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STATUS OF THE NORTHWEST ATLANTIC MACKEREL STOCK - 1984

by

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SUMMARY

The international catch (commercial and recreational) of Atlantic mackerel (Scomber scombrus) in the Northwest Atlantic increased from about 27,500 metric tons (mt) in 1982 to 32,500 mt in 1983. Canada and the United States (US) accounted for 61% and 21%, respectively, of the 1983 total. The total catch in 1984 is estimated to be 38,500 mt.

Age 2 fish comprised 26% of the 1983 catch in numbers followed by age 9 with 19%. Ages 3, 5, 8, and 10 collectively accounted for 40% of the total catch in 1983.

Catch per tow (kg) of mackerel in NEFC spring and autumn bottom trawl surveys increased sharply from 1983 to 1984. Catch per day (mt) of mackerel in the US commercial fishery increased from 1982 to 1983.

Mean annual fishing mortality (F) at ages 3 and older was estimated to be 0.06 in 1983 (M=0.20) compared to an average of 0.08 during 1978-82. Separable virtual population analysis indicated a fairly consistent dome-shaped exploitation pattern during 1978-83 with maximum F occurring generally at ages 6-7. The estimated catch of 38,500 mt in 1984 would result in a $\bar{F}_{3-14+}$ of 0.05.

The 1980-82 and 1984 year classes are much stronger than any produced since 1974. The 1982 and 1984 year classes appear to be the strongest since 1969. The 1983, 1977, 1976, and 1979 year classes are all very weak.

Total stock biomass increased from about 475,000 mt in 1980 to nearly 1,200,000 mt at the beginning of 1985 (147% increase). Spawning stock biomass increased from about 400,000 mt in 1981 to 1,000,000 mt in 1985 (149% increase).

Equilibrium yield simulations indicate that, under the average 1978-83 exploitation pattern, $F_{0.1} = 0.29$. Long-term equilibrium yield at this level of F, assuming constant recruitment at the 1962-84 average level, would be 134,000 mt per year.

Projections for 1985 indicate that if fishing mortality remains equivalent to the 1984 level, the catch would be about 54,000 mt. Fishing mortality at $F_{0.1}$ in 1985 would result in a catch of about 270,000 mt and a spawning stock biomass of 844,000 mt in 1986 (16% decrease from 1985).

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, commercial 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 (1983).

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 based 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 provided 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), was implemented on 7 February 1984. The specification of optimum yield (OY), domestic annual harvest (DAH), 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.

The initial specifications for the 1984-85 fishing year included an AC of 87,000 mt, an OY of 83,500 mt, a DAH of 26,500 mt, a TALFF of 28,500 mt, and a reserve of 28,500 mt.

CATCH

Commercial

The international commercial catch in SA 2-6 increased about 12% from 26,356 mt in 1982 to 29,545 mt in 1983 (Table 1). The 1983 catch was the highest since 1979 and about 6% above the 1972-82 mean of 27,980 mt.

About 67% of the 1983 catch was from Canadian waters in SA 3-4, with 26% each from the east coast of Newfoundland (Divs. 3KL) and the Gulf of St. Lawrence area (Divs. 4RT and Subdiv. 4Vn) (Table 2) mainly during June-November. About 81% of the 1983 catch in US waters (SA 5-6) was from SA 6, with 92% taken during February-May.

The Canadian catch in 1983 of 19,785 mt represented a 21% increase from 1982, but was only 65% of the peak of 30,244 mt in 1979 (Table 1). The US catch increased from 1,377 mt in 1977 to 3,805 mt in 1983, the highest since 1970. Catches by countries other than Canada and the US totalled 5,955 mt in 1983, a 10% decrease from 1982. All but 20 mt of this was taken in US waters.

The international commercial catch in 1984 was estimated to be about 35,500 mt, a 20% increase from 1983 and the highest since 1977. The US catch was estimated to be 5,000 mt, the highest since 1952 and a 31% increase from 1983, reflecting increased participation by US vessels in joint ventures with European companies. The estimated Canadian catch was only 14,500 mt, a 27% decrease from 1983, reflecting a poor Canadian market for mackerel in 1984. Catches in 1984 by other countries were estimated to total 16,000 mt, the highest since 1977 and a 170% increase from 1983. This total includes 5,531 mt taken by Poland in a research fishery for mackerel conducted in cooperation with the NEFC and about 9,100 mt taken by GDR and the Netherlands.

Recreational

Estimates of the annual US recreational catch of mackerel between Maine and North Carolina since 1960 are given in Table 1. The sources of and basis for the 1960-78 estimates are described by Anderson (1980). Estimates for 1979-82 were obtained from results of the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) conducted in those years (U.S. Dept. of Commerce 1984; Holliday[1]). The 1979-82 estimates varied between 1,131 mt (1982) and 5,052 mt (1981) and averaged 3,072 mt per year. In the absence of results from the MRFSS, the catch in each year after 1982 was assumed to be 3,000 mt.

Total

The total international catch in SA 2-6 increased from 27,487 mt in 1982 to 32,545 mt in 1983 (Table 1). Catches during 1978-83 remained relatively stable averaging 31,900 mt per year. Canada and the US accounted for 61% and 21%, respectively, of the 1983 total.

The estimated catch in 1984 was 38,500 mt, an 18% increase from 1983.

CATCH COMPOSITION

Length frequency samples from US commercial catches in 1983 were obtained during June (5), July (2), November (3), and December (3) from Div. 5Y, during January (1) from Subdiv. 5Ze, during May (2), August (3),

[1]Mark C. Holliday, National Marine Fisheries Service, Washington, DC, personal communication.

and November (2) from Subdiv. 5Zw, during February (5), March (1), May (8), and November (1) from Div. 6A, and during March (1) from Div. 6B. A total of 4,008 lengths was represented in these 37 samples; sampled catches were from trawls, gill nets, purse seines, pound nets, floating traps, and hand lines.

Length frequency samples were collected in 1983 by NMFS foreign fisheries observers during January (8), February (17), and March (17) aboard Italian (22), Spanish (12), and Japanese (8) vessels fishing in SA 5-6 (42 samples, 3,255 lengths). In addition, observers collected 24 samples (2,291 lengths) from GDR vessels and 25 samples (2,531 lengths) from US vessels participating in a mackerel joint venture during February-April 1983.

A total of 193 samples (31,868 lengths) was collected by NMFS and Polish scientists aboard two Polish factory trawlers during the US-Poland research fishery for mackerel conducted during February-May 1983 in SA 5-6.

US commercial length frequency samples were summed by NAFO division/ subdivision - month - gear category and expanded to estimate numbers caught at length in each category. Italian, Spanish, and Japanese samples were summed across countries by month and applied to the respective monthly catches (summed across countries) to obtain expanded numbers at length. Length frequencies from catches by these three countries were quite similar since they came from the same general area and were caught by trawls having the same size mesh in the codends. Length samples from individual tows by GDR and US vessels in the mackerel joint venture were expanded to the tow weight, summed across sampled tows, and raised to include non-sampled tows. In the Polish research fishery where sampling was rather intensive (75% of all tows were sampled), individual samples were expanded to the tow weight and any unsampled tow was assumed to have the same length frequency as the closest (in time and distance) sampled tow.

Age/length keys for 1983 were prepared for the first and second quarters combined using sampling data from Polish, GDR, Italian, and US commercial catches and for the third and fourth quarters combined using US and Canadian commercial age/length data (Maguire[2]). Age data were combined for the first and second quarters because of relatively little growth during that time; third and fourth quarter data were combined because of insufficient data for each quarter separately. These keys were applied to the above expanded length frequencies to obtain numbers at age (Table 3). The summed numbers at age from the sampled US commercial catches (by NAFO division or subdivision, month, and gear) for the entire year were raised to the total catch in tons.

Numbers at age from the 1983 Canadian catch were obtained from Maguire (see footnote 2) based on length and age samples collected in various areas and time periods.

The percentage age composition of the US recreational catch in 1983 was assumed to be the same as the SA 3-6 commercial total (Table 3). Although length frequency samples have been collected by the NMFS MRFSS since 1979, they have not been available for analysis.

Numbers at age for the 1983 international catch are given in Table 3. The 1981 year class at age 2 comprised 26% of the catch in numbers, followed by the 1974 year class (age 9) with 19%, the 1978 year class (age 5) with 13%, and the 1980 (age 3), 1975 (age 8), and 1973 (age 10) year classes

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[2] J. J. Maguire, Department of Fisheries and Oceans, Fisheries Research Branch, Quebec, P.Q., Canada, personal communication.

with 10%, 9%, and 8%, respectively. The Canadian catch in SA 3-4 had the greatest contribution in numbers from age 9 fish (24%), followed by age 5 (15%), age 3 (13%), age 8 (12%), age 10 (10%), and age 2 (9%). Both the US and non-US commercial catches in SA 5-6 were dominated by the 1981 year class (age 3).

The international numbers-at-age catch data for 1962-83 for SA 2-6 are given in Table 4.

MEAN WEIGHTS AT AGE

Estimated mean weights for ages 1-14+ in the international catch from SA 2-6 during 1962-83 are given in Table 5, and mean weights at age of the stock on 1 January are given in Table 6 (see Anderson 1982 for method).

Mean weights at age increased beginning in 1977 and have since remained at levels higher than observed previously, although a noticeable decrease occurred from 1982 to 1983, particularly at the younger ages. The higher mean weights at age in the catch since 1977 are a reflection of either increased growth rates, capture later in the year, or a combination of the two factors.

Following extended jurisdiction in 1977 by Canada and the US, there was a sharp drop in catch during the winter and spring in US waters (distant-water-fleet fishery) and a resultant sharp increase in the proportion of the total catch taken in Canadian waters later in the year (traditional Canadian fishery). During 1970-76, the proportion of the total catch taken annually in Canadian waters averaged only 10%, with 50% of the annual catch taken, on average, by early April. During 1978-83, the catch in Canadian waters averaged 70% of the total and 50% of the annual catch was not taken, on average, until late July. Previous growth studies, summarized by Anderson and Paciorkowski (1980), indicate that length at age as well as weight at length are greater for mackerel sampled during summer and autumn in Canadian waters than for those sampled in the winter in US waters. Therefore, the shift in time and area of capture during 1978-83 resulted in an increase in mean weights at age of the catch.

Some of the increase in mean weight at age in recent years could also be the result of density-dependent growth. MacKay (1973) and Dery and Anderson (1983) have found an inverse relationship between growth and year-class size. The recent increase in mean weight at age occurred at a time when a series of relatively weak year classes entered the fishery. The decrease in mean weight at age from 1982 to 1983 could be due in part to improved year-class sizes beginning in 1980 and to an increase in stock biomass in the last several years.

The 1982-83 average mean weights at age for catch (Table 5) and stock (Table 6) were used in calculating projected catches in 1984-85 and stock biomass in 1984-86.

STOCK BIOMASS INDICES

Research Vessel Survey Catch Per Tow

Indices of mackerel stock biomass have been calculated from catches made during NEFC spring and autumn bottom trawl surveys. In previous assessments (e.g., Anderson 1983), spring indices were based on catches in sampling strata 1-25 and 61-76 (Figure 2) and autumn indices were based on catches in strata 1-42 and 49. In the present assessment, catch data from inshore strata (Figure 3), obtained from surveys conducted by the NEFC since the mid-1970's, were combined with those from offshore strata to take advantage of significant catches of mackerel in inshore strata and hopefully improve the survey indices. The revised spring indices were based on catches from inshore strata 1-66 (Cape Hatteras, North Carolina to Cape Ann, Massachusetts) and the previously-used offshore strata, and autumn indices were based on catches from inshore strata 1-14 and 45-66 (Manasquan Inlet, New Jersey to Cape Ann) and the previously-used offshore strata. The inshore strata sets reflected those areas in which mackerel were caught during the respective surveys.

In addition to combining the inshore and offshore survey data, the 1973-81 spring catches (kg), taken with a No. 41 trawl, were adjusted to equivalent No. 36 trawl catches using a 3.25:1 ratio (41:36) (Anderson 1976).

Although a consistent time-series of inshore survey data collected with either a No. 36 or a No. 41 trawl did not begin until 1976, the entire time-series of both spring (1968-84) and autumn (1963-84) indices were adjusted to reflect the inclusion of inshore catch data. Catch-per-tow (kg) indices were calculated for spring and autumn for 1976-84 based on (1) offshore strata and (2) inshore and offshore strata combined. Ratios between offshore and inshore-offshore indices indicated that the spring inshore-offshore indices averaged 1.03 times smaller than the offshore indices and the autumn inshore-offshore indices averaged 1.09 times larger than the offshore indices. These average ratios were used to adjust the respective spring and autumn offshore indices prior to 1976 to equivalent inshore-offshore indices.

Besides incorporating additional catches of mackerel into the survey indices, inclusion of the inshore strata also resulted in a decrease in the variance of the stratified mean catch per tow. During 1976-84, the coefficient of variation decreased, on average, 8.5% for the spring catch per tow and 7.6% for the autumn catch per tow.

Spring catch per tow rose sharply from 0.13 kg in 1983 to 0.83 kg in 1984, the highest index since 1971 (Table 7, Figure 4). Although the spring index has fluctuated markedly since 1980, it has exhibited a pronounced upward trend. Autumn catch per tow increased from 1983 (0.03 kg) to 1984 (0.08 kg). This index has also fluctuated considerably in recent years, but has also displayed an increasing trend, although to a lesser extent than the spring index. Both indices exhibit year-to-year changes which reflect both the variability in the timing of seasonal migrations relative to the timing of the survey and the inherent variability of mackerel catches in the NEFC bottom trawl survey. The increasing trend in both of these indices in recent years, however, is a reflection of increasing stock biomass.

US Commercial CPUE

The standardized US commercial catch-per-day index (all ages) (Anderson 1976), derived by standardizing effort from various gear-tonnage categories to that of floating traps tended by 0-50 GRT vessels, increased from 0.86 mt in 1982 to 1.08 mt in 1983 (Table 8, Figure 5). Although CPUE rose sharply in 1980 and fell almost as abruptly in 1981 and 1982, the indices in 1980-83 were all higher than any since 1971 and are reflective of an increase in stock biomass in recent years.

Standardized US CPUE for ages 4 and older (Table 9, Figure 5) increased from 0.31 mt in 1981 to 0.51 mt in 1982 and to 0.53 mt in 1983. This index has generally been similar to the CPUE for all ages, except during 1968-70 and 1980-81 when about 68% of the CPUE for ages 1 and older was due to ages 1-3 and during 1982-83 when 46% was attributed to ages 1-3. CPUE for ages 4 and older has undergone a net increase since the mid-1970's.

NATURAL MORTALITY

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

FISHING MORTALITY

Mean instantaneous fishing mortality (F) for ages 4 and older in 1983 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 (Figure 6). F values for ages 4 and older from VPA were weighted by stock size at age (numbers) to obtain a mean annual F ($\bar{F}_{4-14+}$). Annual fishing effort directed towards ages 4 and older was determined by dividing the international catch (mt) at ages 4 and older by US standardized catch per day for ages 4 and older (Table 9).

Separable virtual population analysis (SVPA) (Pope and Shepherd 1982; Anonymous 1983; Shepherd and Stevens 1983) was used to estimate the exploitation pattern (pattern of F at age) of the fishery in 1983. A data set comprised of ages 3-10 during 1978-83 and input parameters of age 5 for the terminal F reference age and a selection factor (S) of 1.0 at age 10 in the last year (1983) were found to be most suitable. The approximate coefficient of variation (CV) of the log catch data was 26%. Only three of the 35 log catch ratio residuals were in excess of the recommended level of 2 $\log_e$ (1 + CV/100), with all of these occurring in 1982-83. The results indicate a fairly consistent set of catch-at-age data and a relatively constant dome-shaped exploitation pattern during 1978-83. These years represent a period of very low and stable catches relative to earlier years.

The exploitation pattern at ages 4-13 in 1983 from the extended analysis of the SVPA (using terminal populations option) (Anonymous 1983) was used to factor the terminal F for 1983 for use in the conventional VPA, as this pattern fits the 1983 catch data exactly. Values of $\bar{F}_{4-14+}$ in 1964-82, determined from conventional VPA using trial F values at ages 4 and older in 1983, were regressed (functional power curve) against fishing effort in order to predict the $\bar{F}_{4-14+}$ for 1983. The VPA-regression process was followed through several iterations until the $\bar{F}_{4-14+}$ predicted by the regression for 1983 remained unchanged from the 1983 $\bar{F}_{4-14+}$ used in the previous VPA. Since the extended analysis of the SVPA extends the exploitation pattern calculated for the 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 1983 and for age 13 in 1978-82. F values at age 14+ in 1979-83 and at the oldest age in years prior to 1976 were assumed equal to the $\bar{F}_{3-14+}$ in that year. A value of $\bar{F}_{4-14+}$ = 0.105 was thus estimated for 1983 (Table 9, Figure 6).

Age-specific F values estimated for 1962-83 are given in Table 10. The $\overline{F}_{3-14+}$ increased from an average of 0.061 in 1962-64 to a high of 0.586 in 1976 before dropping to an average of 0.075 during 1978-82 and to 0.056 in 1983. The values for $\overline{F}_{4-14+}$ (Table 9) were slightly higher than for $\overline{F}_{3-14+}$, increasing from an average of 0.094 during 1962-64 to 0.528 in 1976 before dropping to average 0.081 in 1978-82.

RECRUITMENT

The sizes of the 1961-79 year classes at age 1, estimated from VPA, ranged from 43 million (1977 year class) to 5,081 million fish (1967 year class) (Table 10), with a mean size of 1,093 million and a median size of 740 million. The estimates for the strongest and weakest year classes differed by a factor of 117. The 1975-79 year classes were all below the mean and median levels (range = 43-317 million, average = 166 million).

Catch-per-tow indices for age 0 mackerel from NEFC autumn bottom trawl surveys and for ages 1 and 2 from spring surveys (Table 11) were combined into a single index for each year class (Anderson 1982). As described previously in this report, catch data from inshore surveys were combined with those from offshore surveys in the present analysis. In addition to combining the inshore and offshore survey data, the 1973-81 spring catches (numbers), taken with a No. 41 trawl, were adjusted to equivalent No. 36 trawl catches using a 3.25:1 ratio (41:36) (Anderson 1976). As described for the catch-per-tow (kg) indices, catch-per-tow (number) indices were calculated for 1976-84 for ages 0, 1, and 2 using (1) offshore strata, and (1) inshore and offshore strata combined. Indices based on the combined strata had a lower variance than those based on only the offshore strata. The coefficient of variation decreased an average of 6% for all the age 0-2 indices. Ratios between offshore and inshore-offshore indices showed that the autumn age 0 inshore-offshore indices averaged 1.05 times larger than the offshore indices and the spring age 1 and age 2 inshore-offshore indices averaged 1.05 and 1.10 times smaller, respectively, than the offshore indices. These average ratios were used to adjust the respective offshore indices prior to 1976 to equivalent inshore-offshore indices. The revised indices, combined into a single set of age 1 indices, were regressed against year-class size at age 1 from VPA for the 1963-79 year classes, using a functional linear regression (r = 0.940) (Table 11, Figure 7), to provide a basis for predicting the sizes of the 1980-84 year classes.

The 1980 (720 million), 1981 (590 million), 1982 (1,780 million), and 1984 (1,810 million) year classes at age 1 were all estimated to be much stronger than the 1975-79 year classes. The 1980 and 1981 year classes, although stronger than the 1975-79 year classes, are still less than the mean and median levels of 1961-79. However, the 1982 and 1984 year classes appear to be the strongest since the 1969 year class. The 1983 year class was estimated to be only 40 million fish at age 1, which would make it the poorest since 1961 and comparable in size to the 1977, 1976, and 1979 year classes.

The current estimate of the 1982 year class (1,780 million) is nearly twice the estimate (930 million) made in the previous assessment (Anderson 1983). This increase is due to the high catch per tow of age 2 mackerel in the 1984 spring survey (Table 11) which was about twice as high as any previous age 2 catch per tow. The strong 1984 year-class estimate was based on only the 1984 autumn age 0 catch per tow and will be subject to change when the 1985 spring age 1 catch per tow becomes available. However, the 1984 year class is insignificant in the catch and spawning stock biomass projections for 1985.

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 contributing significantly to the fishery (considered here to be ages 3 and older). The exploitation patterns for the mackerel fishery during 1962-83 are presented in Table 12.

The exploitation pattern or selection factors for ages 4 and older in 1983 were determined by SVPA, with factors in earlier years based on results of the conventional VPA. The selection factors at ages 1-3 in 1983, ages 1-2 in 1982, and age 1 in 1981 were based on F values derived from predicted year-class sizes (Table 11) and known catches. The exploitation pattern for 1983 was generally dome-shaped, increasing from 2% at age 1 to a maximum of 268% at age 9 and decreasing to 50% at age 13. This same general pattern was also evident during 1978-82.

Given the rather constant pattern which has persisted during 1978-83, there is no reason to believe that any significant changes will occur in 1984-85. Therefore, for the purpose of simulating the 1984 catch and projecting possible catches in 1985, the exploitation pattern was assumed equal to the geometric mean of the 1978-83 patterns (Table 12).

STOCK BIOMASS

Age-specific stock size estimates from VPA are given in Table 10. Annual stock biomass estimates for 1962-84 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 in 1962-65 to 1.9 million mt in 1970-71 and then declined to a stable low level during 1977-81 which averaged 485,000 mt per year (Table 10, Figure 8). Total stock biomass subsequently increased sharply to an estimated 950,000 mt at the beginning of 1984, nearly a 100% increase from the 1977-81 level.

Spawning stock biomass, defined as 50% of the age 2 and 100% of the age 3 and older fish, increased from an average of about 265,000 mt during 1962-67 to 1.6 million mt in 1971 and then decreased to a low of about 400,000 mt in 1981 (Table 10, Figure 8). Spawning biomass increased nearly 90% from 1981 to an estimated 763,000 mt at the beginning of 1984.

STOCK-RECRUITMENT

An examination was made of the stock-recruitment relationship for mackerel. The relationship between year-class size at age 1 and spawning stock biomass (SSB) that produced that year class (Figure 9) indicates a high probability of low spawning stock levels producing poor year classes. Although there is not a distinct separation between levels of SSB which have typically produced poor year classes and those which have produced a high proportion of strong year classes, a level of about 700,000 mt appears to be appropriate. During 1962-84, the estimated SSB was 634,000 mt or less during 15 of those 23 years (averaging 391,000 mt per year) and only

27% of the year classes produced were above median size (740 million fish at age 1). In the remaining 8 years, SSB was 721,000 mt or higher (averaging 1,145,000 mt per year) and 88% of the year classes produced were above median size. All year classes were above median size when SSB was 763,000 mt or higher.

From the array of points plotted in Figure 9, there seems to be a stock-recruitment relationship sufficient to be of guidance for management purposes. From the standpoint of ensuring a high probability of good recruitment, the existing data base would suggest maintaining an SSB of 700,000 mt or higher. However, since environmental factors also exert a strong influence on year-class size, maintenance of the stock at or above such a level also helps to ensure an adequate and stable resource on which to base a fishery and which will provide a buffer in the event of the production of a poor year class.

As noted earlier, there is a minimum SSB constraint of 400,000 mt as part of the management strategy in Amendment #1 to the FMP for mackerel prepared by the Mid-Atlantic Fishery Management Council (MAFMC 1983). This level was based on earlier assessment results which, at the time, indicated that 400,000 mt was appropriate. In light of the results of the current assessment, a minimum of 700,000 mt may now be more appropriate than 400,000 mt.

EQUILIBRIUM YIELD

Long-term equilibrium yield and stock biomass levels were simulated for the SA 2-6 mackerel stock by assuming constant recruitment each year at age 1 equivalent to the geometric mean of the 1962-84 year classes

(560 million fish). The exploitation pattern of the fishery was assumed equal to the mean of the 1978-83 conditions, and mean weights at age for the catch and the stock were assumed to be the same as the average for 1982-83 (Table 13). Catch and stock biomass simulations were made with $\overline{F}_{3-14+}$ ranging from 0 to nearly 0.8.

Results of this simulation indicated that $F_{0.1}$ = 0.29 and F_{max} = 0.62 (Figure 10). The value for $F_{0.1}$ is nearly the same as that calculated in the previous assessment (0.30), although the value for F_{max} is about 20% less than the previous estimate (0.77) (Anderson 1983).

Equilibrium yield under the simulated conditions would be 134,000 mt if fishing mortality was maintained at $F_{0.1}$ and would be 148,000 mt at F_{max} (Figure 10). Total stock biomass would be 1.3 million mt in the absence of a fishery and would decrease to 617,000 mt at the $F_{0.1}$ level and 397,000 mt at the F_{max} level. Spawning stock biomass with no fishery would be 1.2 million mt and would drop to 510,000 mt at $F_{0.1}$ and to 292,000 mt at F_{max}.

The results of this simulation are especially useful in illustrating the long-term effects of different management strategies. An increase of 114% in fishing mortality from $F_{0.1}$ (0.29) to F_{max} (0.62) would result in only a 10% increase in yield, but would produce a 36% decrease in total stock biomass and a 43% decrease in SSB (Figure 10). A decrease of 31% in fishing mortality from $F_{0.1}$ (0.29) to 0.20 would result in only a 12% decrease in catch, but a 20% increase in total stock biomass and a 24% increase in SSB.

Since recruitment for mackerel can be highly variable, the specific percentage increases or decreases in catch and stock biomass corresponding to the above indicated changes in fishing mortality could not be guaranteed to actually occur. However, the general trends would be realized if a particular management strategy (e.g., a fixed fishing mortality rate) were in effect for an extended period of time.

The assumption of constant recruitment in this simulation assumes no stock-recruitment relationship. However, there does appear to be a strong tendency for low spawning stock levels of mackerel to produce poor year classes (Figure 9). Therefore, the decrease in stock biomass that would occur from an increase in fishing mortality between $F_{0.1}$ and F_{max}, as illustrated in Figure 10, would, in reality, probably be much greater since recruitment would very likely suffer as spawning stock levels dropped, thus leading to even lower stock levels.

CATCH AND STOCK BIOMASS PROJECTIONS

The input parameters for the catch and stock biomass projections are given in Table 13.

The estimated catch in 1984 of 38,500 mt will generate a $\overline{F}_{3-14+}$ of 0.051, compared to 0.056 in 1983. Total stock biomass at the beginning of 1985 was projected to be 1,171,000 mt, a 23% increase from 1984. Spawning stock biomass at the beginning of 1985 was estimated to be 1,004,000 mt, a 32% increase from 1984.

Projected catches in 1985 ranging from 30,000 mt to 270,000 mt (Table 14) would require levels of $\overline{F}_{3-14+}$ ranging from about 0.03 to 0.29. These catches would result in projected SSB levels at the beginning of 1986 varying from 1,063,000 mt (6% increase from 1985) to 844,000 mt (16% decrease from 1985). Fishing at the $F_{0.1}$ level of 0.29 would result in a catch of 270,000 mt in 1985 and leave a spawning stock in 1985 of 844,000 mt. If fishing mortality in 1985 remains at the 1984 level, the catch would be about 54,000 mt and the SSB would increase 3-4% from 1985 to 1986.

CONCLUSION

The mackerel stock in the Northwest Atlantic has undergone a dramatic increase in size in the last several years. Total stock biomass (ages 1 and older) increased from about 475,000 mt in 1980 to an estimated 1,171,000 mt in 1985, while spawning stock biomass climbed from 404,000 mt in 1981 to 1,004,000 mt in 1985. The increasing trend in stock biomass, as estimated from results of virtual population analysis, is supported by NEFC trawl survey results and US commercial fishery catch rates. This recovery has been due to a substantial improvement in recruitment as well as low catches and fishing mortality. Following a period of poor recruitment during the mid-late 1970's (1975-79 year classes), year classes beginning with the 1980 cohort have been much stronger (except for the apparently weak 1983 year class), particularly the 1982 and 1984 year classes which are the strongest to appear since 1969. Catches and fishing mortality rates during 1978-84 were very low (average of 32,800 mt and 0.07, respectively), compared to the levels during 1970-76 (average of 340,000 mt and 0.41, respectively).

Concurrent with stock recovery, the total mackerel catch has begun to rise. Catches increased about 40% from 1982 to 1984 and are expected to increase further in the near future. US commercial catches in 1984 (5,000 mt) were the highest in over 30 years, having increased over 260% since 1977. US recreational catches have fluctuated in recent years without exhibiting a definite trend (average of about 3,100 mt during 1979-82), but are also expected to rise in response to increased abundance. Catches by vessels from foreign countries have increased from 440 mt in 1979 to an estimated 16,000 mt in 1984, mainly because of joint venture arrangements with US vessels. The big jump in foreign catch was from 1983 to 1984 (10,000 mt increase), and is expected to increase even more from 1984 to 1985 if approved joint ventures materialize. Contrary to the trend in US waters, Canadian catches have dropped in recent years (over 50% decrease from 1979 to 1984), reflecting primarily a poor market for mackerel in Canada.

Under the present 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 $F_{0.1} = 0.29$. The projected catch in 1985 corresponding to this level of F would be 270,000 mt.

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Table 1. Mackerel catch (mt) from NAFO SA 2-6 during 1960-84.

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	3,723	30,244	440	32,674	36,397
1980	2,683	2,381	22,136	566	25,385	27,766
1981	2,941	5,052	19,294	5,361[1]	27,596	32,648
1982	3,330	1,131	16,379	6,647[2]	26,356	27,487
1983	3,805	3,000	19,785	5,955[3]	29,545	32,545
1984[4]	5,000	3,000	14,500	16,000[5]	35,500	38,500

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

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

[3]Includes 4,341 mt taken by Poland in a research fishery conducted with the NEFC.

[4]Estimated.

[5]Includes 5,531 mt taken by Poland in a research fishery conducted with the NEFC.

Table 2. Mackerel catch (mt) in 1983 by country and subarea from NAFO SA 3-6.

Country	Subarea 3	4	5	6	Total
Canada (M)	-	9,318	-	-	9,318
Canada (N)	7,741	561	-	-	8,302
Canada (Q)	-	2,165	-	-	2,165
Cuba	-	1	-	-	1
France	11	-	-	-	11
GDR	-	-	-	1,315	1,315
Italy	-	-		113	113
Japan	-	-	15	38	53
Poland	-	-	220	4,121	4,341[1]
Spain	-	-	21	92	113
USSR	-	8	-	-	8
US (comm)	-	-	1,622	2,183	3,805
Total	7,752	12,053	1,878	7,862	29,545
US (rec)					3,000
Grand total					32,545

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

Table 3. Age composition (thousands of fish) of the 1983 mackerel catch from NAFO SA 3-6.

Age	SA 3-4 Total[1]	SA 5-6 US (comm)	SA 5-6 US (rec)[2]	SA 5-6 Non-US	SA 5-6 Total	SA 3-6 Total
1	268.2	801.2	202.5	924.7	1,928.4	2,196.6
2	2,920.0	7,002.3	1,432.6	4,186.6	12,621.5	15,541.5
3	4,222.8	585.2	576.4	868.8	2,030.5	6,253.2
4	1,473.5	88.7	181.5	225.4	495.6	1,969.2
5	4,870.6	511.8	710.1	1,611.0	2,832.9	7,703.5
6	517.3	36.0	65.3	89.5	190.8	708.1
7	1,512.7	80.7	169.2	72.5	322.3	1,835.0
8	3,892.3	406.4	509.7	720.9	1,637.1	5,529.4
9	7,631.9	789.2	1,072.1	2,137.2	3,998.5	11,630.5
10	3,275.6	331.2	456.6	890.4	1,678.2	4,953.8
11	560.5	95.7	89.6	226.7	412.0	972.5
12	178.8	77.5	38.5	123.1	239.1	417.9
13	2.0	63.3	21.2	143.9	228.4	230.4
14+	205.9	215.2	74.6	313.3	603.1	809.0
Total	31,532.1	11,084.4	5,600.0	12,534.0	29,218.4	60,750.5
Weight (mt)	19,805	3,805	3,000	5,935	12,740	32,545

[1]Based on Canadian data and raised to include 20 mt from other countries.

[2]Percentage age composition assumed same as SA 3-6 commercial total.

Table 4. Mackerel commercial and recreational catch at age (millions of fish) from NAFO SA 2-6 during 1962-83.

	Age																	
Year	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	4.8
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	2.3	0.7	1.9	0.6	1.0	58.6	36.4	6.2
1980	-	1.2	10.9	1.0	1.0	6.9	13.8	4.7	2.0	1.0	1.0	1.6	0.5	1.3	0.8	47.7	27.8	5.6
1981	+	10.4	4.8	8.7	2.0	2.8	7.9	13.1	5.6	2.7	0.9	0.4	0.4	0.7	0.8	61.2	32.6	5.1
1982	+	3.6	9.9	2.7	8.4	1.2	2.7	4.4	8.1	2.6	1.3	0.6	0.3	0.7	1.3	47.8	27.5	5.4
1983	-	2.2	15.5	6.3	2.0	7.7	0.7	1.8	5.5	11.6	5.0	1.0	0.4	0.2	0.8	60.7	32.5	5.7

[1]Thousands of mt.

Table 5. Mean weight at age (kg) of the international mackerel catch from NAFO SA 2-6 during 1962-83.

	Age														
Year	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
1983	-	.098	.257	.479	.593	.628	.659	.712	.709	.705	.727	.735	.752	.744	.805
1982-83[1]	-	.125	.299	.510	.600	.647	.701	.725	.716	.712	.734	.763	.782	.771	.817

[1]Arithmetic mean.

Table 6. Mean weight at age (kg) of the mackerel stock on 1 January in NAFO SA 2-6 during 1962-83.

	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
1983	.073	.218	.399	.516	.572	.611	.669	.679	.683	.710	.723	.743	.741	.800
1982-83[1]	.090	.252	.435	.534	.596	.655	.687	.690	.693	.719	.752	.773	.767	.812

[1]Arithmetic mean.

Table 7. Stratified mean catch (kg) per tow of mackerel from NMFS, NEFC bottom trawl surveys in the spring (offshore strata 1-25, 61-76, and inshore strata 1-66) and autumn (offshore strata 1-42, 49, and inshore strata 1-14, 45-66).

Year	Spring	Autumn
1963	-	.02
1964	-	<.01
1965	-	.04
1966	-	.04
1967	-	.17
1968	1.62	.11
1969	.03	.21
1970	.85	.05
1971	.86	.04
1972	.59	.11
1973	.37	.05
1974	.37	.02
1975	.16	.01
1976	.16	.04
1977	.06	.04
1978	.17	.11
1979	.09	.07
1980	.13	.06
1981	.64	.03
1982	.33	.15
1983	.13	.03
1984	.83	.08

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
1983	1.08

Table 9. Data used in estimating fishing mortality (F) in 1983 for the NAFO SA 2-6 mackerel fishery. Catch per day, international catch, fishing effort, and F values apply to age 4 and older fish.

Year	US std. catch per day (mt)	International catch (thousands of mt)	Fishing effort[1] (thousands of days)	$\bar{F}_{4-14+}$[2]
1964	.33	13.7	41.0	.088
1965	.43	17.8	41.6	.097
1966	.62	19.7	31.9	.098
1967	1.24	27.4	22.0	.153
1968	1.04	32.9	31.6	.198
1969	.52	39.5	75.5	.182
1970	.70	83.9	119.2	.221
1971	.98	295.6	301.9	.383
1972	.65	327.5	506.2	.378
1973	.35	281.7	811.8	.429
1974	(.33)[3]	218.3	653.6	.444
1975	.27	148.9	553.5	.465
1976	.28	118.8	418.3	.528
1977	.29	43.6	150.3	.186
1978	.36	32.7	92.1	.085
1979	.64	35.5	55.0	.087
1980	.54	22.9	42.7	.066
1981	.31	25.4	83.0	.093
1982	.51	22.1	43.1	.072
1983	.53	25.3	48.1	(.105)[4]

[1] Expressed as equivalent US standardized days fished.

[2] Weighted mean fishing mortality for ages 4 and older obtained from virtual population analysis assuming a mean F of 0.105 at ages 4 and older in 1983.

[3] Actual value of 0.11 replaced by 0.33 [see Anderson (1982) for explanation].

[4] Predicted from regression of fishing effort (f) on F for 1964-82:

$$\ln F = -4.632 + 0.613 \ln f, \; r = 0.848.$$

Table 10. Fishing mortality (F) and stock size (millions of fish) by age and year for mackerel in NAFO SA 2-6 derived from VPA (M = 0.20).

FISHING MORTALITY

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
1	0.053	0.007	0.074	0.036	0.036	<0.001	0.031	0.004	0.095	0.069	0.019	0.177
2	0.011	0.017	0.053	0.026	0.059	0.052	0.044	0.074	0.039	0.203	0.106	0.348
3	0.042	0.006	0.021	0.028	0.049	0.136	0.155	0.156	0.207	0.121	0.274	0.596
4	0.142	0.094	0.025	0.026	0.032	0.042	0.416	0.258	0.234	0.357	0.253	0.431
5	0.062	0.347	0.093	0.040	0.038	0.051	0.238	0.099	0.163	0.512	0.456	0.462
6	0.086	0.020	0.424	0.127	0.079	0.053	0.137	0.072	0.170	0.316	0.432	0.440
7	0.069	0.014	0.376	1.059	0.204	0.081	0.009	0.056	0.174	0.339	0.378	0.270
8	0.145	0.012	0.061	0.837	0.324	0.524	0.017	0.051	0.425	0.172	0.266	0.298
9	0.187	0.049	0.063	0.080	0.084	0.330	0.174	0.047	0.231	0.331	0.728	0.449
10	0.050	0.065	0.063	-	-	-	0.174	0.378	0.107	0.296	0.548	0.926
11	0.054	0.065	-	-	-	-	-	-	0.211	0.303	0.344	0.471
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14+	-	-	-	-	-	-	-	-	-	-	-	-
MEAN F	0.054	0.065	0.063	0.080	0.084	0.144	0.174	0.164	0.211	0.303	0.344	0.471
REC AGE	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
1	0.068	0.275	0.045	0.029	0.003	0.001	0.014	0.016	0.007	0.002
2	0.436	0.485	0.453	0.128	0.004	0.019	0.051	0.069	0.019	0.036
3	0.639	0.376	0.655	0.224	0.029	0.029	0.040	0.052	0.051	0.015
4	0.439	0.540	0.543	0.255	0.054	0.057	0.028	0.104	0.065	0.048
5	0.388	0.492	0.605	0.132	0.092	0.076	0.072	0.104	0.083	0.078
6	0.538	0.421	0.449	0.215	0.129	0.123	0.074	0.110	0.138	0.064
7	0.463	0.518	0.481	0.154	0.150	0.133	0.059	0.093	0.082	0.128
8	0.372	0.410	0.798	0.126	0.083	0.115	0.058	0.093	0.077	0.140
9	0.283	0.312	0.324	0.181	0.124	0.112	0.059	0.103	0.057	0.150
10	0.546	0.156	0.649	0.078	0.101	0.086	0.068	0.069	0.066	0.147
11	0.502	0.440	0.134	0.026	0.135	0.062	0.079	0.035	0.060	0.066
12	-	-	-	0.038	0.065	0.076	0.058	0.026	0.033	0.052
13	-	-	-	-	0.100	0.086	0.068	0.107	0.057	0.028
14+	-	-	-	-	-	0.084	0.065	0.081	0.070	0.056
MEAN F	0.502	0.440	0.586	0.204	0.074	0.084	0.065	0.081	0.070	0.056
REC AGE	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+

STOCK SIZE

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
1	345.0	182.5	199.8	281.5	739.5	1878.4	5080.9	1919.1	2360.6	1231.9	1316.5	1095.8
2	275.9	268.0	148.5	151.9	222.4	583.8	1563.4	4033.0	1568.3	1758.3	941.3	1057.4
3	411.9	223.4	215.7	115.3	121.1	171.7	454.0	1224.5	3065.5	1234.9	1174.7	693.4
4	31.6	323.5	181.9	172.9	91.8	94.4	122.7	318.2	857.8	2039.9	896.3	731.4
5	22.1	22.5	241.2	145.4	138.0	72.8	74.1	66.3	201.4	555.7	1168.2	569.6
6	21.5	17.0	13.0	179.9	114.3	108.7	56.7	47.8	49.1	140.0	272.7	606.5
7	23.3	16.1	13.7	7.0	129.8	86.5	84.4	40.4	36.5	33.9	83.5	145.0
8	6.5	17.8	13.0	7.7	2.0	86.6	65.3	68.5	31.3	25.1	19.8	46.9
9	2.6	4.6	14.4	10.0	2.7	1.2	42.0	52.6	53.3	16.8	17.3	12.4
10	2.3	1.8	3.6	-	-	-	0.7	28.9	41.1	34.7	9.9	6.8
11	6.3	1.8	-	-	-	-	-	-	16.2	30.2	21.1	4.7
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14+	-	-	-	-	-	-	-	-	-	-	-	-
TOT NOS	1148.9	1079.0	1044.8	1071.6	1561.6	3084.2	7544.2	7799.4	8281.0	7101.3	5921.2	4969.7
WGHTUNAD	248.8	283.7	307.3	316.2	370.4	553.7	1107.2	1511.6	1855.7	1888.7	1666.1	1421.4
SPUN NOS	666.0	762.5	770.7	714.1	710.9	913.9	1681.6	3863.8	5136.3	4990.3	4134.1	3345.3
WGHTUNAD	191.3	242.4	275.0	275.8	279.7	321.7	481.1	970.5	1490.3	1614.8	1456.4	1222.7

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	1605.6	1708.7	316.6	76.2	43.3	296.4	97.9	720.0	590.0	1780.0	40.0
2	751.4	1228.2	1062.9	247.9	60.6	35.4	243.6	79.1	580.1	479.7	1454.4
3	611.4	398.0	619.0	553.3	178.7	49.5	28.4	189.6	60.4	466.0	378.8
4	312.7	264.2	223.8	263.3	362.1	142.1	39.3	22.4	147.4	47.0	375.9
5	389.3	165.0	126.1	106.5	167.0	280.8	109.9	31.3	16.5	113.1	36.7
6	293.8	216.2	82.6	56.4	76.4	124.7	213.1	83.8	23.1	12.4	85.6
7	319.7	140.5	116.2	43.1	37.2	55.0	90.3	162.0	61.4	16.5	9.6
8	90.6	164.7	68.5	58.8	30.3	26.3	39.4	69.7	120.9	46.3	11.9
9	28.5	51.1	89.5	25.3	42.5	22.8	19.2	30.5	52.0	91.7	33.0
10	6.5	17.6	30.6	53.0	17.3	30.7	16.7	14.8	22.5	40.3	64.6
11	2.2	3.1	12.3	13.1	40.1	12.8	23.1	12.8	11.3	17.3	28.5
12	-	-	-	8.8	10.5	28.7	9.8	17.4	10.1	8.7	13.2
13	-	-	-	-	6.9	8.0	21.8	7.6	13.9	8.0	6.8
14+	-	-	-	-	-	13.7	14.0	11.3	21.2	16.1	18.6
TOT NOS	4411.8	4357.2	2748.1	1505.7	1072.8	1126.9	966.6	1452.2	1730.9	3143.0	2557.6
WGHTUNAD	1143.5	993.6	758.2	498.1	473.2	500.3	474.5	481.4	590.7	688.4	950.1
SPUN NOS	2430.5	2034.4	1900.1	1305.5	999.2	812.8	746.9	692.7	850.8	1123.2	1790.4
WGHTUNAD	922.8	720.8	633.8	468.8	460.2	457.3	425.8	403.5	444.9	506.2	763.1

Table 11. Stratified mean catch (numbers) per tow of age 0, 1, and 2 mackerel from NMFS, NEFC autumn and spring bottom trawl surveys, catch per tow adjusted to equivalent age 1 values on 1 January (see Anderson 1982), geometric mean of adjusted values, and year-class size at age 1 (millions of fish) from virtual population analysis (VPA) assuming a mean F of 0.105 at ages 4 and older in 1983.

	Mean catch per tow			Adjusted mean catch per tow				
Year class	Autumn age 0	Spring age 1	Spring age 2	Autumn age 0	Spring age 1	Spring age 2	Geometric mean	VPA age 1
1963	.056	-	-	.297	-	-	.297	199.8
1964	.010	-	-	.054	-	-	.054	281.5
1965	.058	-	-	.303	-	-	.303	739.5
1966	.088	-	.378	.459	-	.361	.407	1878.4
1967	.645	12.347	.129	3.395	12.976	.128	1.780	5080.9
1968	.004	.029	.168	.022	.030	.162	.047	1919.1
1969	.300	.266	.858	1.568	.288	.965	.758	2360.6
1970	.017	.313	.281	.086	.338	.301	.206	1231.9
1971	.071	.832	.309	.368	.883	.346	.483	1316.5
1972	.085	.335	.163	.443	.381	.237	.342	1095.8
1973	.211	.332	.209	1.097	.364	.283	.483	1605.6
1974	.090	.624	.368	.465	.772	.633	.610	1708.7
1975	.009	.085	.042	.049	.092	.046	.059	316.6
1976	<.001	.008	.099	<.001	.009	.098	.010	76.2
1977	.045	.053	.003	.238	.056	.003	.034	43.3
1978	.310	.013	.159	1.605	.014	.153	.151	296.4
1979	.027	.020	.116	.141	.021	.115	.070	97.9
1980	.040	.331	.193	.205	.353	.188	.239	(722.5)[1]
1981	.012	.401	.316	.059	.424	.305	.197	(594.6)[1]
1982	.111	.225	1.534	.573	.237	1.478	.585	(1776.1)[1]
1983	<.001	.217	-	<.001	.228	-	.015	(40.4)[1]
1984	.115	-	-	.595	-	-	.595	(1806.6)[1]

[1] Predicted from functional (geometric mean) regression between geometric mean of adjusted mean catch per tow and year-class size for the 1963-67 and 1969-79 year-classes: $Y = -5.303 + 3045.201 X$, $r = 0.940$.

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 1962-83.

Year	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1962	98	20	78	263	115	159	128	269	346	93	100	-	-	-
1963	11	26	9	145	534	31	22	18	75	100	100	-	-	-
1964	117	84	33	40	148	673	597	97	100	100	-	-	-	-
1965	45	33	35	33	50	159	1324	1046	100	-	-	-	-	-
1966	43	70	58	38	45	94	243	386	100	-	-	-	-	-
1967	<1	36	94	29	35	37	56	364	229	-	-	-	-	-
1968	18	25	89	239	137	79	5	10	100	100	-	-	-	-
1969	2	45	95	157	60	44	34	31	29	230	-	-	-	-
1970	45	18	98	111	77	81	82	201	109	51	100	-	-	-
1971	23	67	40	118	169	104	112	57	109	98	100	-	-	-
1972	6	31	80	74	133	126	110	77	212	159	100	-	-	-
1973	38	74	127	92	98	93	57	63	95	197	100	-	-	-
1974	14	87	127	87	77	107	92	74	56	109	100	-	-	-
1975	63	110	85	123	112	96	118	93	71	35	100	-	-	-
1976	8	77	112	93	103	77	82	136	55	111	23	-	-	-
1977	14	63	110	125	65	105	75	62	89	38	13	19	-	-
1978	4	5	39	73	124	174	203	112	168	136	182	88	135	-
1979	1	23	35	68	90	146	158	137	133	102	74	90	102	100
1980	22	78	62	43	111	114	91	89	91	105	122	89	105	100
1981	20	85	64	128	128	136	115	115	127	85	43	32	132	100
1982	10	27	73	93	119	197	117	110	81	94	86	47	81	100
1983	2	64	27	86	139	114	229	250	268	263	118	93	50	100
1978-83[1]	6	33	47	78	117	144	144	128	133	120	95	68	96	100

[1]Geometric mean.

Table 13. Input data for forecasts of catch in 1984-85 and stock in 1985-87 of mackerel in NAFO SA 2-6.

Age	Stock size in 1984 (millions)	Exploitation pattern	Mean weight of the catch (kg)	Mean weight of stock on 1 Jan (kg)	Maturity ogive
1	40.0	0.06	0.125	0.090	0.00
2	1455.3	0.33	0.299	0.252	0.50
3	378.8	0.47	0.510	0.435	1.00
4	375.8	0.78	0.600	0.534	1.00
5	36.7	1.17	0.647	0.596	1.00
6	85.7	1.44	0.701	0.655	1.00
7	9.5	1.44	0.725	0.687	1.00
8	11.9	1.28	0.716	0.690	1.00
9	33.0	1.33	0.712	0.693	1.00
10	64.6	1.20	0.734	0.719	1.00
11	28.5	0.95	0.763	0.752	1.00
12	13.3	0.68	0.782	0.773	1.00
13	6.8	0.96	0.771	0.767	1.00
14+	18.9	1.00	0.817	0.812	1.00

Table 14. Various levels of projected catch of mackerel in 1985 in NAFO SA 2-6 and associated fishing mortality ($\bar{F}_{3-14+}$), with resultant spawning stock biomass in 1986 and the percentage change from 1985. These projections assume a 1984 catch of 38,500 mt ($\bar{F}_{3-14+}$ = 0.051). Catch and stock biomass are expressed as thousands of mt.

Spawning stock in 1985	Catch in 1985	$\bar{F}_{3-14+}$ in 1985	Spawning stock in 1986	% change in stock from 1985
1004.0	30.0	.028	1062.6	+5.8
1004.0	40.0	.037	1053.5	+4.9
1004.0	50.0	.047	1044.3	+4.0
1004.0	60.0	.056	1035.2	+3.1
1004.0	70.0	.066	1026.1	+2.2
1004.0	80.0	.076	1017.0	+1.3
1004.0	90.0	.086	1007.9	+0.4
1004.0	100.0	.096	998.8	-0.5
1004.0	140.0	.138	962.3	-4.2
1004.0	180.0	.182	926.0	-7.8
1004.0	220.0	.228	890.0	-11.4
1004.0	270.3	.290[1]	844.0	-15.9

[1] $F_{0.1}$ applicable to average 1978-83 exploitation pattern.

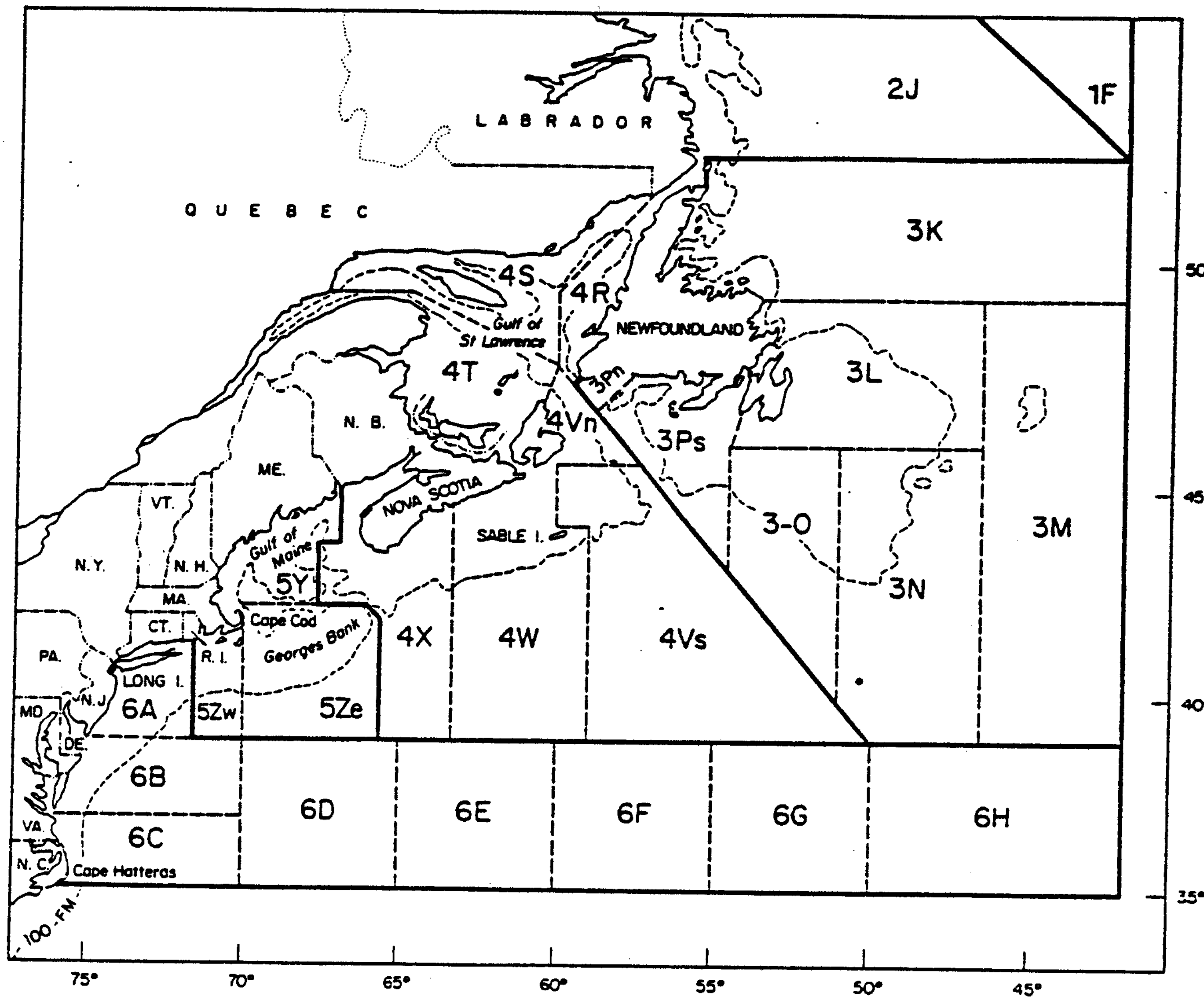

Figure 1. Northwest Atlantic from Labrador to North Carolina showing NAFO SA 2-6.

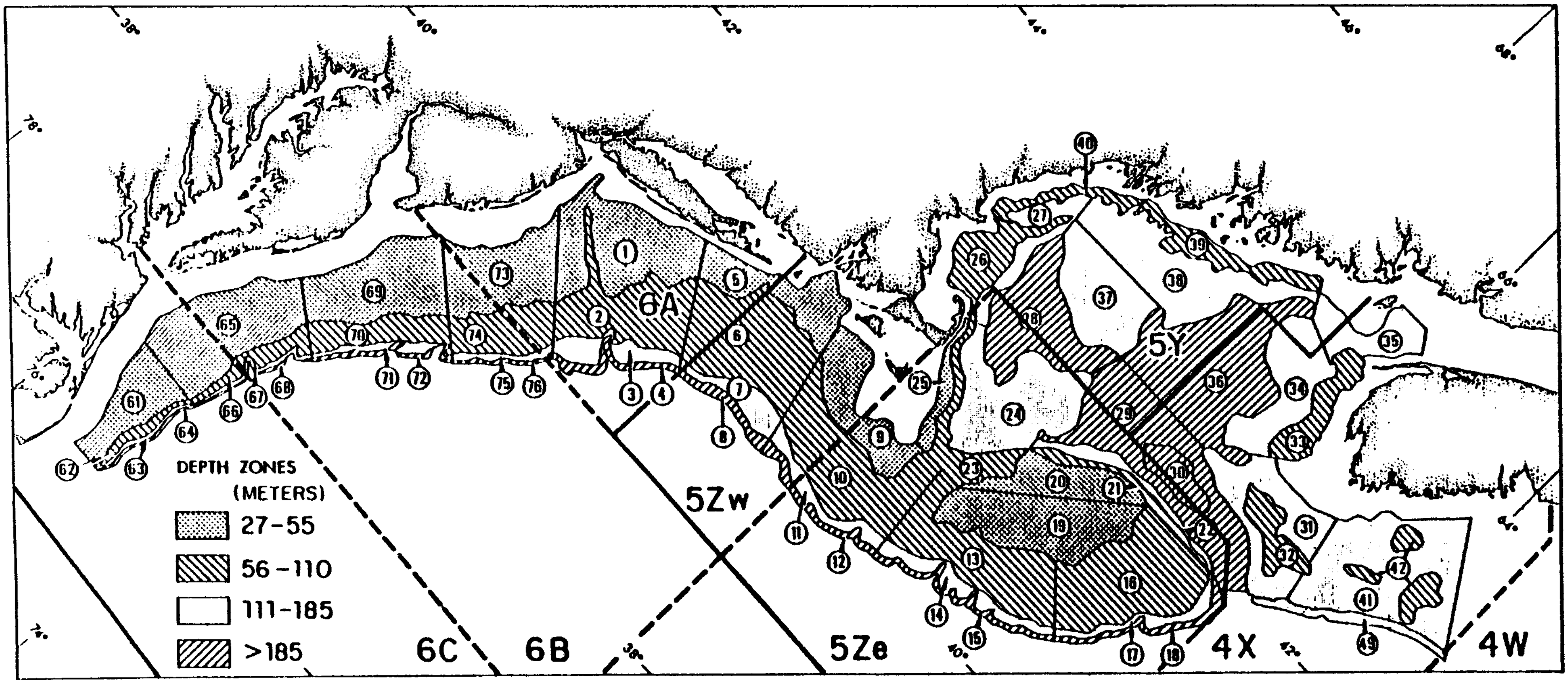

Figure 2. NMFS, NEFC offshore bottom trawl survey sampling strata in the Northwest Atlantic between Cape Hatteras and Nova Scotia.

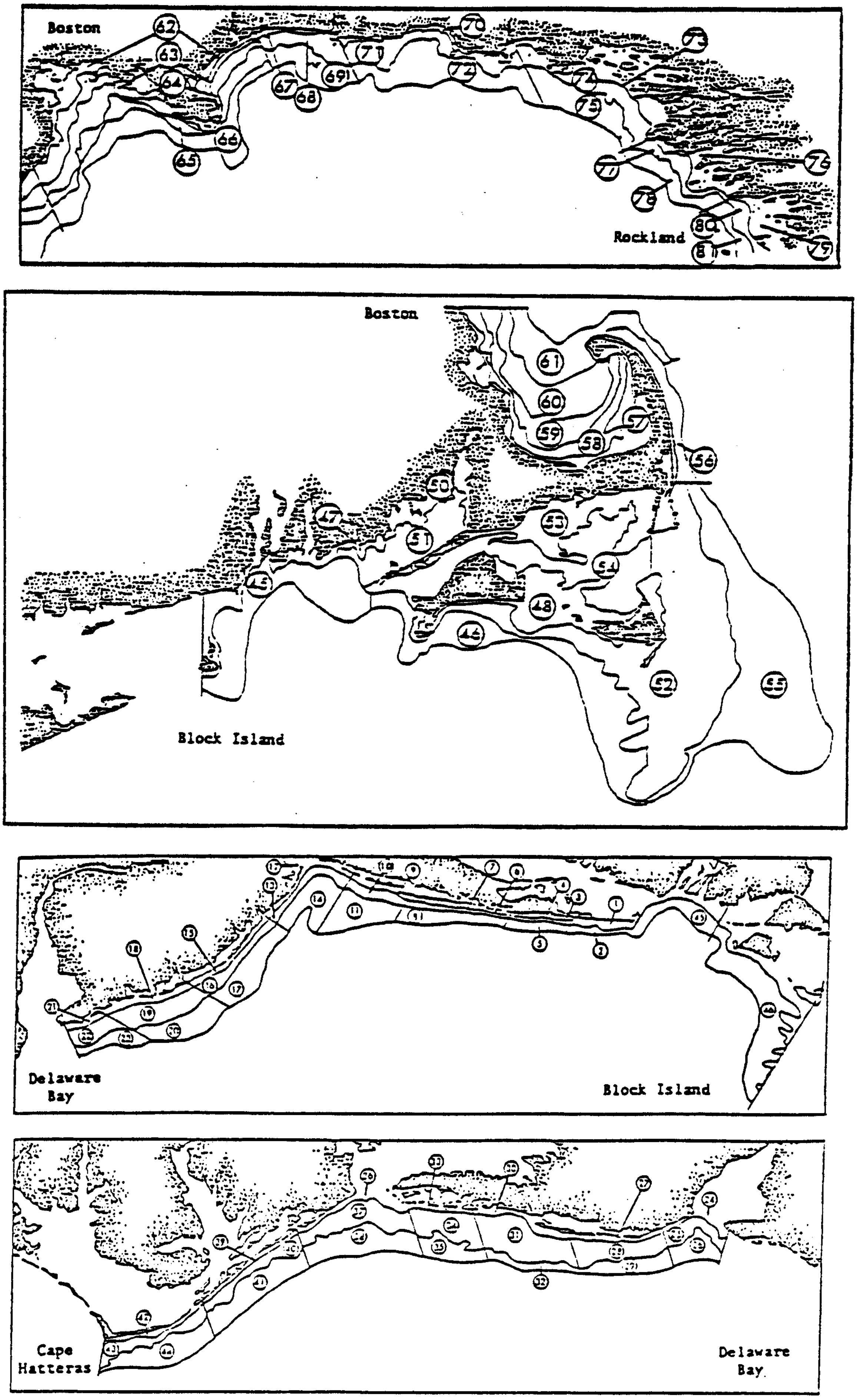

Figure 3. NMFS, NEFC inshore bottom trawl survey sampling strata in the Northwest Atlantic between Rockland Maine and

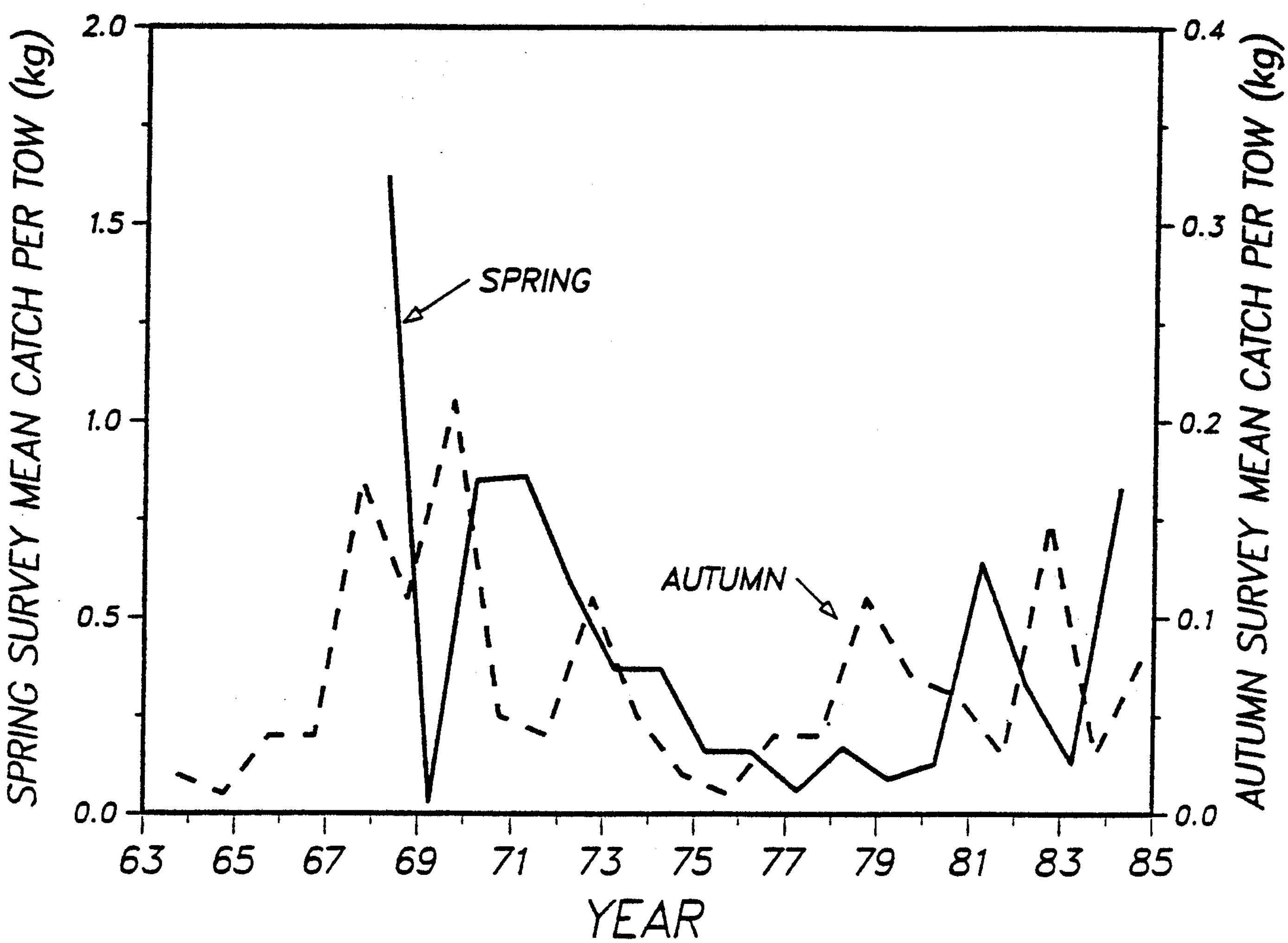

Figure 4. Mean catch per tow (kg) of mackerel from NMFS, NEFC spring (1968-84) and autumn (1963-84) bottom trawl surveys in NAFO SA 4-6.

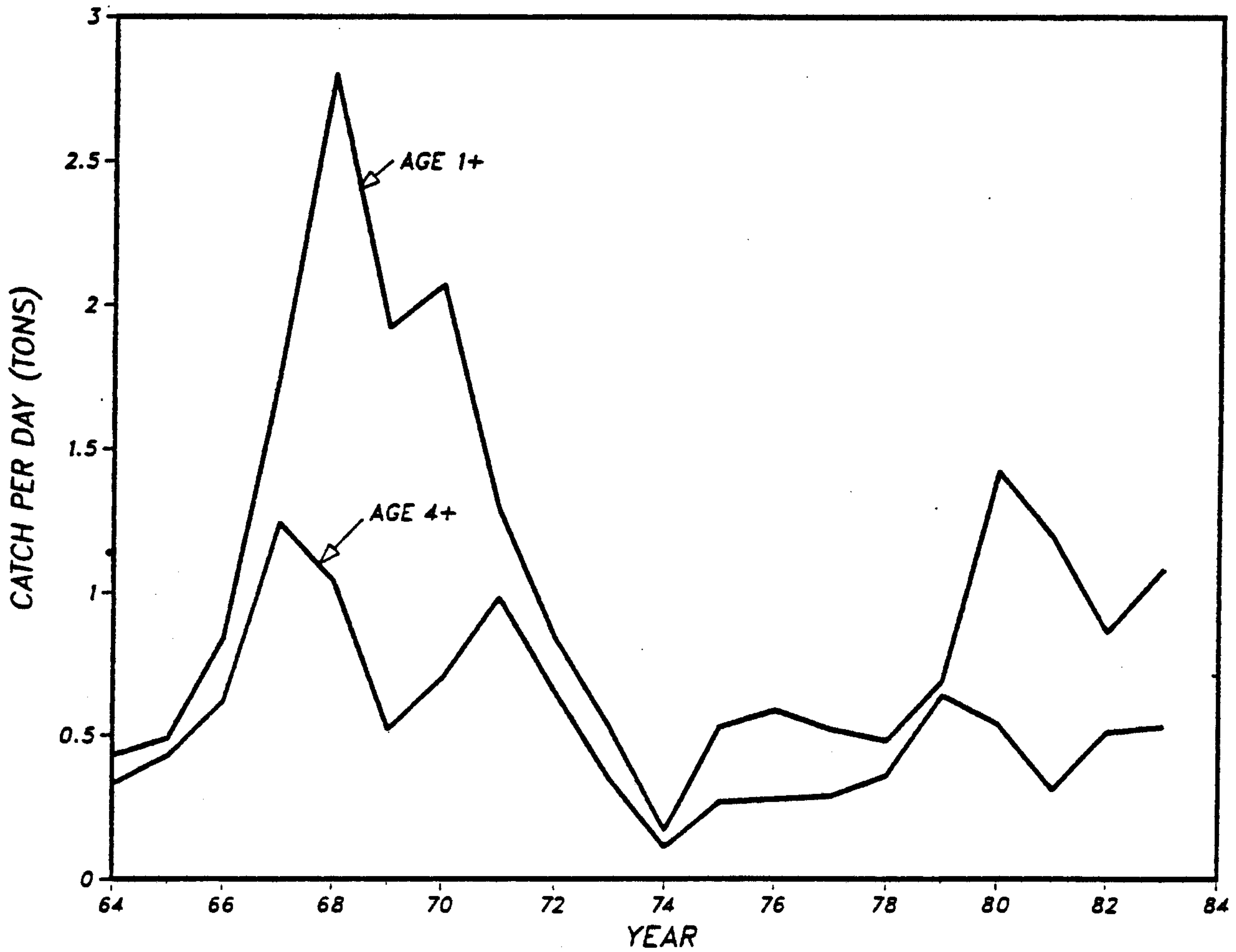

Figure 5. Catch per standardized day fished for (1) ages 1 and older and (2) ages 4 and older in the US commercial mackerel fishery in NAFO SA 5-6.

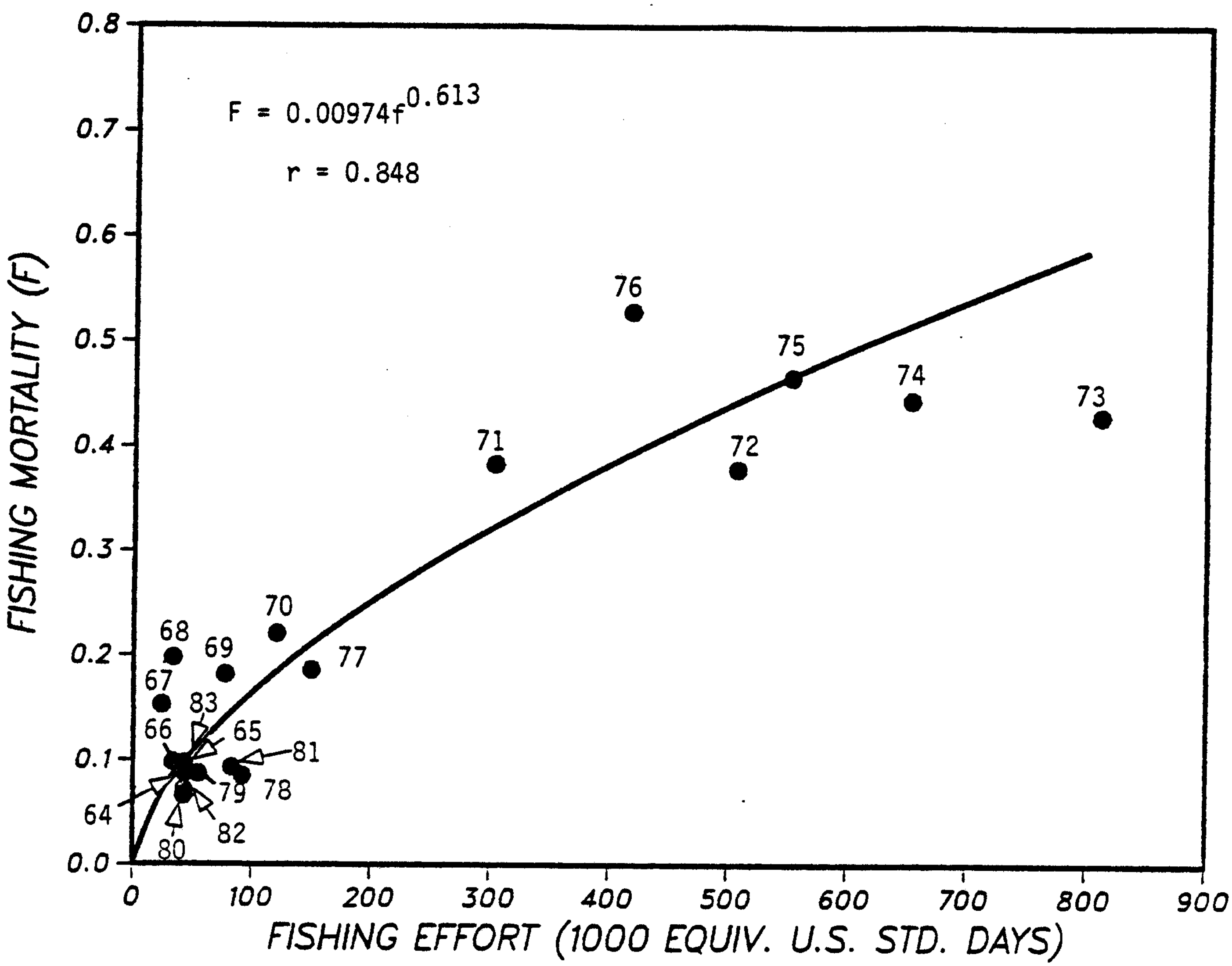

Figure 6. Relationship between mean fishing mortality (F) for age 4 and older mackerel from VPA assuming mean F=0.105 at ages 4 and older in 1983 (M=0.20) and fishing effort directed towards ages 3 and older expressed as equivalent US standardized days fished.

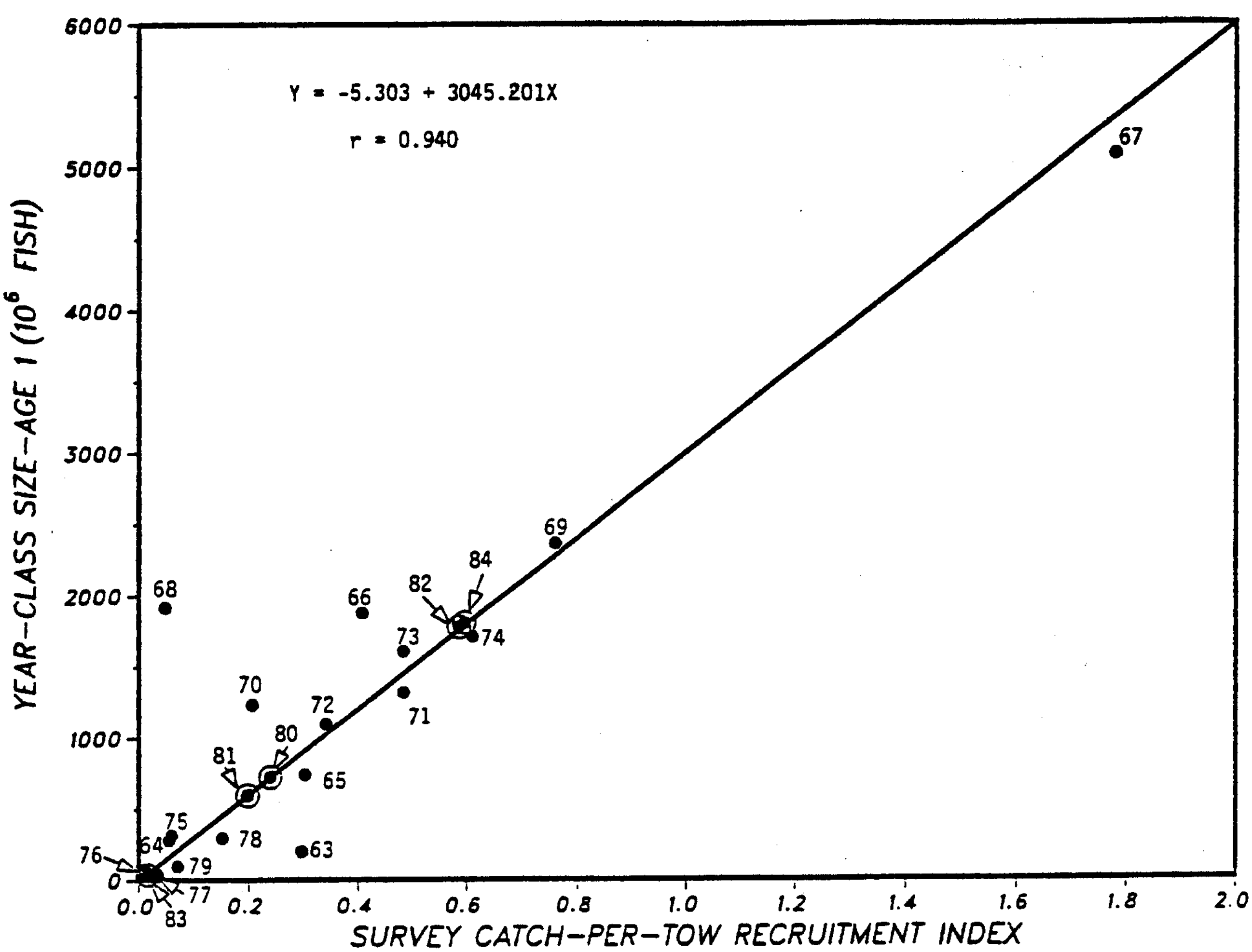

Figure 7. Relationship between mackerel year-class size at age 1 from VPA assuming mean F=0.105 at ages 4 and older in 1983 (M=0.20) and a catch-per-tow recruitment index from NMFS, NEFC autumn and spring bottom trawl surveys in NAFO SA 4-6. Circled points are predicted.

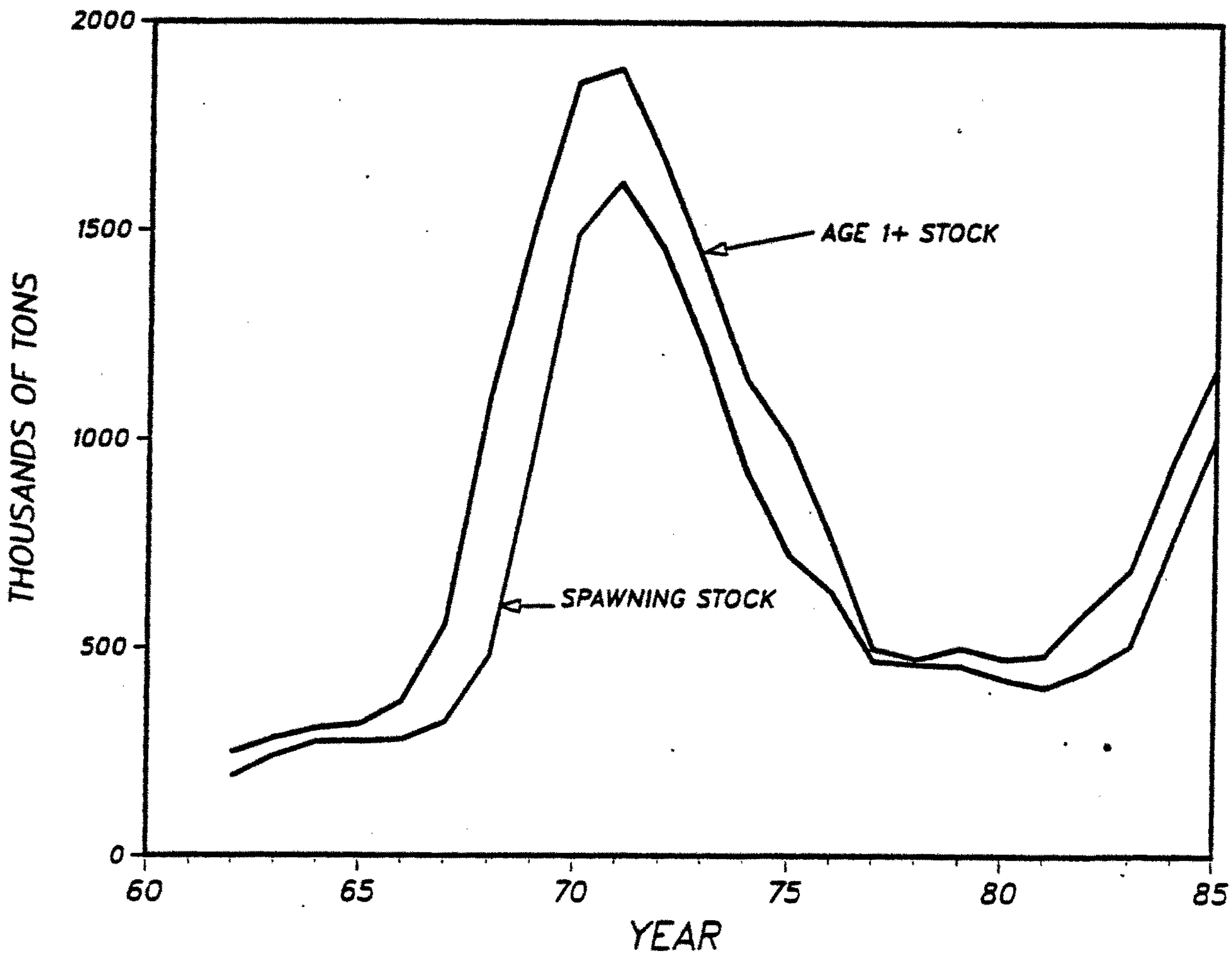

Figure 8. Total stock biomass (ages 1 and older) and spawning stock biomass (50% age 2 and 100% age 3 and older) of mackerel in NAFO SA 2-6 during 1962-85 estimated from VPA and stock projections.

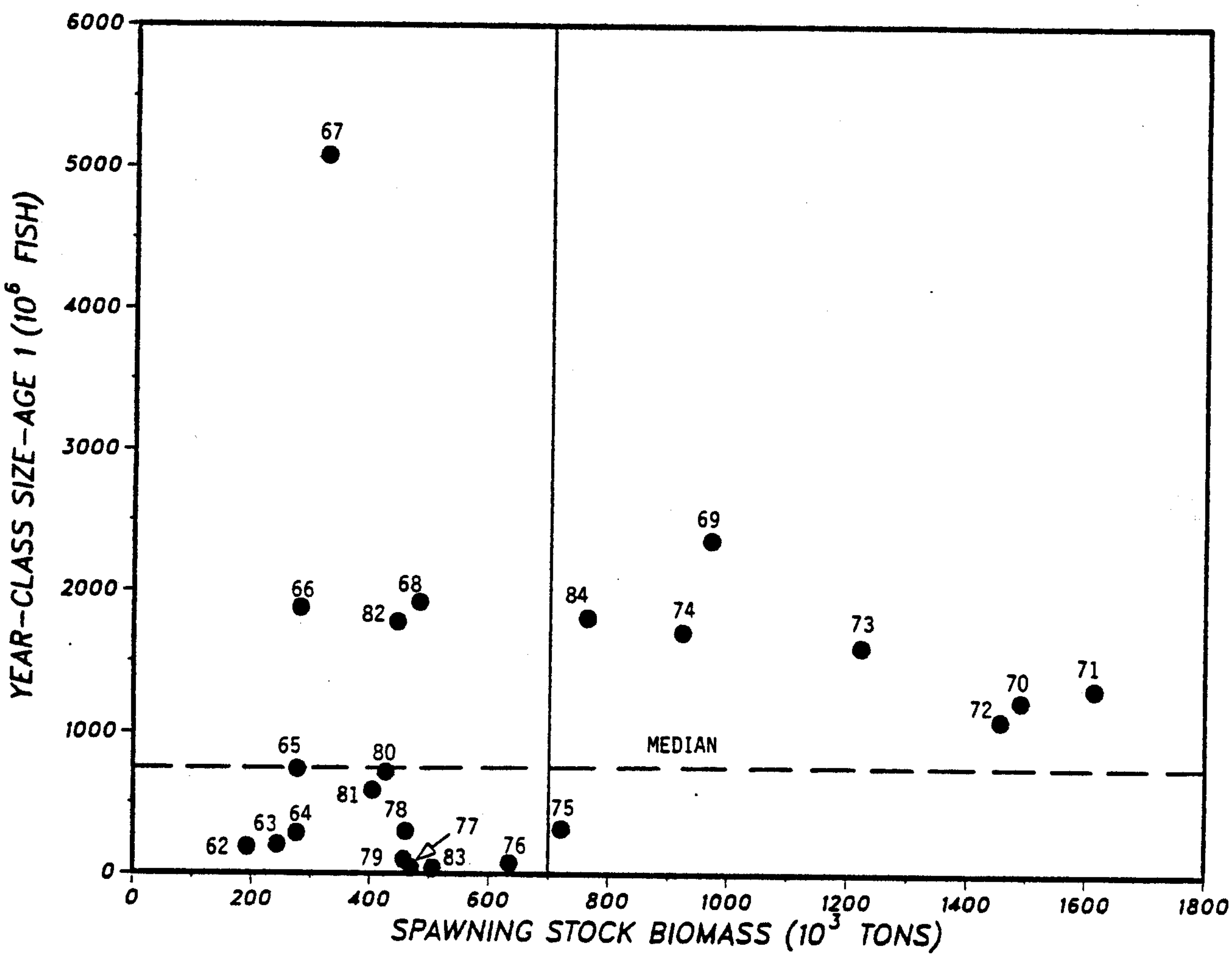

Figure 9. Relationship between mackerel year-class size at age 1 and the parental spawning stock biomass during 1962-84 in NAFO SA 2-6.

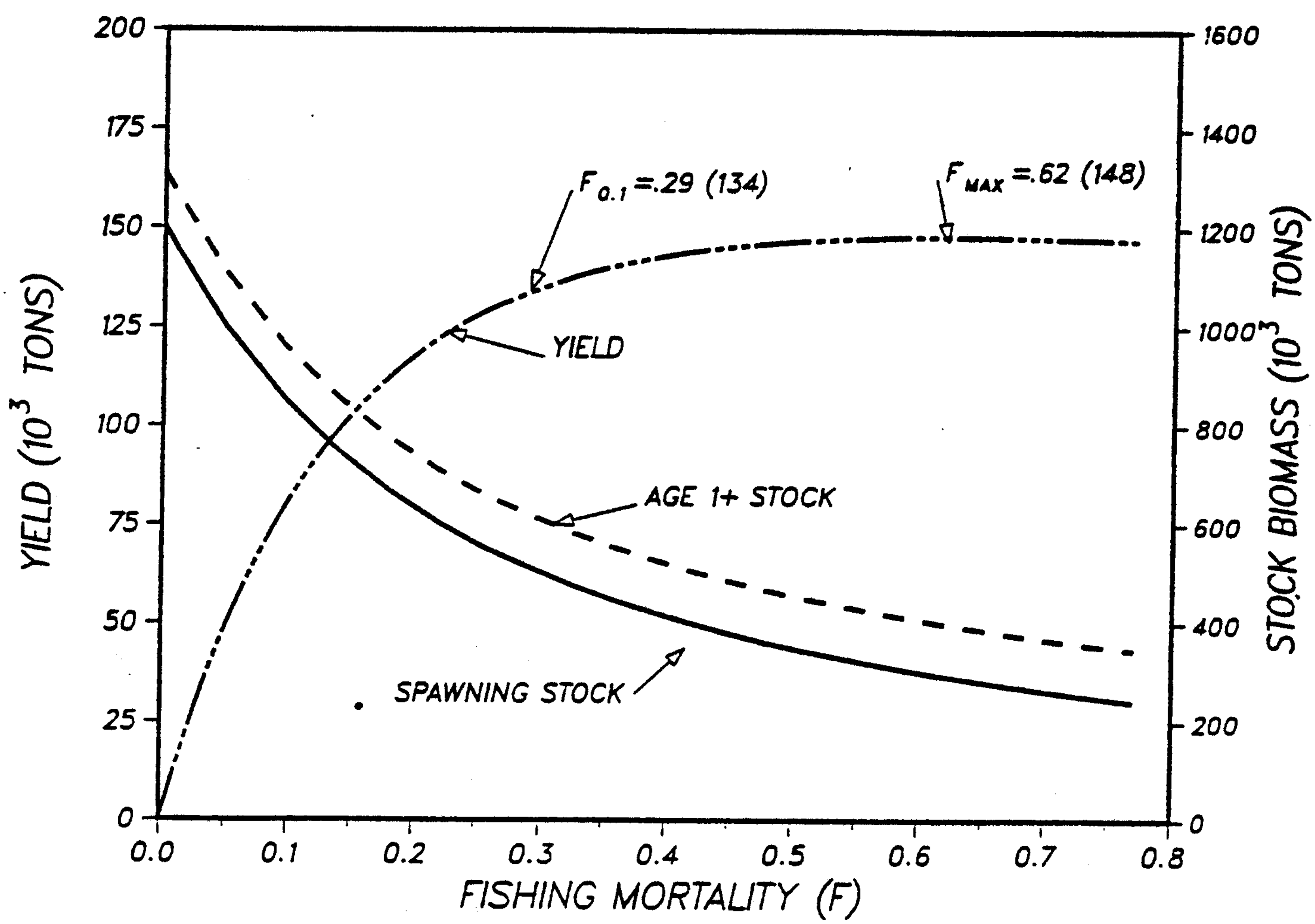

Figure 10. Equilibrium yield and stock biomass for mackerel in NAFO SA 2-6 assuming constant recruitment equivalent to the geometric mean level estimated during 1962-84.