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STATUS OF THE NORTHWEST ATLANTIC MACKEREL STOCK - 1980

by

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INTRODUCTION

This report analyzes the status of the Atlantic mackerel (*Scomber scombrus*) resource distributed throughout NAFO (Northwest Atlantic Fisheries Organization - formerly International Commission for the Northwest Atlantic Fisheries) Subareas 2, 3, 4, and 5 and Statistical Area 6 (SA 2-6) (Figure 1). The analysis reported herein represents an update of previous assessments, the most recent by Anderson and Overholtz (1979). Previous assessments considered only SA 3-6; however, since catches of up to several hundred tons have been reported in various years by Canada (Newfoundland) from SA 2 (off Labrador), it was decided to redefine the stock as encompassing SA 2-6 instead of SA 3-6. The report contains international commercial and United States (US) recreational catch statistics (including revisions of previous estimates of recreational catch); NMFS research vessel bottom trawl survey abundance indices; fishing mortality and stock size estimates from virtual population analysis; recruitment estimates; and projected catch levels for 1981 and spawning stock biomass levels for 1982 over a range of fishing mortality rates and assuming various levels of catch in 1980.

CATCH

Recreational

Various national and regional marine angler surveys provided estimates of the recreational catch of mackerel along the Atlantic coast between North Carolina and Maine in 1960, 1965, 1970, and 1974 (Clark 1962, Deuel

and Clark 1968, Deuel 1973, and Deuel[1]). Localized creel surveys conducted primarily in the New Jersey - New York area (Christensen et al. 1976, 1979a, and Christensen[2]) provided a basis for estimating recreational catches in 1976-78. More recently, the NMFS Marine Recreational Fishery Statistics Survey provided an estimate of the 1979 catch (Deuel, see footnote 1). These various estimates increased from 4,957 metric tons (tons) in 1960 to 32,078 tons in 1970, dropped to 7,640 tons in 1974, and varied between 522 and 6,571 tons in 1976-79.

The 1979 estimated catch was 2,992 tons, with 1,573 tons (53%) estimated from SA 6 and 1,419 tons (47%) from SA 5. The total estimated catch numbered about 4,025,000 fish, with 54% of this total consisting of fish in the landed category (whole fish which were weighed and measured during the on-site interviews), 42% harvested (fish which were headed, gutted, filleted, etc. by the angler prior to the interview thus preventing accurate weighing or measuring), and 4% released. The entire catch was assumed to have a mean weight equal to that of the landed category (0.74 kg or 1.64 lb).

An earlier analysis (Anderson 1977) indicated a close relationship between estimates of recreational catch and stock biomass levels determined from cohort analysis applied to commercial catch data (ICNAF 1977). This relationship provided the basis for estimating recreational catches

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[1]David G. Deuel, National Marine Fisheries Service, Resource Statistics Division, Washington, DC, personal communication.

[2]Darryl J. Christensen, National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory, Highlands, NJ, personal communication.

in years without angler surveys. It was recognized, however, that other factors such as water temperature, weather, angler effort, abundance of other species, etc. also have had and will continue to have an effect on the size of the recreational catch.

Of all the previous estimates of mackerel catch based on angler surveys, the 1979 value is considered most accurate because of the improved survey methodology. The 1979 survey employed on-site interviews to obtain catch data for individual fishing trips. In contrast, the 1960, 1965, and 1970 survey results were based on angler memory recall of catch for an entire year, and the 1974 regional survey employed different methods than those utilized in the three previous national surveys and relied on memory recall for 2-month periods. A recent study conducted in southern California (Hiett and Worrall 1977), which examined the ability of marine recreational fishermen to recall catch and effort over time, found that fishermen interviewed 15-60 days following given fishing trips overestimated their catch by 33-123%. Based on these findings, the lengthy recall period for the earlier surveys strongly suggests that catch estimates from those surveys were likely overestimated. This possibility has generally been acknowledged by those familiar with the conduct of the earlier surveys (Deuel, see footnote 1).

The relationship between recreational catch estimates and stock biomass determined from commercial catch data (ICNAF 1977) was re-examined using spawning stock biomass instead of total stock biomass, as done originally. The age composition of the catch was considered to be more equivalent to that of the spawning stock (50% of age 2 fish and 100% of ages 3 and older)

than the total stock. Comparison of the catch estimates for 1965, 1970, 1974, and 1976 with spawning stock biomass estimates determined for those years from commercial data (ICNAF 1977) indicated that the catch/biomass ratios in 1965 and 1970 were about twice as great as those in 1974 and 1976. This suggests that the recreational catch estimates for 1965 and 1970 were about 100% higher than expected, based on the catch/stock biomass ratios for 1974 and 1976.

It was assumed, therefore, in view of the available evidence, that the recreational catch estimates for 1960, 1965, and 1970 were overestimated by 100%, and should be adjusted downwards accordingly. Catches in the intervening years were estimated utilizing the catch/spawning stock biomass ratios from adjacent years as described by Anderson and Paciorkowski (in press). Adjusted recreational catch estimates are given in Table 1, indicating an increase from 2,478 tons in 1960 to a high of 16,426 tons in 1971, followed by a corresponding decrease in subsequent years. Estimated catches during 1960-79 averaged 6,900 tons per year. The ratio between estimated recreational catch and spawning stock biomass calculated herein from VPA results using commercial and recreational catch data (Table 10) was 0.0058 for 1979 compared to 0.0049 and 0.0064 for 1976 and 1974, respectively, and 0.0079 and 0.0084 for 1970 and 1965, respectively, indicating general agreement between 1979 and earlier years.

Commercial

The international commercial catch in SA 2-6 in 1979 was 32,666 tons, compared to 27,875 tons in 1978, 77,806 tons in 1977, and a peak of 419,714 tons in 1973 (Table 1).

The US commercial catch increased slightly from 1,605 tons in 1978 to 1,989 tons in 1979. Approximately 55% of the 1979 catch came from SA 5, with the balance from SA 6 (Table 2). US catches during 1960-79 did not change greatly, varying between 938 and 4,364 tons and averaging 2,200 tons per year.

The Canadian catch in 1979 was 30,237 tons (Table 1), representing a 19% increase from 1978 and about the highest annual Canadian mackerel catch ever reported. Canadian catches have exhibited a generally increasing trend since the late 1950's - early 1960's. The Canadian catch represented 93% of the total commercial catch in 1979, with 51% coming from SA 4, 49% from SA 3, and 5 tons from SA 2 (Table 2).

Catches by countries other than the US and Canada totalled only 440 tons in 1979, the lowest since 1962 (Table 1), compared with 841 tons in 1978 and a high of 396,759 tons in 1973. In 1979, 84% (368 tons) of this catch was taken in SA 4, with 14% (60 tons) from SA 5 and 3% (12 tons) from SA 6. A total of eight countries (other than the US and Canada) reported catches in 1979 (Table 2), with 63% (275 tons) of that amount taken by the USSR. Directed fishing for mackerel by other countries was prohibited in US waters in 1979, with only 1,200 tons allowed as by-catch in directed fisheries for squid and hake.

Total

The total international catch in 1979 in SA 2-6 was 35,658 tons (Table 1), an increase of 3.5% from 1978 (34,446 tons); however, this represented only about 8% of the peak catch of 430,437 tons taken in 1973. Nearly 86%

(30,605 tons) of the total catch in 1979 came from SA 2-4 (Canadian waters) with 44% from SA 4 and 42% from SA 3 (only 5 tons from SA 2). The Canadian catch in 1979 comprised 85% of the SA 2-6 total. The US catch (commercial and recreational) in 1979 was 4,981 tons (14% of the total), with 50% from each SA 5 and SA 6 (Table 2).

CATCH COMPOSITION

The international mackerel catch in numbers at age for 1979 is given in Table 3. Numbers at age for most of the Canadian catch in SA 3-4 were obtained from Hunt[3] for the Maritimes and from Moores[4] for Newfoundland. Age composition data for the Romanian catch (10 tons) in SA 5-6 were obtained from Maxim et al. (1980). Numbers at age were also determined for portions of the US commercial and recreational catch in SA 5-6. The unsampled commercial catch was assumed to be the same age composition as the cumulative age composition of the sampled commercial catch.

The age composition of the 1979 recreational catch sampled in the New Jersey - New York area (Clifford and Christensen 1980) was assumed to be representative of the total recreational catch. Although estimated catches of mackerel in the New Jersey - New York area represented only 30% of the Maine - Virginia total (Deuel, see footnote 1), the average weight of fish sampled in the former area was similar to the average weight determined from the recreational survey for the total area.

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

[4]John A. Moores, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Center, St. John's, Newfoundland, personal communication.

The 1974 and 1973 year classes comprised 32 and 23%, respectively, of the total 1979 catch in numbers. These two year classes have clearly been dominant in the catch each year since 1975, ranging from 49% of the total in 1978 to 69% in both 1976 and 1977. Year classes since 1974 have contributed very little to the catch, with annual percentage contributions by these year classes being about the lowest observed during 1962-79. These low catches of young fish reflect, for the most part, poor year-class strength. Mean age of the catch increased steadily from 2.8 years in 1975 to 6.1 years in 1979 (Table 5), a reflection of the progression of the 1973 and 1974 year classes through the fishery coupled with the scarcity of younger fish in the catch.

The 1979 recreational catch in the New Jersey - New York area consisted of much older fish than the commercial catch taken primarily in SA 3-4. Average age of the recreational catch was 10.2 years compared to 5.8 years for the commercial catch. Nearly half of the recreational catch was comprised of fish from the 1969 (29%) and 1967 (20%) year classes (Table 4). Sampling of the New Jersey - New York recreational catch in 1978 (Christensen et al. 1979b) and 1980 (Christensen, see footnote 2) indicated that these two year classes comprised 50 and 44%, respectively, of the catch in numbers in those years (Table 4). As discussed by Anderson and Overholtz (1979), the phenomenon of old, large mackerel dominating the spring recreational catches appears to be a result of these fish comprising the first wave of spawners moving inshore. The recreational age compositions for 1978-80 indicate, as do the commercial age compositions, a scarcity of fish younger than the 1974 year class.

The international mackerel numbers-at-age catch data for 1962-79 are presented in Table 5.

MEAN WEIGHTS AT AGE

Mean weights at age for mackerel adopted by scientists in the ICNAF Assessments Subcommittee (ICNAF 1974) were used in previous assessments (Anderson and Overholtz 1979) to convert numbers at age of both catch and stock into weight. These values for mean weight were originally determined from Canadian samples in SA 4 during September - October 1973. Since these values were obtained during the autumn of the year, they are not indicative of average weights applicable to stock size at the beginning of the year determined from virtual population analysis using calendar-year catch data.

New mean weights for ages 1-15 were calculated using von Bertalanffy (1938) growth parameters and length-weight parameters. Growth parameters utilized were L_∞ = 40.9 cm, K = 0.250, and t_o = -1.900, which were agreed upon by the ICNAF Mackerel Working Group (ICNAF 1973) and are quite close to the averages from various studies reviewed by Anderson and Paciorkowski (in press). Length-weight parameters used from the relationship:

$$W = aL^b \qquad (1)$$

were a = 0.0048 and b = 3.2482. These values also represent averages from various studies (Anderson and Paciorkowki in press).

Mean weights at age are given in Table 6 for various times of the year: (1) January 1 for calculating stock biomass; (2) the first week of August representing the approximate midpoint for 1979 catches throughout SA 2-6 and

used for calculating projected catches in 1980-81; and (3) the second week of June representing the average midpoint for 1962-79 catches and used for calculating long-term equilibrium yield.

STOCK ABUNDANCE INDICES

Catch-per-tow data from NMFS, Northeast Fisheries Center (NEFC) spring and autumn research vessel bottom trawl surveys have been utilized to monitor changes in mackerel abundance. The spring index is based on survey catches in sampling strata 1-25 and 61-76 (Figure 2). The autumn index was previously based on data from strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, and 25-26; however, in the present analysis, catches in strata 1-42 and 49 were employed.

When the analysis of bottom trawl survey data was initiated for mackerel (Anderson 1973), the indicated strata set for the autumn survey was selected as representing the area where most of the mackerel catches were consistently made at that time of year. This area included all sampling strata less than 110 m in depth extending from Hudson Canyon through Georges Bank and along the east side of Cape Cod north to Cape Ann, Massachusetts. During the 1970's, survey catches of mackerel diminished in response to declining stock abundance, and a greater proportion of the mackerel catch, particularly young-of-the-year fish, came from strata in the Gulf of Maine and on the Nova Scotian shelf. This change in location may have been in response to the general warming trend in water temperature throughout the area in the 1970's (Davis 1979), which may have resulted in a more northerly summer distribution of mackerel and/or a delay in the

southerly migration towards overwintering grounds. Anderson and Almeida (1977) were able to associate northward shifts in spring survey catches of mackerel during this period with the increase in water temperature. Because of the increased proportion of autumn catches of mackerel in strata not previously included in the analysis, it was decided to establish a new strata set incorporating all strata from Hudson Canyon to LaHave Bank on the Scotian shelf. The new strata set, therefore, effectively encompasses NAFO Div. 6A, Subarea 5, and Div. 4X.

Catch-per-tow indices (kg, retransformed) from the spring and autumn surveys have monitored the gross changes in mackerel abundance since 1963 (Table 7, Figure 3). Following a continuous sharp decrease since 1970 to a low of 0.20 kg in 1977, the spring index has since begun to increase. After rising to 0.45 kg in 1978, catch per tow declined to 0.22 kg in 1979 but increased to 0.35 kg in 1980. In spite of the year-to-year fluctuations, the index has undergone a net increase from 1977 to 1980, suggesting an improvement in mackerel abundance.

The autumn survey index (Table 7, Figure 3) has, in spite of substantial annual fluctuations, exhibited close agreement with the spring index in monitoring the relative changes in mackerel abundance. From a peak of 0.19 kg in 1969, the autumn index decreased to a low of 0.01 kg in 1975, but increased steadily to 0.10 kg in 1978. Even though the index declined to 0.06 kg in 1979, the net improvement since 1975 is indicative of an increase in mackerel abundance.

The standardized US commercial catch-per-day index (Anderson 1976) increased from 0.48 tons in 1978 to 0.69 tons in 1979, a 44% improvement

(Table 8, Figure 4). The 1979 value is the highest observed since 1972, and suggests, as do the recent research vessel survey indices, an increase in mackerel abundance. Although catches from which this index is calculated have represented a very small fraction of the total catch from the stock (an average of less than 1% per year) (Anderson 1976, 1979), the index has generally monitored the gross changes in mackerel abundance since 1964 and is in general agreement with other measures of stock abundance. At the present time, it constitutes the only available time-series of commercial catch-per-unit-effort (CPUE) data for mackerel in the Northwest Atlantic.

NATURAL MORTALITY

Instantaneous natural mortality (M) was assumed to be 0.30 for all ages in all years, as adopted previously by scientists in the ICNAF Assessments Subcommittee (ICNAF 1974).

FISHING MORTALITY

Instantaneous fishing mortality (F) for fully-recruited age groups of mackerel in the most current year of catch-at-age data was estimated, in previous assessments (e.g. Anderson and Overholtz 1979), from a linear relationship between mean annual F values derived from cohort analysis and relative exploitation indices (ratios between international catch and NMFS, NEFC spring survey catch per tow). This method was first proposed for mackerel by Anderson et al. (1976). Application of this method suggested an F of 0.19 in 1979. This estimate, as well as that calculated

for 1978 (0.14), appeared to be high when compared with the F values determined for 1964-66 (about 0.04) when (1) catches were only slightly less than in 1978-79 (17,600-26,800 vs 34,400-35,700 tons), (2) standardized US commercial CPUE was similar to that in 1978-79 (0.43-0.84 vs 0.48-0.69 tons per day, and (3) stock biomass estimates from preliminary computations were comparable to those for 1978-79. In addition, the linear regression between fishing mortality and relative exploitation intercepted the y-axis at 0.10 implying that even in the absence of a fishery (zero catch), F would be 0.10. Since the relative exploitation index for 1979 was near the extreme lower left-hand portion of the regression line (implying a low level of fishing mortality), it was decided to examine other data sets to find a relationship to estimate the current level of fishing mortality.

A power curve fit between mean annual F and fishing effort expressed as equivalent US standardized days fished (international catch divided by US standardized CPUE) for 1964-77 (Table 9, Figure 5) with a correlation coefficient (r) of 0.885 ($p = 0.01$) provided a fairly consistent relationship between these two parameters over a broad range of values and also provided a realistic intercept of the y-axis (e.g. $F = 0$ when fishing effort = 0). The only adjustment made to the CPUE data base before calculating fishing effort was to replace the value of 0.17 tons per day for 1974 (Table 8, Figure 4) with 0.53, which was the value for both 1973 and 1975. It was felt that the sharp drop in 1974 to 0.17 tons per day was not indicative of the actual abundance of mackerel in that year, given that CPUE varied only slightly (0.48-0.59) in other years during 1973-78. Using 0.17 tons per day would have implied a level of fishing effort

vastly excessive to that in adjacent years and grossly out of proportion to fishing mortality in 1974.

Mean annual F values for ages 3 and older from virtual population analysis (VPA) (Gulland 1965), assuming F = 0.10 at ages 4 and older in 1979, were regressed against fishing effort values for 1964-77. The F for 1979 predicted from this regression was used as the terminal F in a second VPA. The VPA-regression process was followed through several iterations until the terminal F used in the VPA was the same as that predicted by the regression. An F of 0.084 was thus estimated for ages 4 and older in 1979.

Age-specific F values for 1962-78 estimated from VPA are given in Table 10. Mean annual F for ages 3 and older increased from 0.03 in 1962-64 to a high of 0.40 in 1976 and then declined to 0.065 in 1978.

F in 1976 was estimated to be 0.67 in the previous assessment (Anderson and Overholtz 1979) compared to 0.40 determined herein. The 41% reduction in F in 1976 is a consequence of the fact that F in 1978 was calculated to be 58% lower in the current analysis (0.065) than assumed in the previous assessment (0.153). Estimates of F for all years prior to 1978 decreased herein at a progressively decreasing rate until 1970, when the current F was only 5% less than the previous estimate. The decrease in F for some of the years during 1970-78 was due, in part, to the decrease in the recreational component of the total catch. Decreases in F during 1962-69, which averaged over 15% each year, were virtually all due to the downward adjustment to recreational catch.

RECRUITMENT

The sizes of the 1961-75 year classes at age 1, estimated from VPA, ranged from 317 million (1975 year class) to 7,816 million fish (1967 year class) (Table 10, Figure 10), with a mean size of 2,126 million and a median size of 1,872 million.

Power curve relationships, fitted by least squares, between (1) autumn survey catch per tow at age 0 (numbers, retransformed) and year-class size at age 1 estimated from VPA for 1963-75 (Table 11, Figure 6), (2) spring survey catch per tow at age 1 and year-class size at age 1 for 1967-75 (Table 11, Figure 7), and (3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-75 (Table 11, Figure 8) were used to estimate the sizes of the 1976-79 year-classes.

The 1976 year class was estimated to be 516 and 246 million fish at age 1 based on the autumn age 0 and spring age 1 survey catch-per-tow indices, respectively, and 493 million at age 2 based on the spring age 2 index (Table 11, Figures 6-8). The catch (C_1) of 2.0 million fish at age 1 in 1977 (Table 5) and a year-class size (N_2) of 493 million fish at age 2 in 1978 implied from:

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

an F_1 in 1977 of 0.00347. From the relationship:

$$\frac{N_2}{N_1} = e^{-(F_1+M)} \qquad (3)$$

where M = 0.3, a year-class size of 668 million at age 1 (N_1) was determined. An additional estimate of the size of the 1976 year class at age 1 was 37 million obtained from VPA assuming an F of 0.084 (100% recruitment to the fishery) at age 3 in 1979. Given that 100% recruitment occurred at age 3 every year during 1973-77 except 1975 (75%), full recruitment at age 3 in 1979 must be considered a possibility. Based on four estimates of its size at age 1 (516, 246, 668, and 37 million fish), which averaged 366 million, the 1976 year-class was assumed to be 350 million at age 1.

The 1977 year class was estimated to be 1,154 and 594 million fish at age 1 based on the autumn age 0 and spring age 1 survey catch-per-tow indices, respectively, but only 52 million fish at age 2 based on the spring age 2 index (Table 11, Figures 6-8). The catch (C_1) of 108,000 fish at age 1 in 1978 and a year-class size (N_2) of 52 million fish at age 2 in 1979 implied from Equations 2 and 3 a year-class size (N_1) of 72 million at age 1. In view of the estimates of 1,154 and 594 million, the estimate of 72 million was considered to be unrealistically low. As discussed by Anderson and Overholtz (1979), the spring survey catch of mackerel dropped unexpectedly in 1979, due in part perhaps to warmer water temperatures relative to 1978, and was not indicative of actual mackerel abundance. The estimate of 72 million fish at age 1 was, therefore, not considered, and the 1977 year class was assumed to be 900 million fish at age 1 based on the remaining two estimates which averaged 874 million.

The 1978 year class was estimated to be 3,391 and 288 million fish at age 1 based on the autumn age 0 and spring age 1 survey indices, respectively, and 761 million at age 2 based on the spring age 2 index (Table 11, Figures

6-8). The catch (C_1) of 409,000 fish at age 1 in 1979 (Table 3) and a year-class size (N_2) of 761 million fish at age 2 in 1980 implied from Equations 2 and 3 a year-class size (N_1) of 1,028 million at age 1. As indicated earlier, the 1979 spring survey catch of mackerel was unexpectedly low; therefore, the estimate of 288 million at age 1 based on the 1979 spring age 1 index was considered to be unrealistic.

An attempt was made to adjust for the unusually low spring catch-per-tow index at age 1 in 1979. The catch-per-tow index at age 2 in 1979 (1977 year class) predicted a year class of only 52 million at age 2 and 72 million at age 1 compared to estimates of 1,154 and 594 million at age 1 based on age 0 and 1 survey indices. Assuming that the mean (874 million) of the latter two estimates represented the true size of the 1977 year class at age 1, the catch of 108,000 fish from that year class at age 1 in 1978 implied a year-class size of 647 million at age 2 in 1979, instead of 52 million. The survey catch-per-tow index at age 2 in 1979 needed to predict 647 million fish from the power curve relationship (Table 11, Figure 8) would be 0.326 instead of 0.009, the former differing from the latter by a factor of 36.22. Assuming that the spring survey catch rate of age 1 mackerel in 1979 was proportionately as low as the catch rate of age 2 mackerel, the age 1 catch-per-tow index of 0.029 was increased by the factor of 36.22, resulting in a corrected index of 1.050. A year-class size of 1,654 million fish at age 1 was predicted from the power curve relationship (Table 11, Figure 7) using the index of 1.050. Therefore, based on estimates of 3,391, 1,028, and 1,654 million (average = 2,024 million), the 1978 year-class at age 1 was considered to be 2,000 million fish.

The 1979 year class at age 1 was estimated to be 864 and 455 million fish, based on the autumn age 0 and spring age 1 survey indices, respectively (Table 11, Figures 6-7). Based on these two estimates which averaged 660 million, the 1979 year class was considered to be 650 million at age 1.

For the purpose of catch and stock size projections and lacking any information, the 1980 year-class size at age 1 was set conservatively at 300 million, which was the approximate size of the poorest year class observed (1975).

Results of VPA and estimates based on survey catch-per-tow-at-age indices indicate that the 1978 year class is the largest to enter the fishery since the 1974 year class (Table 10). The 1975-77 and 1979 year classes all appear to be poor.

PARTIAL RECRUITMENT

Partial recruitment of an age group to the fishery in a given calendar year is defined here as the ratio of F at that age to the average F of fully-recruited ages in that year. Examination of age-specific F values from VPA (Table 10) indicates that mackerel have, on average, become fully recruited to the fishery by about age 3. Partial recruitment ratios or coefficients for the international fishery in SA 2-6 during 1962-79 for ages 1-3 varied from <1 to 100% (average = 27%) at age 1, 1 to 100% (average = 50%) at age 2, and 9 to 100% (average = 70%) at age 3 (Table 12). Partial recruitment was especially high (71%) at age 1 in 1975 (1974 year class), with full recruitment of that year class at ages 2 and older. The 1973 and 1975 year

classes were only 12% recruited at age 1, but were completely recruited at age 2. Full recruitment (at or near 100%) at age 3 occurred in 44% of the years during 1962-79 and in 73% of the years during 1967-77, the latter being the period of the intensive international fishery.

Partial recruitment at age 1 decreased sharply from 71% in 1975 to 12% in 1976 and was less than 1% in 1978-79 (Table 12). Similarly, partial recruitment at age 2 declined from 97% in 1977 to only 2% and 1% in 1978 and 1979, respectively, and at age 3 from 100% in 1977 to 60% in 1978 and 9% in 1979. These decreases in partial recruitment imply corresponding declines in fishing mortality at those ages relative to the F at older ages. The percentage contribution of young fish to the total catch in the last several years has decreased markedly, and year classes since 1974 (except 1978) are estimated to be weak. The sharp decreases in percentage age composition may signify a shift in fishing effort away from young fish towards older fish. It is also possible that the recent low partial recruitment coefficients are underestimated. This would have occurred if recent year-class sizes were, in fact, overestimated resulting in underestimates of fishing mortality at those ages.

Since a high proportion of the international catch in the last several years was taken by Canada (74% in 1978 and 85% in 1979), it was decided to examine the age composition of the Canadian catch for 1968-79 (Table 13) and estimate age-specific F values applicable to that catch. Age-specific F values for the Canadian fishery were determined by applying the ratio between the Canadian catch in numbers (Table 13) and the international catch in numbers (Table 5) at each age in each calendar year to the appropriate

F calculated from VPA for the international fishery (Table 10). Partial recruitment coefficients for ages 1-3 were calculated (Table 14) in the same way as described earlier for the international fishery.

The catch age composition and partial recruitment coefficients for the Canadian fishery were generally similar to those for the international fishery, although partial recruitment, on average (for 1968-79) was lower in the Canadian fishery (17 vs 18% at age 1; 36 vs 52% at age 2; 66 vs 79% at age 3).

Since the low partial recruitment coefficients estimated in 1978-79 at ages 1-3 for both the Canadian and international fisheries fall within the range of previous values, they are considered potentially valid. However, since there is no evidence to indicate a dramatic shift by the Canadian fishery from past patterns or in the geographic distribution of young fish, there is a high probability that these coefficients are too low, with the most likely explanation being that recent year classes may, in fact, be weaker than estimated herein.

For the purpose of catch and stock size projections, the mean partial recruitment coefficients from the Canadian fishery during 1968-79 (excluding from consideration the high and low values at each age) were chosen to represent expected conditions in the fishery in 1980-81. These coefficients were 15% at age 1, 35% at age 2, and 70% at age 3, with 100% recruitment at ages 4 and older (Table 15).

STOCK SIZE

Age-specific stock size estimates generated from VPA and annual

biomass values obtained by applying mean weights at age (Table 6) to the stock size estimates are given in Table 10. Total stock biomass (ages 1 and older) increased from about 600,000 tons during 1962-66 to 2.6 million tons in 1970 (Figure 10) and then declined to about 640,000 tons in 1978. The total stock has since increased nearly 28% to an estimated 816,000 tons at the beginning of 1980.

Spawning stock biomass, defined as 50% of the age 2 fish and 100% of ages 3 and older, increased from an average of 487,000 tons during 1962-67 (range = 385,000 - 538,000 tons) to 2.1 million tons in 1971 followed by a drop to an estimated 515,000 tons in 1979. The spawning stock estimate at the beginning of 1980 was 622,000 tons, a 20% increase from 1979.

EQUILIBRIUM YIELD

Long-term equilibrium conditions were simulated for the SA 2-6 mackerel resource by assuming constant recruitment each year at age 1 equivalent to the median level (1,670 million fish) estimated for 1962-80 (1961-79 year classes). Partial recruitment to the fishery was assumed equal to average 1962-79 conditions: 25% at age 1, 50% at age 2, and 70% at age 3, with 100% recruitment at ages 4 and older. Mean weights at age for catch, which also represented average conditions in the fishery during 1962-79, and for stock are given in Table 6.

Results (Figure 9) indicate that equilibrium yield is maximized (224,000 tons) at a fishing mortality rate (F_{max}) of 1.2. Equilibrium yield at $F_{0.1}$ = 0.4, the level of F at which the change in yield with respect to the change in F is only 10% of that which would occur if the

fishery began on a virgin stock (Gulland and Boerema 1973), would be 200,000 tons. These values of equilibrium yield are less than the maximum sustainable yield estimates of 310,000 tons (Anderson 1973) and 263,000 tons (Walter 1975) calculated for this stock using the Schaefer (1954, 1957) model.

Total stock biomass would decrease from 1.9 million tons in the absence of a fishery (virgin stock) to 861,000 tons with fishing mortality maintained at $F_{0.1}$ and to 481,000 tons with F at F_{max}. Spawning stock biomass would decrease from 1.65 million tons in a virgin state to 601,000 tons at $F_{0.1}$ and 239,000 tons at F_{max}.

In addition to simulating potential long-term yield levels under conditions of a constant level of recruitment, these results illustrate the long-term effect of different management strategies. For example, the benefits of maintaining F at the $F_{0.1}$ level vs the F_{max} level are clearly evident. Increasing fishing mortality from 0.4 ($F_{0.1}$) to 1.2 (F_{max}) (a 200% increase) would generate only a 12% increase in yield, but would result in a 44% decrease in total stock biomass and a 60% decrease in spawning stock biomass. This simulation of equilibrium yield assumes no stock-recruitment relationship.

CATCH AND STOCK SIZE PROJECTIONS

Projections of spawning stock biomass available at the beginning of 1981 were made assuming variable levels of catch in 1980 ranging between 35,000 and 100,000 tons (Table 16). Fishing mortality rates estimated to produce these catches varied from 0.066 to 0.199. Spawning stock biomass available at the beginning of 1981 was estimated to range from

728,000 tons (17% increase from 1980) to 669,000 tons (8% increase from 1980) given a 1980 catch varying from 35,000 to 100,000 tons.

Projected catches in 1981 at F values ranging from 0.05 to 0.40 and resultant spawning stock biomass levels available at the beginning of 1982 were estimated (Table 17) for each 1980 catch option. Given a 1980 catch of 35,000 tons, or about the same level as in 1978-79, the catch in 1981 would range from 30,000 tons at F = 0.05 to 212,000 tons at F = 0.40. Resultant spawning stock biomass at the beginning of 1982, given this range in catch in 1981, would vary from 698,000 tons (12% increase from 1980 and 4% decrease from 1981) to 534,000 tons (14% decrease from 1980 and 27% decrease from 1981).

Assuming a catch in 1980 of 100,000 tons, the catch in 1981 would range from 28,000 tons at F = 0.05 to 194,000 tons at F = 0.40. Spawning stock biomass in 1982 would range from 648,000 tons (4% increase from 1980 and 3% decrease from 1981) to 498,000 tons (20% decrease from 1980 and 26% decrease from 1981).

DISCUSSION

Available data indicate that the mackerel resource in SA 2-6 is now beginning to rebuild following its rapid and precipitous decline in abundance in the 1970's. Catches in 1978-79 were only 8% of the peak level in 1973, and fishing mortality in 1978-79 was only about 20% of the peak level in 1976. Of concern, however, is the fact that all year classes since 1974 (except 1978) appear to be poor. The 1973 and 1974 year classes have dominated the catch since 1975. The substantial variability in the estimates of year-class strength obtained from research vessel

bottom trawl survey catch data casts considerable uncertainty on the sizes of recent year-classes assumed herein. The extremely low partial recruitment coefficients at ages 1-3 determined for the last several years suggest the possibility that recent year classes may, in fact, be weaker than assumed. In view of these uncertainties, projected levels of catch and stock must be viewed as only approximate.

Improvements in recruitment will be necessary to insure the continued recovery of the mackerel resource. Based on the 1962-79 spawning stock-recruitment pattern, the probability of improved recruitment should increase as the spawning stock continues to rebuild. During 1962-79, the estimated spawning biomass was less than 700,000 tons in half of those years (averaging 511,000 tons per year) and only 33% of the year classes produced were above median size. In contrast, in the remaining years, when spawning biomass exceeded 700,000 tons (averaging 1,417,000 tons per year), 78% of the year classes produced were at or above median size.

The simulation of equilibrium yield and stock biomass under conditions of constant recruitment at the median level observed during 1962-79 indicates that maintaining fishing mortality at $F_{max} = 1.2$ would result in a spawning biomass of about 240,000 tons, and at $F_{0.1} = 0.4$ a spawning biomass of about 600,000 tons. Since observations suggest only a 33% probability of obtaining at least median-sized year classes when the spawning stock is less than 700,000 tons, constant fishing at the above F levels would very likely not be sustainable.

Recognizing that environmental factors, particularly climatic conditions (Murray et al. 1980) over which man has no control, are strongly

instrumental in determining mackerel year-class size, management must be cognizant of the fact that building a large spawning stock for the purpose of enhancing recruitment prospects does not insure concomitant strong recruitment. However, the establishment of a spawning stock in excess of some pre-determined minimal level does provide a reserve or buffer which would serve to support the maintenance of a desired level of yield even in the event of the recruitment of a weak year class or several weak year classes due to the influence of unpredictable and uncontrollable climatic conditions.

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Table 1. Mackerel catch (tons) from NAFO SA 2-6 during 1960-69.

Year	US Commercial	US Recreational	Canada	Other countries	Total
1960	1,396	2,478	5,957	-	9,831
1961	1,361	3,022	5,459	11	9,853
1962	938	3,565	6,801	175	11,479
1963	1,320	3,981	6,363	1,299	12,963
1964	1,644	4,343	10,786	801	17,574
1965	1,998	4,292	11,185	2,945	20,420
1966	2,724	4,535	11,577	7,951	26,787
1967	3,891	4,498	11,181	19,047	38,617
1968	3,929	7,781	11,134	65,747	88,591
1969	4,364	13,050	13,257	114,189	144,860
1970	4,049	16,039	15,710	210,864	246,662
1971	2,406	16,426	14,942	355,892	389,666
1972	2,006	15,588	16,254	391,464	425,312
1973	1,336	10,723	21,619	396,759	430,437
1974	1,042	7,640	16,701	321,837	347,220
1975	1,974	5,190	13,544	271,719	292,427
1976	2,712	4,202	15,746	223,275	245,935
1977	1,377	522	20,362	56,067	78,328
1978	1,605	6,571	25,429	841	34,446
1979	1,989	2,992	30,237	440	35,658

Table 2. Mackerel catch (tons) in 1979 by country and subarea from NAFO SA 2-6.

Country	Subarea 2	3	4	5	6	Total
Bulgaria	-	-	52	-	-	52
Canada	5	14,839	15,393	-	-	30,237
Cuba	-	-	50	-	-	50
Italy	-	-	-	28	-	28
Japan	-	-	-	6	2	8
Mexico	-	-	-	12	-	12
Romania	-	-	-	8	2	10
Spain	-	-	-	5	-	5
USSR	-	-	266	1	8	275
US (comm.)	-	-	-	1,091	898	1,989
US (rec.)	-	-	-	1,419	1,573	2,992
Total	5	14,839	15,761	2,570	2,483	35,658

Table 3. Age composition (thousands of fish at age) of the 1979 commercial and recreational catch of mackerel from NAFO SA 2-6.

		Age														
Country	Area	1	2	3	4	5	6	7	8	9	10	11	12	13+	Total	Tons
Sampled Commercial catch																
Canada	SA 3	-	7.8	759.2	3,809.4	7,608.6	4,300.2	2,531.8	1,135.5	932.8	483.1	1,342.1	-	-	22,910.5	14,839
Canada	SA 4	197.5	458.0	393.5	2,603.6	9,067.9	7,644.6	2,887.5	1,076.8	717.3	253.1	304.2	-	-	25,604.0	14,475
Romania	Subdiv. 5Ze-Div. 6A (Feb)	-	-	-	0.9	2.9	2.3	2.9	5.7	2.6	0.9	-	-	-	18.2	10
US	Div. 6A (Apr-May)	-	-	4.3	12.7	78.2	12.8	34.9	24.0	53.1	197.7	31.7	153.9	116.9	720.2	512
US	Div. 5Y (Jul-Aug)	177.1	46.3	2.5	15.9	19.3	9.2	1.6	1.9	-	-	-	-	-	273.8	81
Total		374.6	512.1	1,159.5	6,442.5	16,776.9	11,969.1	5,458.7	2,243.9	1,705.8	934.8	1,678.0	153.9	116.9	49,526.7	29,917
Unsampled commercial catch																
Canada	SA 2															5
Canada	SA 4															918
US	SA 5-6															1,396
Others	SA 4-6															430
Total																2,749
Total commercial catch[1]		409.0	559.2	1,266.0	7,034.5	18,318.5	13,068.9	5,960.3	2,450.1	1,862.5	1,020.7	1,832.2	168.0	127.6	54,077.5	32,666
Sampled recreational catch																
US	SA 5-6	-	8.1	8.1	28.2	277.7	76.5	233.4	136.8	309.9	1,171.3	309.9	809.0	656.1	4,025.0	2,992
Total catch		409.0	567.3	1,274.1	7,062.7	18,596.2	13,145.4	6,193.7	2,586.9	2,172.4	2,192.0	2,142.1	977.0	783.7	58,102.5	35,658

[1]Total numbers at age from sampled commercial catch raised to include unsampled commercial catch.

Table 4. Percentage age composition of the US recreational mackerel catch from the Middle Atlantic area (NAFO SA 6) in 1978-80.

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1978	-	0.1	2.4	7.7	5.6	12.0	10.1	2.9	22.9	2.4	26.8	3.4	3.7	-
1979	-	0.2	0.2	0.7	6.9	1.9	5.8	3.4	7.7	29.1	7.7	20.1	6.0	10.3
1980	-	<0.1	1.7	1.5	3.8	8.5	5.9	4.0	7.5	8.9	25.8	6.2	18.0	8.2

Table 5. Mackerel commercial and recreational catch at age (millions of fish) from NAFO SA 2-6 during 1962-1979.

	Age																
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13+	Total	Tons[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	-	-	1004.2	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	-	-	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	-	-	1073.7	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	-	-	1409.0	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	-	-	1075.8	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	-	-	1267.9	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	0.6	-	-	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	4.9	0.9	-	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	2.1	1.0	0.8	58.2	35.7	6.1

[1]Thousands of tons.

Table 6. Mean weight at age (kg) of Atlantic mackerel calculated from growth and length-weight parameters.

Age	Stock[1]	Catch[2] (1980-81)	Catch[3] (1962-79 average)
1	.096	.143	.130
2	.178	.231	.216
3	.267	.320	.306
4	.353	.405	.392
5	.436	.480	.469
6	.507	.546	.536
7	.570	.601	.593
8	.622	.646	.640
9	.661	.683	.678
10	.695	.713	.709
11	.725	.737	.733
12	.743	.756	.753
13	.761	.771	.769
14	.774	.782	.781
15	.786	.792	.790

[1]On January 1.

[2]At about first week in August.

[3]At about second week in June.

Table 7. Stratified mean catch (kg) per tow (linear, ln, and retransformed) 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.

	Spring[1]			Autumn[2]		
Year	Linear	Ln	Retransformed	Linear	Ln	Retransformed
1963	-	-	-	.02	.02	.02
1964	-	-	-	<.01	<.01	<.01
1965	-	-	-	.04	.02	.03
1966	-	-	-	.04	.02	.04
1967	-	-	-	.32	.09	.15
1968	18.23	.58	4.00	.14	.06	.10
1969	.18	.03	.06	1.11	.08	.19
1970	7.14	.47	2.04	.05	.03	.05
1971	10.21	.42	1.97	.04	.03	.04
1972	5.01	.35	1.33	.15	.06	.11
1973	21.90	.23	.75	.05	.03	.05
1974	2.10	.28	.77	.10	.03	.05
1975	.50	.12	.26	.01	.01	.01
1976	.82	.14	.32	.04	.03	.04
1977	.27	.12	.20	.05	.03	.04
1978	1.12	.18	.45	.16	.06	.10
1979	.29	.12	.22	.08	.04	.06
1980	.66	.17	.35	-	-	-

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

[2]Based on catches with No. 36 trawl.

Table 8. Mackerel catch per standardized US day fished.

Year	Catch per day (tons)
1964	0.43
1965	0.49
1966	0.84
1967	1.75
1968	2.80
1969	1.92
1970	2.07
1971	1.29
1972	0.84
1973	0.53
1974	0.17
1975	0.53
1976	0.59
1977	0.52
1978	0.48
1979	0.69

Table 9. Estimation of fishing mortality (F) in 1979 for the NAFO SA 2-6 mackerel fishery.

Year	US std. catch per day (tons)	International catch (tons)	Fishing effort[2]	F[3]
1964	.43	17,574	40,870	.032
1965	.49	20,420	41,673	.043
1966	.84	26,787	31,889	.049
1967	1.75	38,617	22,067	.089
1968	2.80	88,591	31,640	.123
1969	1.92	144,860	75,448	.116
1970	2.07	246,662	119,160	.164
1971	1.29	389,666	302,067	.230
1972	.84	425,312	506,324	.266
1973	.53	430,437	812,145	.364
1974	(.53)[1]	347,220	655,132	.387
1975	.53	292,427	551,749	.319
1976	.59	245,935	416,839	.396
1977	.52	78,328	150,631	.155
1978	.48	34,446	71,763	.065
1979	.69	35,658	51,678	(.084)[4]

[1] Actual value of 0.17 replaced by 1973 and 1975 mean (see text for explanation).

[2] Expressed as equivalent US standardized days fished.

[3] Weighted mean fishing mortality for ages 3 and older obtained from virtual population analysis assuming F = 0.084 at ages 4 and older in 1979.

[4] Predicted from regression of fishing effort on F for 1964-77: $\ln Y = -8.723 + 0.575 \ln X$, $r = 0.885$.

Table 10. Fishing mortality rates (F) and stock size (millions of fish) by age for mackerel in NAFO SA 2-6 derived from virtual population analysis assuming M = 0.30 at all ages and F = 0.084 at ages 4 and older in 1979.

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13+	100% Recruitment Mean F	100% Recruitment Age
	Fishing mortality														
1962	.020	.004	.023	.106	.038	.037	.030	.066	.092	.024	(.030)[1]	-	-	.030	3+
1963	.003	.007	.003	.057	.272	.013	.006	.006	.023	(.033)[1]	(.033)[1]	-	-	.033	3+
1964	.037	.027	.009	.011	.060	.340	.262	.030	(.032)[1]	(.032)[1]	-	-	-	.032	3+
1965	.020	.014	.015	.013	.020	.088	.805	.532	(.043)[1]	-	-	-	-	.043	3+
1966	.024	.036	.029	.019	.020	.042	.148	.225	(.049)[1]	-	-	-	-	.049	3+
1967	<.001	.038	.089	.027	.033	.031	.046	.383	.229	-	-	-	-	.089	3+
1968	.021	.028	.122	.276	.162	.094	.006	.010	.127	(.123)[1]		-	-	.123	3+
1969	.002	.055	.107	.216	.067	.051	.041	.035	.031	.286		-	-	.116	3+
1970	.065	.024	.164	.168	.147	.121	.134	.327	.169	.077	(.164)[1]	-	-	.164	3+
1971	.047	.149	.081	.297	.365	.311	.250	.141	.258	.224	(.230)[1]	-	-	.230	3+
1972	.014	.078	.209	.177	.393	.295	.417	.199	.613	.429	(.266)[1]	-	-	.266	3+
1973	.119	.269	.446	.336	.321	.398	.182	.386	.342	.751	(.364)[1]	-	-	.364	3+
1974	.047	.292	.490	.316	.306	.352	.450	.250	.461	.408	(.387)[1]	-	-	.387	3+
1975	.226	.346	.242	.394	.342	.338	.307	.442	.207	.336	(.319)[1]	-	-	.319	3+
1976	.047	.390	.434	.326	.414	.296	.392	.390	.410	.402	(.396)[1]	-	-	.396	3+
1977	(.007)[2]	.150	.204	.158	.076	.141	.101	.107	.074	.116	.031	-	-	.155	3+
1978	(<.001)[2]	(.001)[2]	.039	.054	.059	.078	.102	.058	.115	.042	.256	.065	-	.065	3+
1979	(<.001)[2]	(.001)[2]	(.008)[2]	.084	.084	.084	.084	.084	.084	.084	.084	.084	.084	.084	4+

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13+	Age 1+ Numbers	Age 1+ Weight[4]	Spawning Stock[3] Numbers	Spawning Stock[3] Weight[4]	Spawning Stock[3] Mean Age
	Stock size (millions)																	
1962	939.3	764.1	759.9	43.5	37.3	51.4	55.2	14.6	5.2	4.9	11.8	-	-	2687.2	542.7	1366.2	384.5	3.3
1963	418.1	682.2	564.3	550.2	29.0	26.6	36.7	39.7	10.1	3.5	3.5	-	-	2363.9	589.9	1604.7	489.0	3.5
1964	407.3	309.5	502.3	418.2	385.1	16.3	19.4	27.0	29.2	7.3	-	-	-	2121.8	604.4	1559.8	537.8	4.0
1965	516.1	290.8	223.3	368.8	306.5	268.7	8.6	11.1	19.4	-	-	-	-	2013.3	585.6	1351.8	510.2	4.4
1966	1152.2	374.7	212.4	163.0	269.8	222.7	182.4	2.9	4.8	-	-	-	-	2584.8	631.0	1245.2	487.0	4.6
1967	3308.3	832.8	267.7	152.8	118.5	195.9	158.1	116.5	1.7	-	-	-	-	5152.4	906.0	1427.7	514.3	4.3
1968	7816.5	2538.7	594.2	181.4	110.2	85.0	140.8	112.0	58.9	1.0	-	-	-	11638.6	1705.6	2552.8	729.3	3.3
1969	3546.3	5670.3	1828.5	389.5	101.9	69.4	57.3	103.8	82.1	38.4	-	-	-	11887.6	2233.3	5506.2	1388.2	2.9
1970	3529.5	2624.0	3976.6	1217.3	232.4	70.6	48.9	40.8	74.3	58.9	21.4	-	-	11894.5	2593.2	7053.0	2020.8	3.3
1971	1872.3	2449.5	1897.3	2500.1	762.7	148.6	46.4	31.7	21.8	46.5	40.4	-	-	9817.1	2534.8	6720.0	2137.0	3.7
1972	1887.6	1323.4	1563.2	1296.6	1376.4	392.1	80.6	26.8	20.4	12.5	27.5	-	-	8007.0	2195.5	5457.7	1896.5	4.0
1973	1669.8	1379.6	907.1	939.6	804.7	688.1	216.2	39.4	16.2	8.2	6.0	-	-	6674.9	1848.0	4315.3	1564.9	4.2
1974	2393.5	1098.8	780.8	430.2	497.4	432.5	342.4	133.5	19.8	8.5	2.9	-	-	6140.3	1521.2	3197.4	1193.6	4.4
1975	2123.7	1691.0	607.8	354.5	232.4	271.2	225.4	161.8	77.0	9.3	4.2	-	-	5758.2	1320.6	2789.0	966.2	4.1
1976	316.8	1254.6	886.0	353.4	177.0	122.3	143.3	122.8	77.0	46.4	4.9	-	-	3504.6	999.0	2560.5	856.9	4.0
1977	(350.0)[5]	224.0	629.3	425.2	188.9	86.7	67.4	71.7	61.6	37.9	23.0	-	-	2165.7	684.7	1703.7	631.2	4.4
1978	(900.0)[5]	257.6	142.8	380.0	268.9	129.7	55.7	45.1	47.8	42.4	25.0	16.5	-	2311.5	638.8	1282.7	529.5	5.0
1979	(2000.0)[5]	666.6	190.6	101.8	266.7	187.8	88.9	37.3	31.5	31.5	30.1	14.3	11.5	3658.5	766.8	1325.3	515.5	4.7
1980	(650.0)[5]	1481.3	493.3	140.1	69.3	181.7	127.9	60.6	25.4	21.5	21.5	20.5	17.5	3310.6	816.1	1920.0	621.9	3.9

[1] Mean F for ages 3 and older in that year

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

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

[4] Thousands of tons

[5] Estimated

Table 11. Stratified mean catch per tow (number, retransformed) of age 0, 1, and 2 mackerel from NMFS, NEFC autumn and spring bottom trawl surveys and year-class sizes at ages 1 and 2 from virtual population analysis (VPA) assuming F = 0.084 at ages 4 and older in 1979.

	Autumn survey	Spring survey	Spring survey	VPA	
Year class	Age 0	Age 1	Age 2	Age 1	Age 2
1963	0.053	-	-	407.3	290.8
1964	0.009	-	-	516.1	374.7
1965	0.055	-	-	1152.2	832.8
1966	0.088[1]	-	1.726	3308.3	2538.7
1967	0.619	40.240	0.198[1]	7816.5	5670.3
1968	0.039[1]	0.238[1]	2.625	3546.3	2624.0
1969	0.289	1.010	2.779	3529.5	2449.5
1970	0.023	0.929	1.368	1872.3	1323.4
1971	0.068	1.894	0.787	1887.6	1379.6
1972	0.076	0.915	0.383	1669.8	1098.8
1973	0.236	0.826	1.277	2393.5	1691.0
1974	0.089	3.186	0.787	2123.7	1254.6
1975	0.009	0.204	0.109	316.8	224.0
1976	0.012	0.021	0.221	(515.5)[2]	(246.5)[3] (493.0)[4]
1977	0.045	0.128	0.009	(1153.6)[2]	(594.0)[3] (52.5)[4]
1978	0.264	0.029	0.411	(3391.3)[2]	(288.4)[3] (760.9)[4]
1979	0.028	0.074	-	(864.0)[2]	(455.0)[3] -

[1] Values not used in calculating curves.

[2] Calculated from power curve relationship between survey catch per tow at age 0 and year-class size at age 1 for 1963-75 year-classes: $\ln Y = \ln 7635.939 + 0.609 \ln X$, $r = 0.853$.

[3] Calculated from power curve relationship between survey catch per tow at age 1 and year-class size at age 1 for 1967-75 year-classes: $\ln Y = \ln 1615.450 + 0.487 \ln X$, $r = 0.829$.

[4] Calculated from power curve relationship between survey catch per tow at age 2 and year-class size at age 2 for 1966-75 year-classes: $\ln Y = \ln 1417.377 + 0.700 \ln X$, $r = 0.950$.

Table 12. Percentage of fishing mortality (F) at ages 1, 2, and 3 compared to the weighted mean F at ages 3 and older for the international mackerel fishery in NAFO SA 2-6.

Year	Age 1	Age 2	Age 3
1962	67	13	77
1963	9	21	9
1964	100	84	28
1965	47	33	35
1966	49	73	59
1967	<1	43	100
1968	17	23	99
1969	2	47	92
1970	40	15	100
1971	20	65	35
1972	5	29	79
1973	33	74	100
1974	12	75	100
1975	71	100	76
1976	12	98	100
1977	4	97	100
1978	<1	2	60
1979	<1	1	9

Table 13. Age composition (thousands of fish at age) of the Canadian mackerel catch in NAFO SA 2-6 during 1968-79.

	Age														
Year	0	1	2	3	4	5	6	7	8	9	10	11+	Total	Tons	% of total
1968	-	22,991	3,821	5,522	3,947	1,505	720	385	885	5,566	52	-	45,394	11,134	12.6
1969	-	4,049	18,751	12,845	1,442	661	608	782	313	329	6,869	-	46,649	13,257	9.2
1970	-	15,165	2,733	25,117	6,018	1,867	337	318	1,180	1,230	871	2,371	57,207	15,710	6.4
1971	922	4,365	4,507	1,038	21,917	4,648	1,069	1,344	931	1,146	605	2,760	45,252	14,942	3.8
1972	-	-	99	3,199	4,028	18,046	3,616	3,815	56	397	2	4,965	38,223	16,254	3.8
1973	254	5,139	11,550	5,404	5,227	7,825	12,485	4,658	1,552	469	375	523	55,461	21,619	5.0
1974	-	3,223	9,103	9,987	5,461	4,710	4,644	5,751	1,516	641	315	339	45,690	16,701	4.8
1975	-	5,306	9,302	4,874	4,346	2,634	2,811	2,038	1,463	308	121	96	33,299	13,544	4.6
1976	-	803	10,082	12,910	5,230	3,686	1,842	2,344	1,894	1,487	340	215	40,833	15,746	6.4
1977	-	647	6,243	19,742	9,902	3,222	2,248	708	1,262	785	1,204	302	46,265	20,362	26.0
1978	-	2	182	3,831	14,733	11,575	6,358	3,157	1,649	1,402	1,098	1,399	45,386	25,429	73.8
1979	-	204	480	1,189	6,615	17,202	12,321	5,590	2,282	1,702	759	1,698	50,042	30,237	84.8

Table 14. Percentage of fishing mortality (F) at ages 1, 2, and 3 compared to the weighted mean F at ages 3 and older for the Canadian mackerel fishery in NAFO SA 2-6 during 1968-79.

Year	Age 1	Age 2	Age 3
1968	17	11	61
1969	12	50	100
1970	56	11	89
1971	33	22	11
1972	0	1	30
1973	29	79	57
1974	11	61	100
1975	23	54	77
1976	14	46	96
1977	6	100	100
1978	<1	2	67
1979	<1	1	9

Table 15. Summary of parameters used in projection of catch and stock size options for mackerel in NAFO SA 2-6.

Parameter		Value
Fishing mortality (F) in 1979 (ages 4 and older)		0.084
Recruitment at age 1:	1976 year class	350×10^6 fish
	1977 year class	900×10^6 fish
	1978 year class	$2,000 \times 10^6$ fish
	1979 year class	650×10^6 fish
	1980 year class	300×10^6 fish
Partial recruitment in 1980-81:	Age 1	15%
	Age 2	35%
	Age 3	70%
	Ages 4 and older	100%
Total stock biomass at beginning of 1980		816,100 tons
Spawning stock biomass at beginning of 1980		621,900 tons

Table 16. Various levels of projected catch of mackerel in NAFO SA 2-6 in 1980 and associated fishing mortality (F) at ages 4 and older with resulting spawning stock biomass in 1981 and its percentage change from 1980. Catch and stock are expressed as thousands of tons.

Stock in 1980	Catch in 1980	F in 1980	Stock in 1981	% change in stock from 1980
621.9	35.0	0.066	727.7	+17.0
621.9	40.0	0.076	723.2	+16.3
621.9	50.0	0.096	714.1	+14.8
621.9	60.0	0.116	705.0	+13.4
621.9	70.0	0.136	695.9	+11.9
621.9	80.0	0.157	686.8	+10.4
621.9	90.0	0.178	677.8	+ 9.0
621.9	100.0	0.199	668.7	+ 7.5

Table 17. Projected mackerel catch in NAFO SA 2-6 in 1981 with fishing mortality ranging from 0.05 to 0.40 assuming eight options for catch in 1980, and the resulting spawning stock biomass in 1982 and its percentage change from 1980 and 1981. Catch and stock are expressed as thousands of tons.

Fishing mortality (F)	Catch in 1981	Stock in 1982	% Change in stock from 1980	% Change in stock from 1981	Catch in 1981	Stock in 1982	% Change in stock from 1980	% Change in stock from 1981	Catch in 1981	Stock in 1982	% Change in stock from 1980	% Change in stock from 1981
	1980 catch = 35.0				1980 catch = 40.0				1980 catch = 50.0			
0.05	30.3	697.6	+12.2	- 4.1	30.1	693.8	+11.6	- 4.1	29.7	686.2	+10.3	- 3.9
0.10	59.4	671.2	+ 7.9	- 7.8	59.1	667.6	+ 7.3	- 7.7	58.3	660.3	+ 6.2	- 7.5
0.15	87.4	645.9	+ 3.9	-11.2	86.8	642.5	+ 3.3	-11.2	85.7	635.5	+ 2.2	-11.0
0.20	114.3	621.6	0.0	-14.6	113.5	618.3	- 0.6	-14.5	112.1	611.7	- 1.6	-14.3
0.25	140.1	598.4	- 3.8	-17.8	139.2	595.2	- 4.3	-17.7	137.4	588.9	- 5.3	-17.5
0.30	164.9	576.1	- 7.4	-20.8	163.8	573.1	- 7.9	-20.8	161.7	567.0	- 8.8	-20.6
0.35	188.7	554.7	-10.8	-23.8	187.5	551.8	-11.3	-23.7	185.1	546.0	-12.2	-23.5
0.40[1]	211.6	534.2	-14.1	-26.6	210.2	531.4	-14.5	-26.5	207.5	525.9	-15.4	-26.4
	1980 catch = 60.0				1980 catch = 70.0				1980 catch = 80.0			
0.05	29.3	678.6	+ 9.1	- 3.7	29.0	671.0	+ 7.9	- 3.6	28.6	663.4	+ 6.7	- 3.4
0.10	57.5	653.1	+ 5.0	- 7.4	56.8	645.8	+ 3.8	- 7.2	56.0	638.5	+ 2.7	- 7.0
0.15	84.6	628.6	+ 1.1	-10.8	83.5	621.6	0.0	-10.7	82.3	614.7	- 1.2	-10.5
0.20	110.6	605.1	- 2.7	-14.2	109.1	598.4	- 3.8	-14.0	107.7	591.8	- 4.8	-13.8
0.25	135.6	582.5	- 6.3	-17.4	133.8	576.2	- 7.4	-17.2	132.0	569.8	- 8.4	-17.0
0.30	159.6	560.9	- 9.8	-20.4	157.5	554.9	-10.8	-20.3	155.4	548.8	-11.8	-20.1
0.35	182.6	540.2	-13.1	-23.4	180.2	534.4	-14.1	-23.2	177.8	528.6	-15.0	-23.0
0.40[1]	204.8	520.3	-16.3	-26.2	202.1	514.8	-17.2	-26.0	199.4	509.2	-18.1	-25.9
	1980 catch = 90.0				1980 catch = 100.0							
0.05	28.2	655.9	+ 5.5	- 3.2	27.8	648.3	+ 4.2	- 3.1				
0.10	55.2	631.3	+ 1.5	- 6.9	54.5	624.0	+ 0.3	- 6.7				
0.15	81.2	607.7	- 2.3	-10.3	80.1	600.8	- 3.4	-10.2				
0.20	106.2	585.1	- 5.9	-13.7	104.7	578.5	- 7.0	-13.5				
0.25	130.2	563.5	- 9.4	-16.9	128.4	557.1	-10.4	-16.7				
0.30	153.3	542.7	-12.7	-19.9	151.2	536.6	-13.7	-19.7				
0.35	175.4	522.8	-15.9	-22.9	173.0	517.0	-16.9	-22.7				
0.40[1]	196.7	503.7	-19.0	-25.7	194.1	498.1	-19.9	-25.5				

[1] $F_{0.1}$

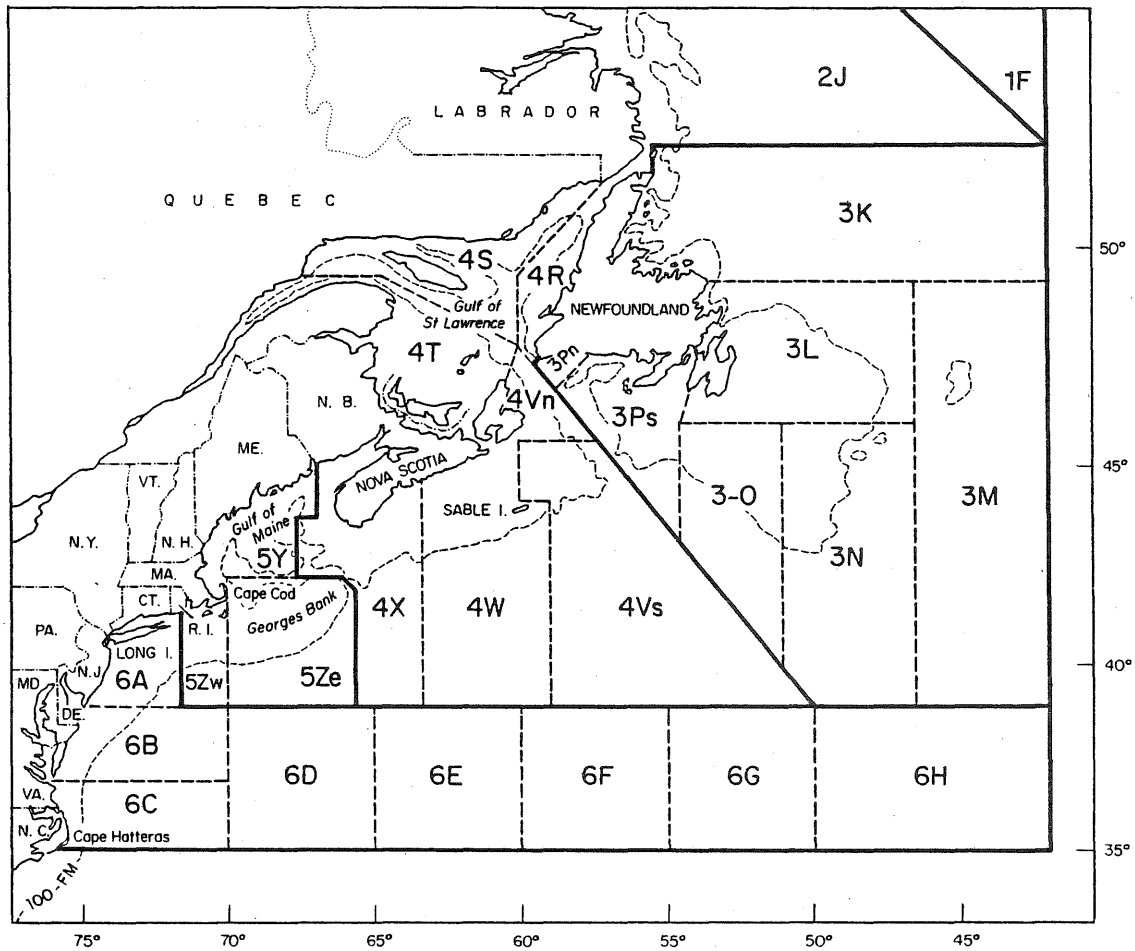

Figure 1. Northwest Atlantic from Labrador to North Carolina showing NAFO SA 2-6.

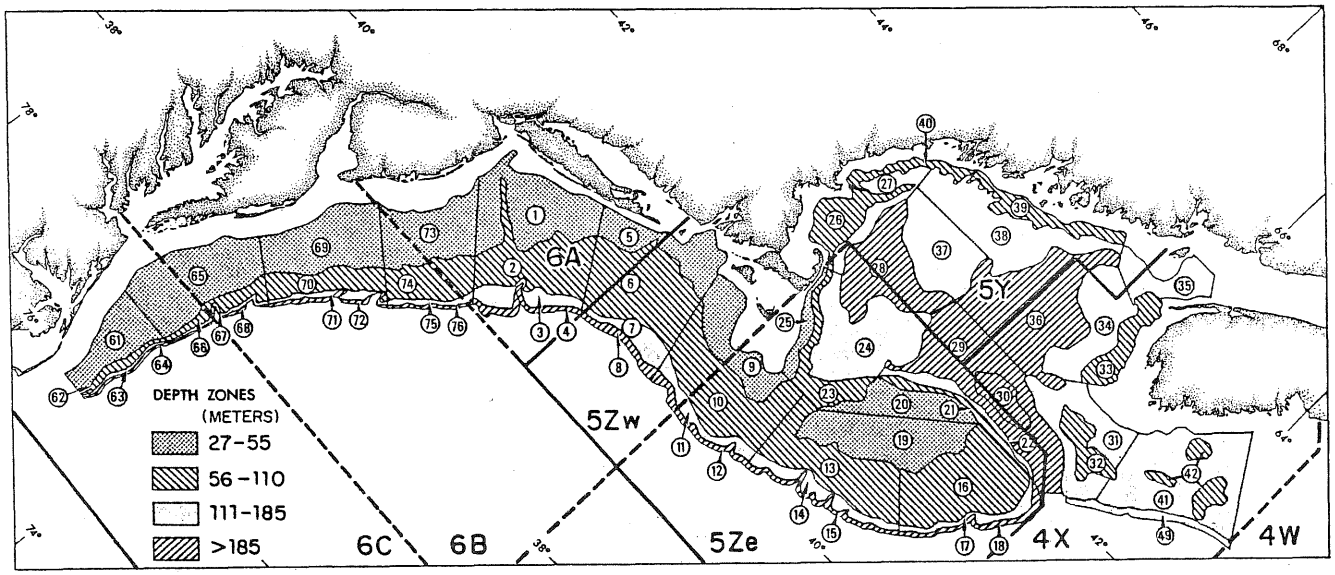

Figure 2. NMFS, NEFC bottom trawl survey sampling strata in the Northwest Atlantic between Cape Hatteras and Nova Scotia.

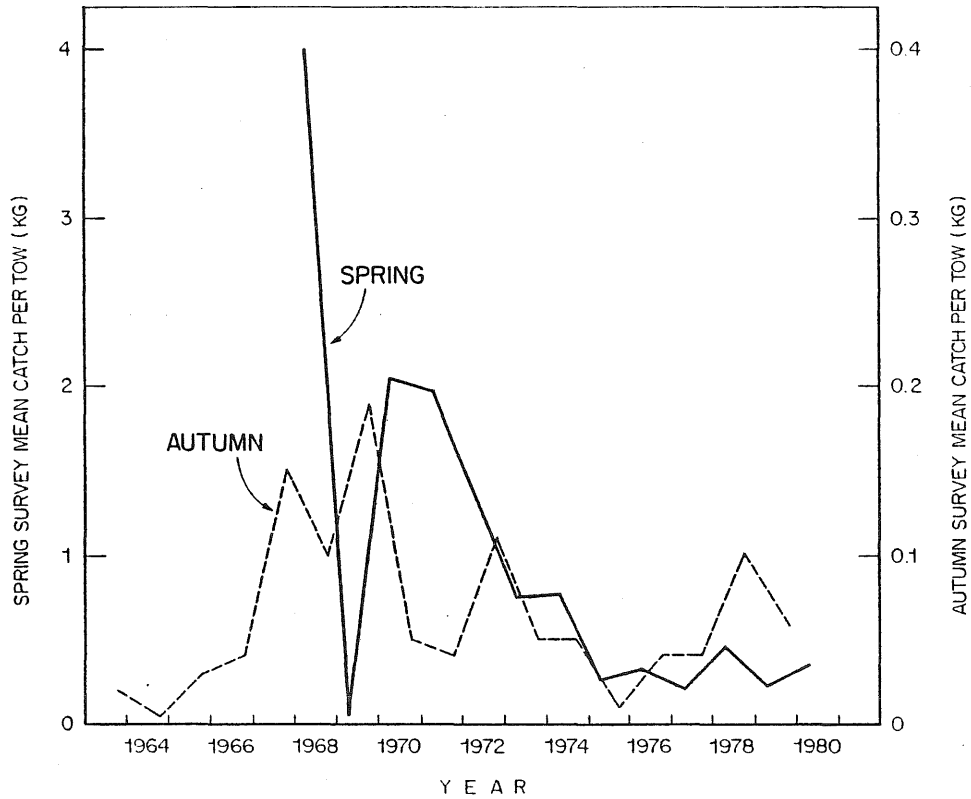

Figure 3. Stratified mean catch per tow (kg, retransformed) of mackerel from NMFS, NEFC spring (1968-80) and autumn (1963-79) bottom trawl surveys in NAFO SA 4-6.

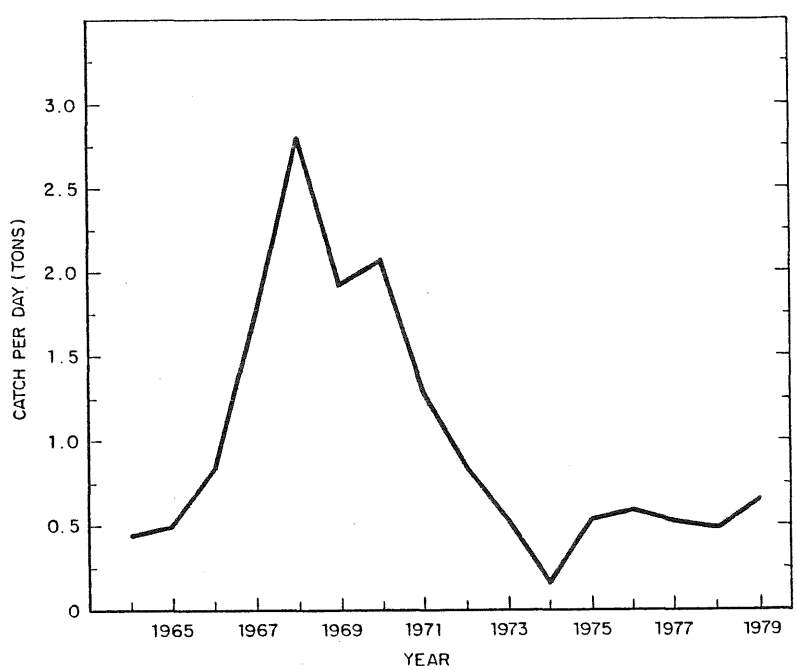

Figure 4. Catch per standardized day fished for the US commercial mackerel fishery in NAFO SA 5-6.

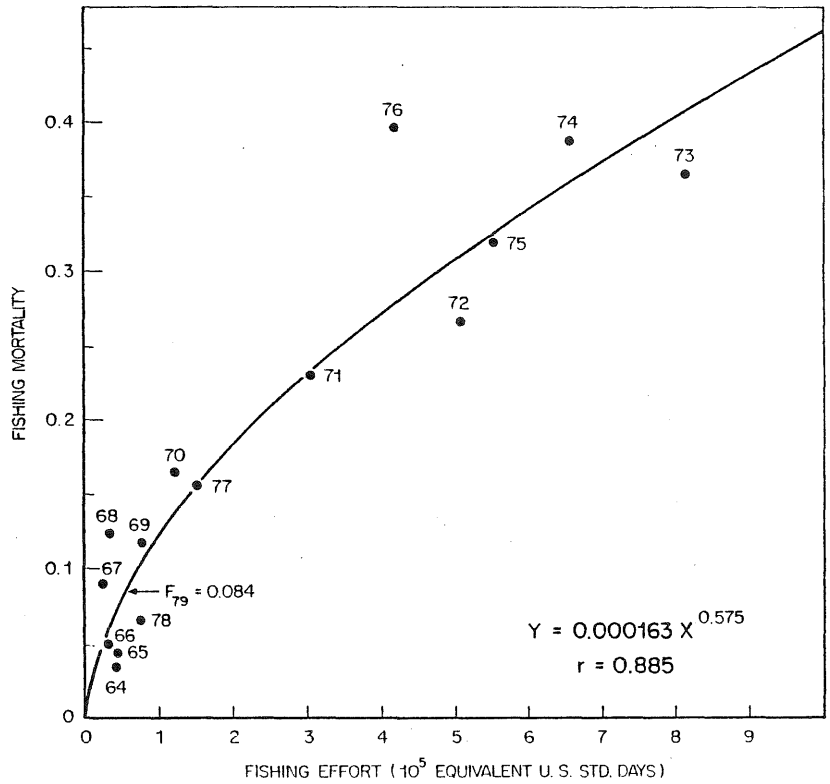

Figure 5. Relationship between fishing mortality from VPA assuming F = 0.084 at ages 4 and older in 1979 and fishing effort expressed as equivalent US standardized days fished in NAFO SA 2-6.

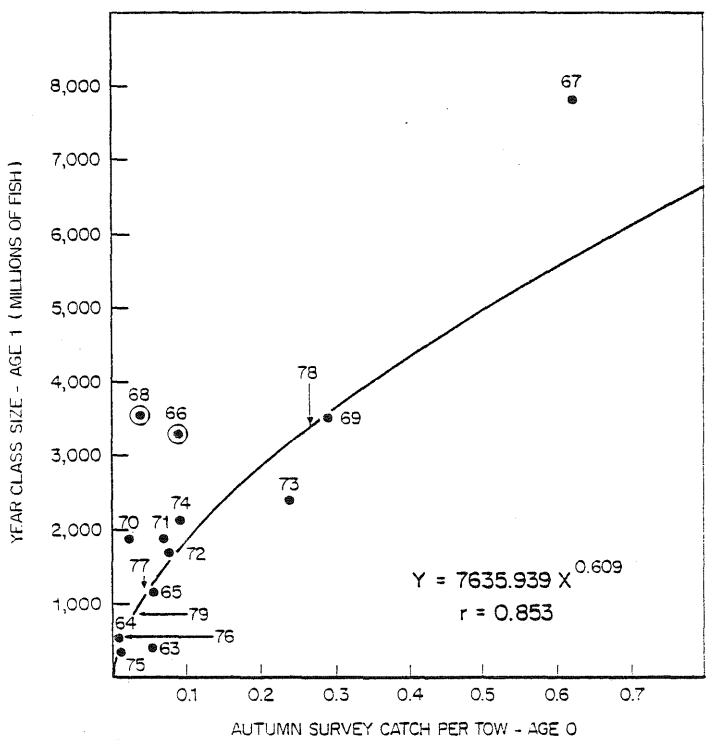

Figure 6. Power curve relationship between mackerel year-class size at age 1 from VPA assuming F = 0.084 at ages 4 and older in 1979 and NMFS, NEFC autumn survey catch per tow at age 0 (1966 and 1968 values omitted from calculation).

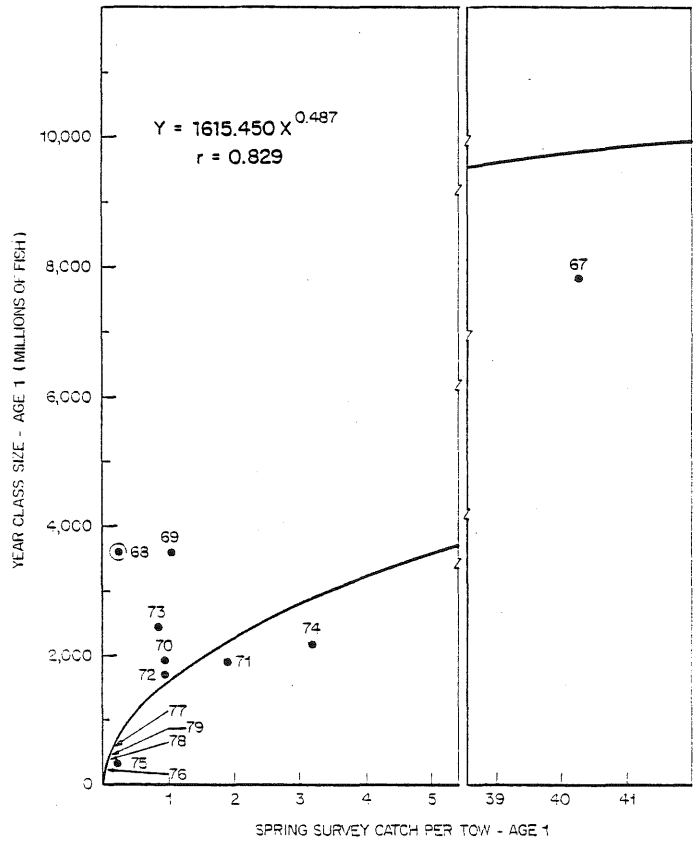

Figure 7. Power curve relationship between mackerel year-class size at age 1 from VPA assuming F = 0.084 at ages 4 and older in 1979 and NMFS, NEFC spring survey catch per tow at age 1 (1968 value omitted from calculation).

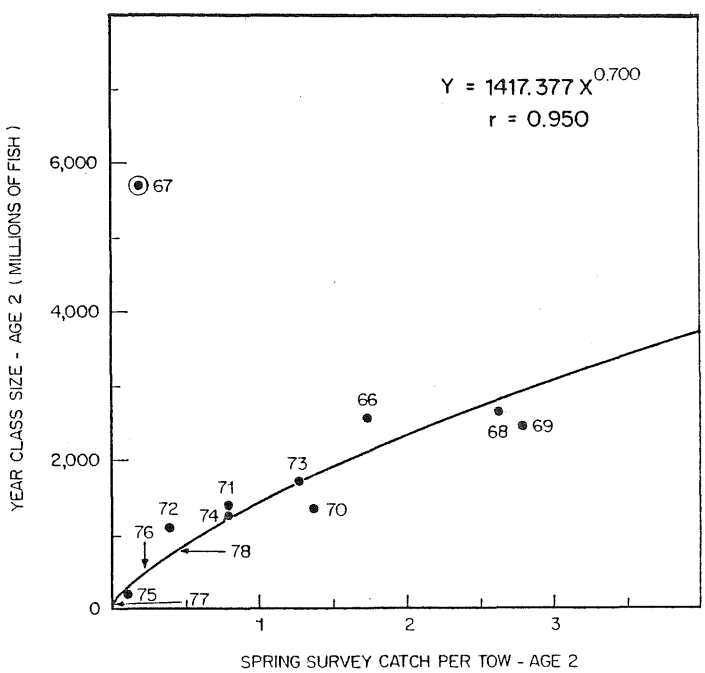

Figure 8. Power curve relationship between mackerel year-class size at age 2 from VPA assuming F = 0.084 at ages 4 and older in 1979 and NMFS, NEFC spring survey catch per tow at age 2 (1967 value omitted from calculation).

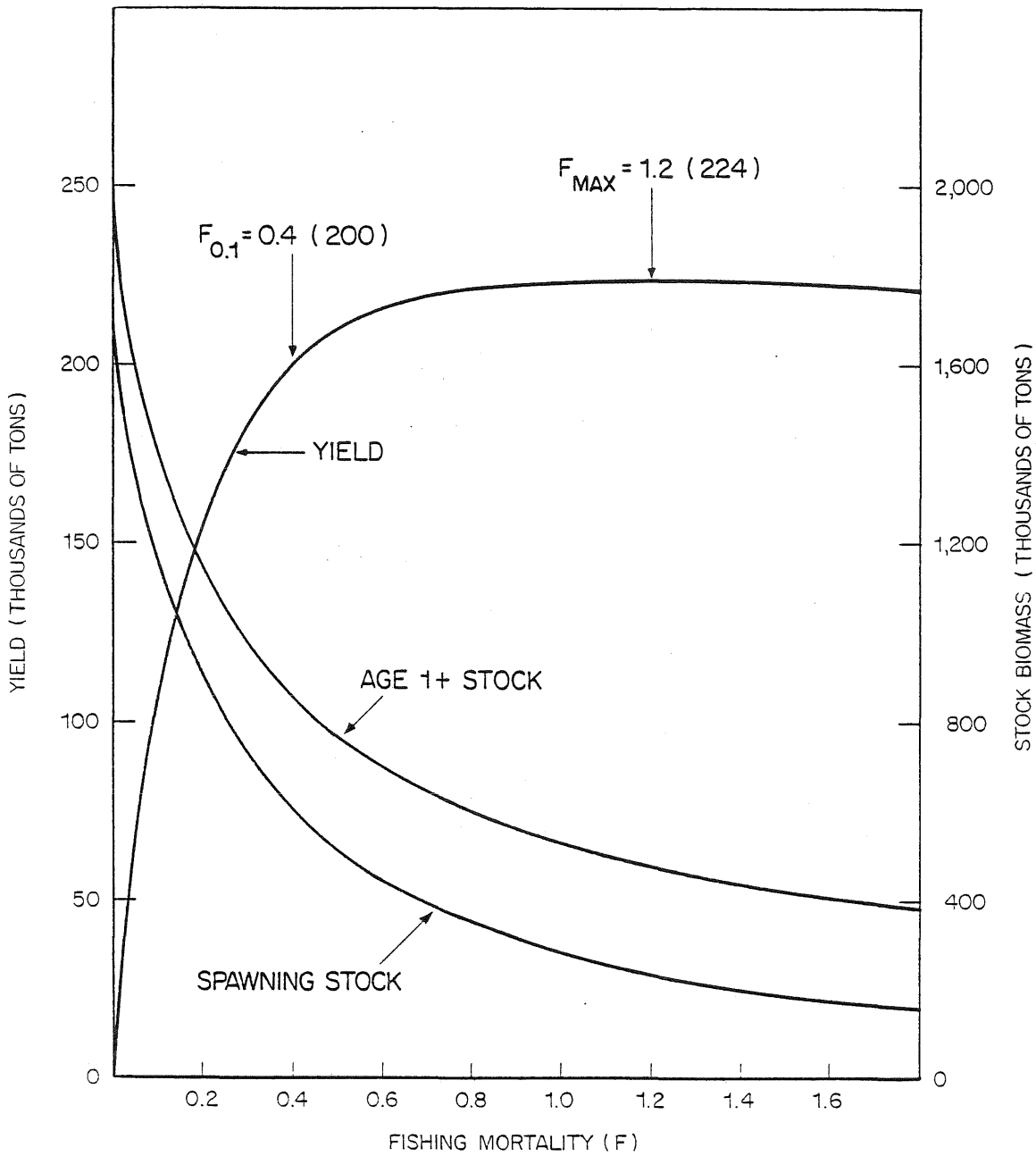

Figure 9. Equilibrium yield and stock biomass for mackerel in NAFO SA 2-6 assuming constant recruitment equivalent to the median level estimated during 1962-80.

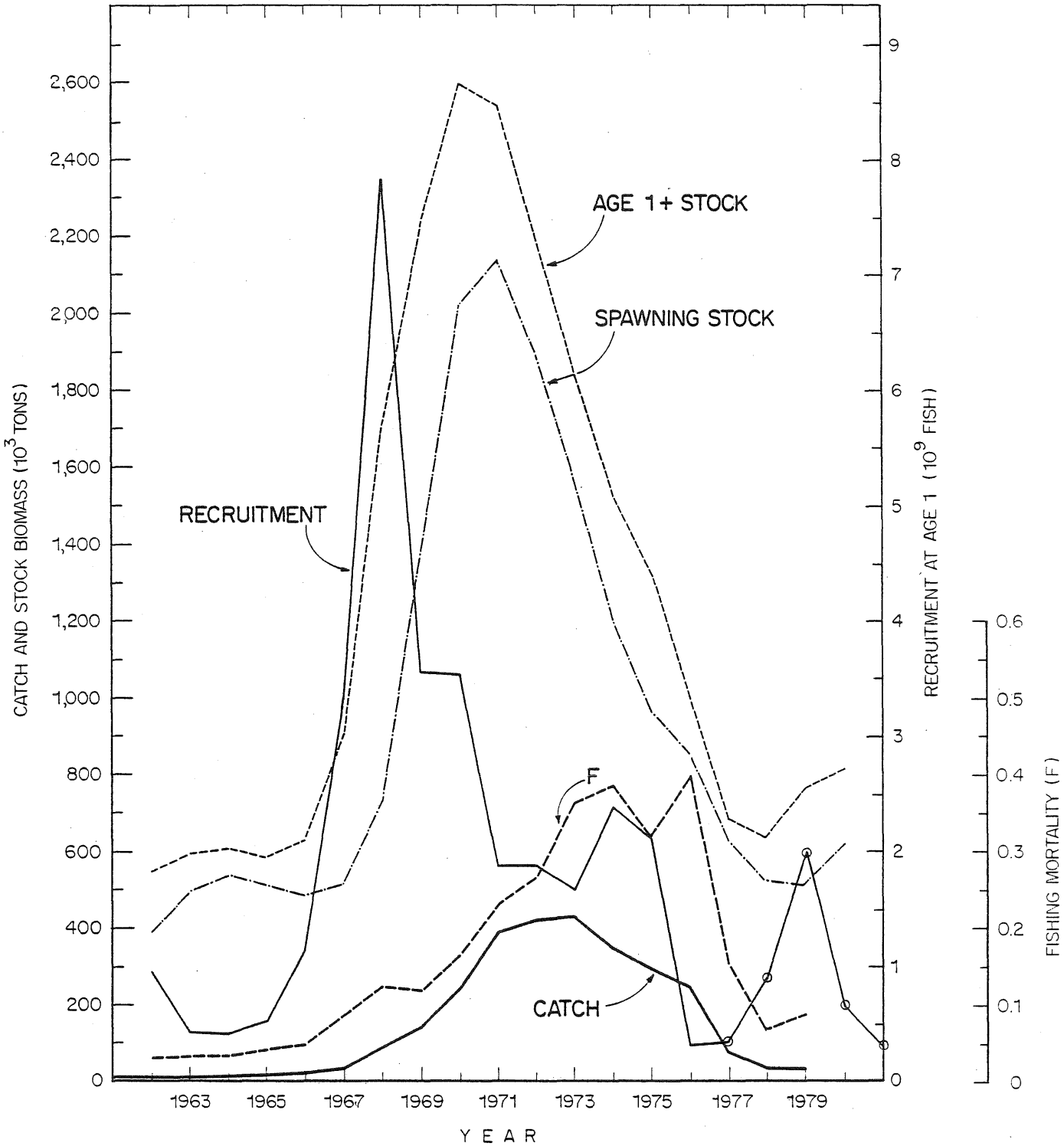

Figure 10. Total mackerel stock biomass (ages 1 and older) and spawning stock biomass (50% age 2 and 100% ages 3 and older) during 1962-80 determined from VPA assuming F = 0.084 at ages 4 and older in 1979; abundance at age 1 of the 1961-80 year classes (open circles represent estimates based on survey data, others determined from VPA); total international catch (commercial and recreational) during 1961-79; and fishing mortality (weighted mean for ages 3 and older, except for ages 4 and older in 1979) during 1962-79 in NAFO SA 2-6.