt (F = 0.080).