Canadian Atlantic Fisheries
Scientific Advisory Committee

CAFSAC
Research Document 80/65

An analytical assessment of mackerel in NAFO SA 3-6

by

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Abstract

Following a period of high exploitation by East European countries in the late sixties to mid seventies the nominal catches of Atlantic mackerel in NAFO SA 3-6 have decreased markedly since 1976 after Canada and the United States extented their jurisdiction over fisheries to 200 miles of their coast. The fishing mortalities on older age-groups appears to be below $F_{0.1}$ but recent year-classes (1975 onwards) are believed to be weak. A TAC of 150,000 t could be taken without adverse effects on the stock.

Résumé

Les captures de maquereau bleu dans les sous-régions OPANO 3-6 ont grandement diminué depuis 1976 à la suite de l'extension par le Canada et les U.S.A. de leur juridiction sur les pêches à 200 milles de leur côtes. De la fin des années soixante jusq'au milieu des années soixante-dix les pays de l'Est de l'Europe ont capturé d'importantes quantités de maquereau dans cette région. La mortalité par pêche sur les poissons âgés est probablement au-dessous de $F_{0.1}$ mais les jeunes classes d'âge (depuis 1975) semblent faibles. Un TPA de 150 000 t pourrait être capturé sans être dommageable au stock.

INTRODUCTION

After Canada and the United States extended their jurisdiction over fisheries to 200 miles of their coast in 1977 the mackerel catches in NAFO SA 3-6 decreased from 245,000 tons in 1976 to 78,000 tons in 1977 and 33,000 tons in 1978. This decrease was mainly due to restrictions on the fishing activities directed towards mackerel of East European countries in SA 5-6.

The interest of the so-called Distant Water Fleet in the mackerel fishery was minimal in the early sixties when Canada and the United States caught 99% of the total catch. The effort applied by other countries on mackerel gradually increased afterwards until the moderately strong 1966 year-class and very strong 1967 year-class started to recruit to the fishery causing a sudden increase of the proportion caught by the Distant Water Fleet Fishery. From 1962 to 1967 the total landings gradually increased from 16,000 tons to 48,000 tons, and averaged 26,740 tons. The Canadian and American catches increased marginally during that period and most of the increase was caught by other countries. With the recruitment of the 1966 and 1967 year-classes the catches more than doubled from 1967 to 1968 going to 110,000 tons from 48,000 tons. The catches increased steadily from then on until 1972 when they peaked at 431,000 tons and then slowly decreased to reach 245,000 tons in 1976 just prior to the extension of the jurisdiction by Canada and the U.S. The average catch during that period was about 300,000 tons. The first TAC was set at 450,000 tons in 1973 to limit the rapid expansion of the fishery in NAFO SA 5-6. The TAC was not reached in 1973 nor in any later years. Table 1 gives the catches since 1962 and associated TAC since 1973.

This paper presents an assessment of the status of the stock following the 1979 fishing season.

CATCH STATISTICS 1979

The total 1979 catch was 37,832 tons, of which Canada caught 78% (29,466 tons), the United States commercial fishery 5% (2,000 tons), the U.S. Recreational fishery 16% (6,000 tons) and other countries 1% (366 tons). The 1979 Canadian catch was almost equally divided between Maritimes-Quebec (14,913 tons) and Newfoundland (14,553 tons) a pattern similar to 1978 but different from historical pattern when the Newfoundland catch was always much lower than the Maritimes-Quebec catch. The fishery was concentrated in the last three quarters of the year: about 200 tons in the first quarter, about 8,000 in the second, 11,500 in the third and 10,500 in the fourth. The catch in the fourth quarter was almost entirely made by Newfoundland (close to 9,000 tons). The 1979 catch shows a slight increase over 1978, with both the Maritimes-Quebec and Newfoundland showing similar increases. Table 2 shows the catch breakdown in 1979.

CATCH AT AGE

The 1962 to 1978 catch at age was taken from Anderson and Overholtz (1979). The 1979 data was obtained from Hunt[1] (pers. comm.) for the Maritimes fishery and from Moores[2] (pers. comm.) for the Newfoundland fishery. The estimated removals at age from these two fisheries were prorated upwards to account for the unsampled catch in other areas and by other countries. Table 3 summarizes the 1979 catch at age information and Table 4 the 1962 to 1979 data. As in 1978, the 1973-1974 year-classes were dominant in the 1979 catch (59% of the total removals in number). The 1975 to 1978 year-classes together accounted for only 17% of the total removals in number. This can be compared to the average contribution of age-groups 1 to 4 of over 50% between 1968 and 1978 in the Canadian fishery even with the catches of the very strong 1967 year-class excluded from the calculations.

ABUNDANCE INDICES

For the last few years, the results of an annual (since 1976) mackerel egg survey in the Gulf of St. Lawrence have been used to calculate the mackerel spawning stock abundance (Maguire, 1979a; Maguire unpublished manuscript). Maguire (1979b) showed that the confidence interval associated with these calculations were fairly wide and re-analysis of the data indicated that the assumption about the duration of the spawning cycle may not always hold. Nevertheless the method was applied again this year. The method used to obtain the population estimates has been described in great detail in Maguire (1979b). Some minor technical modifications have been made to the methods of calculations and to the data set and are documented in Maguire (unpublished manuscript) but the model remains essentially unchanged. The results (Table 5) show a steady increase in egg production since 1976 and a corresponding increase in the spawning population abundance. Given that calculated stock abundance and known catches in 1979, the average fishing mortality (unweighted) for ages 2 to 10 would be 0.022. This is probably an underestimate due to the assumption about the duration of the spawning cycle.

Two other series of abundance indices were used: the American spring research survey catch-per-tow and the U.S. commercial catch per standardized day fished (Anderson and Overholtz, 1979; and Anderson[3], pers. comm. for the 1979 U.S. commercial value). The research and commercial data are respectively shown in Table 6 and 7 while Figure 1 combines both. Both series are unsmoothed and are very well correlated (r = 0.94) indicating that they probably measure the same thing (the 1969 point for the research data was interpolated). Figure 2 shows a plot of the research vessel survey data versus the commercial data.

The research CPUE indicates a continuous decline from 1968 to 1977 (3.998 kg/tow to .199 kg/tow) with a marked increase over 1977 in 1978

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and a return to a low value in 1979. Anderson and Overholtz (1979) believe that the 1979 catch/tow value does not reflect a decrease in abundance of the stock but would rather be due to sampling variability. It should also be noted that substantial quantities of mackerel caught during the spring 1979 American survey were not included in the average catch-per-tow calculations because they were caught in different strata than the ones traditionally used to calculate the index (Anderson, pers. comm.). Since there is no basis to correct the 1979 value, the actual observed datum was used bearing in mind that it is likely to be underestimated.

The U.S. commercial catch per standardized day reached a maximum at 2.8 t/day in 1968 and a minimum of 0.17 t/day in 1974. It then slowly increased to 0.620 t/day in 1979 with small dips in 1977 and 1978.

Both indices show a dramatic decline from 1968 to the mid-70's, 16 and 20 - fold respectively for the commercial and research data. However they differ on the indication of when the recovery started. The commercial data indicates an increase in 1975 over 1974 while according to the research data, the stock would have increased only in 1978.

ASSESSEMENT PARAMETERS

Natural Mortality

Winters (1978) using three techniques calculated an average natural mortality rate of 0.38 for mackerel. The most interesting technique used by Winters (1978) was probably his modification of the Paloheimo's method where he corrected for availability changes from one year to the next by:

$$(1) \quad CPU_t^1 = CPU_t \times q_{t+1}$$

where CPU_t = age specific catch per unit of effort in year t
q_t = catchability coefficient (estimated as the ratio of F/E from VPA with M = 0.3)

Once the CPUE at age for year t are corrected Z is calculated following Paloheimo's method. These Z values were then regressed against the average relative exploitation index calculated by Anderson and Overholtz (1979) and the intercept gave an estimate of M. Winters (1978) obtained an intercept value of 0.37 and accepted it as an estimate of M. In this analysis, the intercept value was used to run another VPA, recalculate the catchability coefficients, the Z values and the regression. Several iterations were run. In each case, the resultant intercept value was higher than the the initial input M until a value M of around 0.6 was used. The second method is described by Winters (1978): "Trial runs of cohort analysis (M = .35) indicate a rapid convergence of estimates of F in 1974 with varying input levels of F in the terminal year (1977). Consequently a functional regression of F (2+) from cohort analyses on the relative exploitation index was calculated for the period 1968-74 resulting in an intercept value of M = 0.36." An iterative process similar to the one described above was used and resulted in M stabilizing around .28. The third method (Silliman method) is very sensitive to initial assumptions and was not considered reliable enough to warrant treatment here. Given the conflicting results derived above, ICNAF agreed the value of M = 0.3 was used for all calculations.

FISHING MORTALITY

Plots of the research and commercial CPUE series against biomass from VPA showed that both relationships were curvilinear whatever the starting F was. This could be due to some density dependent variation in "q" where the availability coefficient would increase with increasing stock size. Although this could be a satisfactory explanation for the commercial data it would not be for the research data. Another hypothesis could be that the CPUE series from both the U.S. commercial fishery and the research vessel surveys do not adequately reflect the fluctuations in the population supporting the bulk of the fishery. Tagging studies (Beckett et al. 1979; Moores et al. 1975; Stobo 1976) indicated that the Distant Water Fleet fishery was exploiting the two known populations of mackerel in the Northwest Atlantic. But this does not disprove the hypothesis since the CPUE series may be entirely or partly based on only one of the two populations. If the contribution of that population to the total catch was comparatively small, even large fluctuations in its abundance would not necessarily be reflected in the main fishery.

The population biomass used to study the aforementioned relationship between population biomass and CPUE was obtained from VPA with a natural mortality rate of M = 0.3. Other VPA runs indicated that the relationship would be linear if M was increased to about 0.6. This, however, does not necessarily means that M is really 0.6. It only means that substantial quantities of fish may have died without being accounted for in the catch-at-age matrix. This may be an indication that the underreporting suspected by U.S. scientists after an analysis of the American surveillance data may have been fairly important (Brennan, 1976). Such mortality should thus be attributed to fishing activities and not to natural causes. Unfortunately there is no correction factors available at this time. This thus makes it impossible to use the CPUE vs biomass relationship to fine-tune VPA.

Using the CPUE data to calculate a relative exploitation index (total catch/CPUE = effort) avoids the curvilinearity problem since only the reported catch is used to calculate both the catch-at-age and the effort index. Athough it is known that there may be some autocorrelation problems with this method, lacking any other way of fine tuning VPA, the fishing mortality vs effort relationship was used.

The input parameters for virtual population analysis are: catch-at-age, natural mortality, fishing mortality at age for the last year and fishing mortality for the oldest age for each year. When, as it is the case for mackerel, the last row in the catch-at-age matrix represents the catches of several ages (11+) it is recommended to drop that combined age-grouping and use only the catch that is specifically attributed to a given year-class. The VPA was thus run with catches from ages 1 to 10 only. The yearly, weighted by population abundance, average F of age 6-7-8 was applied to the oldest age.

Preliminary runs of VPA were made using the partial recruitment multipliers given by Anderson and Overholtz (1979) and various starting fishing mortalities. These were used to calculate a new partial recruitment multipliers based on the fishing mortalities between 1968 and 1976. Since the results were not influenced significantly by varying the starting F, the multipliers obtained with a run at F_{79} = 0.1 was chosen (Table 8). This partial recruitment vector was used for subsequent fine tuning of VPA.

The indices of effort generated by dividing the total reported catch by the U.S. research vessel catch/tow (unsmoothed) and the U.S. commercial catch per standardized day fished were both used in regressions against F from VPA. The effort calculated for the commercial data for 1974 was very high and made that point an outlyer whatever the starting F was. The average CPUE of 1973 and 1975 (0.53 tow/day) was thus used to calculate a new effort value. A weighted average F was calculated for both ages 1 and older and ages 4 and older and regressed against both series of effort. Both ages 1+ and 4+ were used because the U.S. commercial fishery is generally catching significant amounts of the younger ages while these are probably not fully recruited to the research fishing gear. The highest correlations were obtained for the commercial data with a starting F of 0.05 for ages 1+ (r=.92) and starting F of 0.10 for ages 4+ (r=.93). However the relationship for ages 4+ was again curvilinear. Even increasing starting F to 0.4 did not remove the curvilinearity while the correlation coefficient went down to r=.76 (only 50% of the variance explained). The relationship for ages 1+ showed the same problem but the curvilinearity was less pronounced. The data points for 1972 to 1975 were lying on a line with a different slope. Thus it was felt that the commercial CPUE was not suitable for fine tuning VPA and the relationships derived from the research survey data were used.

The relationship between average F (1+) and research effort was marginally better than the relationship between average F (4+) but since the partial recruitment multipliers are not necessarily very accurate for young ages, the relationship for the age-group 4 and older was the final one choosen. The best relationship (r=0.87) was for a starting F=0.30 but the 1979 point was then clearly above the line. With F_{79}=0.25 the 1979 point was much closer to the line (2% difference) and the correlation coefficient equal to .86. Table 9 shows the results of the VPA runs with different starting F and Figure 4 shows the relationship between F and effort for a 1979 fully recruited F=0.25. This starting F produces relatively high F values for the period 1972 to 1976 during which the stock is known to have been fairly heavily exploited.

RECRUITMENT

Several relationships have been used to predict recruitment to this mackerel stock. Anderson and Overholtz (1979) used the U.S. research vessel survey catch per tow at age zero (0), one (1) and two. They fitted a power curve model to the data to obtain an intercept value close to zero. However there is no theoretical basis supporting such a model and Maguire (1979a) found that a linear model gave in all cases a better fit (much better in two of the three relationships). But the intercept values were very high thus making it impossible to predict year-class sizes lower than one (1) billion fish at age one (1), more than twice the size of the weakest year-classes observed. However these data can still be used to give an index of the relative size of the year-classes. The average year-class size for the 1963 to 1974 year-classes is 2,355 million fish at age one while the average catch at age zero during the U.S. Fall survey is 0.302 fish/tow. The ratio of the catch at age zero for the 1975 to 1978 year-class in the U.S. Fall survey to the average catch at age zero in the same survey should be an index of the relative strengths of these year-classes. This ratio multiplied by the average year-class size should give an index of the abundance. The U.S. Fall survey catch/tow at age zero and the U.S. spring survey catch/tow at age one and two data were used and the results are shown in Table 10.

These surveys thus indicate that the 1975 and 1976 year-class are about half (1/2) the size of the lowest observed while the 1977 would be one-third (1/3) the size of the lowest observed and the 1978 would be better than average.

Maguire (1979a) used the relationship between year-class size and the average summer temperature at Entry Island (Magdalen Islands, Quebec) to predict recruitment. Year-class size at age one for the 1961 to 1974 year-class from the VPA in this analysis were used. The data is presented in Table 11. An exponential model was fit to the data and resulted in the following equation (even without the 1967 point, the exponential model gives a much better fit than a linear model, r^2 = .79 compared to r^2 = .63 for the linear model).

$$\text{Year-class size} = 2.2746 \times 10^{-4} e^{1.1141 \times TEMP}$$

where $r^2 = 0.80$

Temp = average surface temperature at Entry Island for the months of June-July-August-September. This relationship predicted the following year-class strengths:

Year-class	Abundance at Age 1
1975	1952
1976	1651
1977	524
1978	2726
1979	5439

These are all much higher abundances than predicted from the U.S. surveys except for the 1978 year-class. However, the predictions from this relationship, although the fit is very good, should not necessarily be taken at face value because actual catches of fish are not included in the equation and since those year-classes have yet to show up significantly in the catches some caution seems warranted. On the other hand the year-class strengths predicted by the U.S. surveys could be too low maybe due to variations in the timing of the migration in relationship to the time of the survey or in the overwintering distributions.

If significant quantities of fish have been caught and not reported in the early to mid-seventies, the year-class strengths estimated by the VPA may be underestimated by a signficant amount. The average year-class size would then be higher than estimated in this analysis and the year-class strengths predicted from the relationships presented above would also be underestimated. Because the strengths of the 1975 to 1978 year-classes may be underestimated by the aforementioned relationships but since these have not contributed significantly to the catches a conservative but yet not pessimistic approach seems appropriate. These year-classes, for the purposes of this analysis, were thus assumed to be approximately the same strengths as the weakest year-classes observed or 500 million fish. Table 12 and 13 respectively show the population and fishing mortalities at age tables while Figure 5 shows the age one (1) and older biomass and catches since 1962.

YIELD-PER-RECRUIT

A Thompson-Bell yield-per-recruit analysis was performed with the partial recruitment multipliers given in Table 8 and the average weights observed in the 1979 fishery (Table 8) and a natural mortality rate of M=0.3. The maximum yield was 0.159 kg/recruit obtained at a fishing mortality of F=1.045 while $F_{0.1}$ was 0.454 and gave a yield of 0.144 kg/recruit or 91% of maximum yield (Figure 7).

PROJECTIONS

Projections to 1981 were made with the 1979 population abundance given in Table 12 and the partial recruitment multipliers of Table 8. The size of the 1979 and 1980 year-classes was assumed to be equal to the average of the 1961 to 1974 year-classes excluding the strong 1967 year-class (1667 million fish). The $F_{0.1}$ catch in 1980 and 1981 would respectively be 150,000 t and 160,000 t. If the 1979 and 1980 year-classes were as weak as the weakest observed, (500 million fish) the yield in 1980 and 1981 would respectively be 133,000 t and 104,000 t. However it should be realized that the weakest year-class size observed is not necessarily the weakest possible and there is indirect evidence that this mackerel stock can produce very weak year-classes. In the late 1800's the nominal catches dropped from about 105,000 t in 1884 to 13,000 tonnes in 1889 (Sette and Needler, 1934). The market for mackerel was then very good and even with an efficient mackerel fishing fleet in the U.S.A. searching actively for mackerel they were unable to achieve important catches. Sette (1950) felt that the year-classes produced after 1884 were very weak and caused the drop in landings. Given the partial recruitment multipliers presented in this assessment and using year-class sizes of 500 million fish, the equilibrium $F_{0.1}$ catch would be 72,000 t, much higher than the 13,000 t caught in 1889. This may be indicative that year-classes weaker than 500 million fish may be produced although different partial recruitment multipliers could generate lower catches if only very young or very old fishes were caught. The areas fished, the relative abundance of the northern and the southern population and the overwintering area may also have played in the low catches of the late 1880's but the production of very weak year-classes cannot be discarded as being a potentially very important factor in that case. Whatever the explanation, the fact still remains that the yield from this stock may at times be very low.

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Table 1. Mackerel nominal catch (tons) from NAFO SA 3-6 since 1962 and TAC since 1973.

Year	USA Commercial	USA Recreational	Canada	Other Countries	Total	TAC
1962	938	8698	6801	175	16612	-
1963	1320	8348	6363	1299	17330	-
1964	1644	8486	10786	801	21717	-
1965	1998	8583	11185	2945	24711	-
1966	2724	10172	11577	7951	32424	-
1967	3891	13527	11181	19047	47646	-
1968	3929	29130	11134	65747	109940	-
1969	4364	33303	13257	114189	165113	-
1970	4049	32078	15690	210864	262681	-
1971	2406	30642	14735	355892	403675	-
1972	2006	21882	16254	391464	431606	-
1973	1336	9944	21247	396759	429286	450000[3]
1974	1042	7640	16701	321837	347220	359000[4]
1975	1974	5968	13544	271719	293205	355000
1976	2712	4202	15746	223275	245935	310000
1977	1376	522	22477	53745	78120	105000
1978[1]	1604	6571	24444	831	33450	105000
1979[1]	2000[2]	6000	29466	366	37832	

[1] Provisional
[2] Estimated
[3] NAFO SA5-6 only
[4] NAFO SA3-6

Table 2. Mackerel 1979 nominal catches breakdown.

	Catch (tons)
Canada - MQ	14,913
Canada - N	14,553
USA - Commercial[1]	2,000
USA - Recreational[1]	6,000
Others	366

[1] Estimated

Table 3. Mackerel catch-at-age ('000) for 1979.

	1	2	3	4	5	6	7	8	9	10	11+	TOTAL
<u>MARITIMES</u>												
Quarter 2	78	34	135	908	4144	3638	1516	739	554	172	183	12101
Quarter 3	119	423	208	1528	4573	3849	1293	296	155	77	97	12618
<u>NEWFOUNDLAND</u>												
Area 3K	0	3.1	128.5	643.2	1455.9	923.9	588.4	252.3	159.8	104.7	283.2	4543.0
Area 3L	0	4.3	577.4	2926.1	5630.6	3072.7	1773.0	802.4	709.3	333.1	927.6	16756.5
Area 3P	0	0	14.3	44.5	131.4	82.8	40.4	22.5	15.8	20.5	62.4	434.6
Area 4R	0	0	49.6	161.7	330.2	140.2	71.9	39.3	6.7	3.5	23.5	826.6
Total Sampled Catch	197	464.4	1112.8	6211.5	16265.1	11706.6	5282.7	2151.5	1600.6	710.8	1576.7	47279.7
Total Sampled + Unsampled Catch	261	616	1476	8240	21577	15530	7008	2854	2123	943	2092	62721

Table 4. Mackerel catch-at-age (millions of fish) from NAFO SA 3-6 during 1962-1979.

Age	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
0	-	-	-	-	-	2.2	1.4	4.5	5.1	2.5	3.6	4.0	2.0	3.7	-	-	-	-
1	23.3	1.5	15.9	10.9	29.0	1.0	175.5	8.1	206.1	77.3	22.4	161.4	95.9	374.7	12.5	2.0	.1	.3
2	4.0	5.6	8.6	4.3	13.9	33.0	76.3	298.8	58.1	304.8	87.0	282.4	242.2	432.6	353.5	26.9	.2	.6
3	22.1	1.7	5.1	3.5	6.4	24.4	73.6	183.2	556.0	132.0	260.0	284.3	264.4	114.0	272.5	100.7	4.6	1.5
4	5.5	35.2	4.9	4.9	3.2	4.3	47.3	75.0	173.5	579.0	185.3	233.0	101.5	101.1	85.7	53.9	17.4	8.2
5	1.7	8.1	24.0	6.3	5.7	4.1	17.8	6.5	29.4	210.8	396.2	191.9	114.3	58.8	52.4	11.9	13.5	21.6
6	2.3	.4	5.1	23.6	9.6	6.3	8.2	3.4	7.5	35.8	88.6	196.7	111.8	68.0	27.3	9.9	8.3	15.5
7	2.1	.2	4.8	5.1	26.4	7.5	0.8	2.3	5.6	9.2	24.4	31.1	108.3	52.0	40.5	5.6	4.5	7.0
8	1.1	.2	.8	4.8	0.6	39.8	1.2	3.5	10.5	3.7	4.3	10.9	25.7	50.6	34.6	6.3	2.1	2.9
9	.6	.2	1.0	.9	0.2	0.4	7.6	2.5	10.6	4.4	8.3	4.1	6.4	12.5	22.6	3.8	3.7	2.1
10	.2	.2	.3	-	-	-	0.1	9.5	4.0	8.4	3.8	3.8	2.5	2.3	13.4	3.6	1.5	.9
11+	.4	.2	-	-	-	-	-	-	3.0	7.5	5.7	1.6	0.8	1.0	1.4	0.6	1.7	2.1

Table 5. Mackerel spawning stock estimate based on egg surveys in the Gulf of St. Lawrence.

Year	Average daily egg production	Sampling date	Peak spawning date	Total egg production	Average fecundity	Spawning stock abundance
1969	$1.08x10^{13}$	170	182	$5.32x10^{14}$	157817	$3371x10^{6}$
1976	$2.05x10^{13}$	183	186	$5.13x10^{14}$	179814	$2852x10^{6}$
1977	$2.29x10^{13}$	199	204	$6.21x10^{14}$	174831	$3552x10^{6}$
1978	$2.45x10^{13}$	186	181	$6.66x10^{14}$	212984	$3127x10^{6}$
1979	$4.35x10^{13}$	169	173	$1.13x10^{14}$	217684	$5191x10^{6}$

Table 6. Stratified mean catch (kg) per tow (retransformed) of mackerel from USA bottom trawl surveys in the spring (strata 1-25, 61-76) from Anderson and Overholtz (1979).

Year	Catch/tow (kg)
1968	3.998
1969	.065
1970	2.039
1971	1.969
1972	1.332
1973	.748
1974	.769
1975	.255
1976	.317
1977	.199
1978	.447
1979	.221

Table 7. Mackerel catch per standarized USA day fished from Anderson and Overholtz (1979) and Anderson (pers. comm.) for the 1979 data point.

Year	Catch/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	.84
1973	.53
1974	.17
1975	.53
1976	.59
1977	.52
1978	.48
1979	.69

Table 8. Mackerel partial recruitment multipliers and weights at age.

Age	Partial Recruitment Multiplier	Weight
1	.26	.149
2	.61	.239
3	.92	.409
4	1.0	.472
5	.90	.495
6	.79	.526
7	.65	.552
8	.70	.613
9	.59	.634
10	.74	.665

Table 9. Relationship between mackerel average (4+) weighted F and relative exploitation index from the USA spring bottom trawl survey.

	Year	Exploitation index	F_{4+}	F_{4+}	F_{4+}	F_{4+}	F_{4+}	F_{4+}
	1968	27499	.107	.110	.112	.113	.114	.114
	1969	61153	.122	.125	.127	.128	.128	.129
	1970	128828	.173	.180	.184	.186	.188	.189
	1971	205015	.317	.329	.335	.339	.341	.343
	1972	324029	.304	.320	.329	.335	.338	.341
	1973	573912	.359	.383	.396	.404	.410	.414
	1974	451521	.358	.400	.426	.442	.454	.463
	1975	1149824	.358	.422	.464	.494	.516	.533
	1976	775820	.335	.438	.519	.583	.636	.680
	1977	392563	.106	.149	.188	.221	.252	.279
	1978	74832	.054	.079	.103	.125	.146	.165
	1979	171186	.081	.122	.163	.204	.245	.286
Predicted value			.152	.177	.194	.208	.220	.231
r			.71	.80	.84	.86	.87	.86
Fully recruited F			.10	.15	.20	.25	.30	.35

Table 10. Mackerel recruitment predictions with USA research survey catch per tow.

From USA autumn bottom trawl survey catch at age 0:

VPA average year-class size at age one (1) for the 1963 to 1974 year-class is 2355×10^6 fish and average catch per tow at age 0 in fall survey in 0.302.

Year-class	Fall survey c/tow at age 0	(c/tow)/average c/tow)	((c/tow)/average) x Average year-class (millions fish).
1975	.012	.040	94
1976	.000	.000	0
1977	.021	.070	164
1978	.491	1.626	3929

From USA spring bottom trawl survey catch at age 1:

VPA average year-class size (year-class 1969 to 1974) is 1957×10^6 fish.
R.V. average c/tow for same year-class is: 1.460.

Year-class	Spring survey c/tow at age 1	(c/tow)/(average c/tow)	((c/tow)/average) x Average year-class (million of fish)
1975	.204	.140	273
1976	.021	.014	28
1977	.128	.088	172
1978	.029	.020	39

From USA spring bottom trawl survey catch at age 2:

VPA average year-class (year-class 1968-1974) is 2127×10^6 fish.
R.V. average c/tow for same year-class is: 1.429

Year-class	Spring survey c/tow at age 2	(c/tow)/(average c/tow)	((c/tow)/average) x Average year-class (millions of fish)
1975	.109	.076	162
1976	.221	.155	329
1977	.009	.006	13

Table 11. Mackerel year-class size (1961-1974) from VPA and average summer temperature (June-September) at Entry Island, Quebec.

Year-class	Abundance at age 1	Average temperature
1961	861	13.75
1962	471	12.88
1963	512	13.25
1964	551	13.48
1965	1194	13.85
1966	3326	14.58
1967	7791	15.00
1968	3146	14.68
1969	3176	14.38
1970	1723	14.68
1971	1747	14.60
1972	1454	13.73
1973	1995	14.80
1974	1645	14.15
1975	1952[1]	14.33
1976	1651[1]	14.18
1977	524[1]	13.15
1978	2726[1]	14.63
1979	5439[1]	15.25

Year-class size = $2.2746 \times 10^{-4} \times e^{1.1141 \times TEMP}$

$r^2 = 0.80$

[1] Predicted

Table 12. Mackerel abundance at age assuming M = 0.3 (millions of fish).

	POPULATION NUMBERS																	
Age	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	861	471	512	551	1194	3326	7791	3146	3176	1723	1747	1454	1995	1645	500	500	500	500
2	465	618	348	366	399	859	2463	5621	2324	2176	1210	1275	939	1396	900	358	367	369
3	2595	341	453	250	267	283	608	1759	3908	1672	1352	822	704	490	667	368	242	272
4	64	1904	251	331	182	193	189	388	1147	2421	1126	780	368	298	266	264	187	175
5	26	43	1380	182	241	132	139	100	223	702	1301	676	380	187	135	124	150	124
6	7	18	25	1002	129	174	95	88	68	140	341	628	338	185	88	56	82	100
7	5	3	13	14	722	88	123	63	62	44	74	177	298	155	79	42	33	54
8	4	2	2	5	6	512	58	91	45	41	25	34	105	129	71	25	27	21
9	8	2	1	1	0	4	345	42	64	24	27	15	16	56	53	24	13	18
10	1	6	1	0	0	0	3	249	29	39	14	13	8	6	31	20	14	6
Total	4036	3407	2987	2703	3141	5572	11815	11548	11047	8982	7217	5874	5151	4547	2788	1779	1613	1636
Age 1+ biomass ('000 tons)	998	905	881	868	949	1118	2403	2594	2304	2194	2148	1585	1257	972	658	484	543	545

Table 13. Mackerel fishing mortality rates assuming M = 0.3.

	FISHING MORTALITY																	
Age	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	0.032	0.004	0.037	0.023	0.029	0.000	0.026	0.003	0.078	0.053	0.015	0.137	0.057	0.303	0.029	0.005	0.000	0.001
2	0.010	0.011	0.029	0.014	0.041	0.045	0.036	0.063	0.029	0.176	0.087	0.294	0.351	0.438	0.594	0.091	0.001	0.002
3	0.010	0.006	0.013	0.016	0.028	0.105	0.150	0.128	0.179	0.096	0.250	0.503	0.560	0.311	0.626	0.377	0.022	0.006
4	0.104	0.022	0.023	0.017	0.021	0.026	0.338	0.252	0.192	0.321	0.210	0.419	0.380	0.491	0.460	0.267	0.114	0.056
5	0.078	0.244	0.020	0.041	0.028	0.036	0.160	0.078	0.165	0.422	0.429	0.394	0.422	0.447	0.583	0.117	0.110	0.224
6	0.480	0.026	0.268	0.028	0.090	0.043	0.105	0.046	0.135	0.346	0.354	0.444	0.476	0.546	0.436	0.228	0.124	0.198
7	0.734	0.076	0.553	0.532	0.043	0.104	0.008	0.043	0.110	0.273	0.477	0.226	0.536	0.482	0.866	0.165	0.171	0.163
8	0.434	0.152	0.545	2.970	0.119	0.094	0.024	0.046	0.314	0.109	0.221	0.460	0.331	0.592	0.804	0.346	0.096	0.174
9	0.088	0.144	8.902	7.994	6.979	0.121	0.026	0.071	0.211	0.235	0.426	0.381	0.618	0.298	0.666	0.205	0.397	0.147
10	0.546	0.042	0.375	0.050	0.051	0.084	0.045	0.045	0.172	0.289	0.367	0.399	0.480	0.538	0.688	0.230	0.130	0.185
Weighted Average F(4 +)	.163	.027	.034	.047	.043	.068	.113	.128	.186	.339	.335	.404	.442	.494	.583	.221	.125	.148

Table 14. Mackerel projections results at $F_{0.1}$ assuming M = 0.3 incoming year-classes size of 1667 millions fish and using the weights at age observed in the 1979 fishery.

Year	Population Biomass ('000 tons)	Catch Biomass ('000 tons)
1980	713	150
1981	797	160

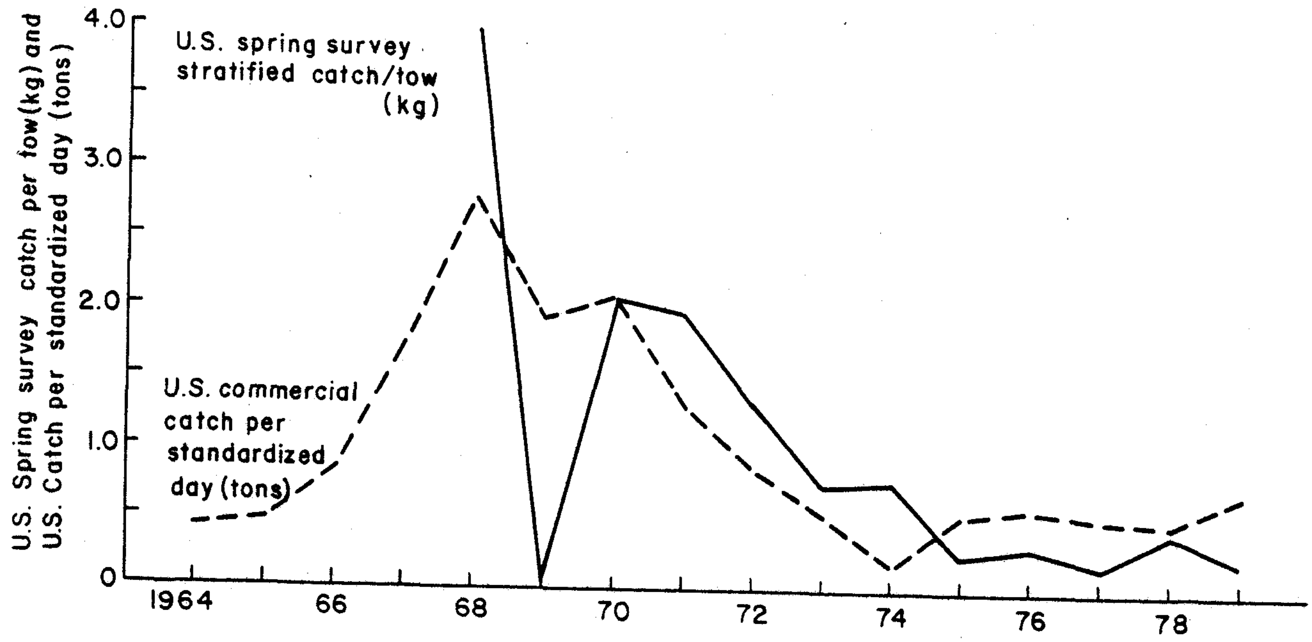

Figure 1. Mackerel U.S.A. spring survey stratified catch per tow (kg) and catch per standardized day (tons) versus time.

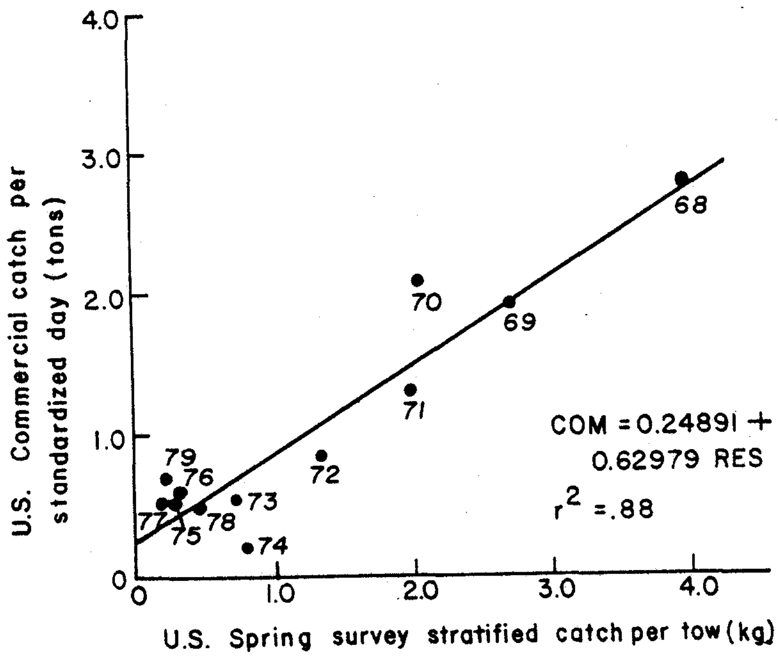

Figure 2. Relationship between the U.S. commercial catch per standarized day (tons) and the U.S. Research vessel survey stratified catch per tow (kg). (The 1969 research catch/tow was interpolated from the 1968 and 1970 values.)

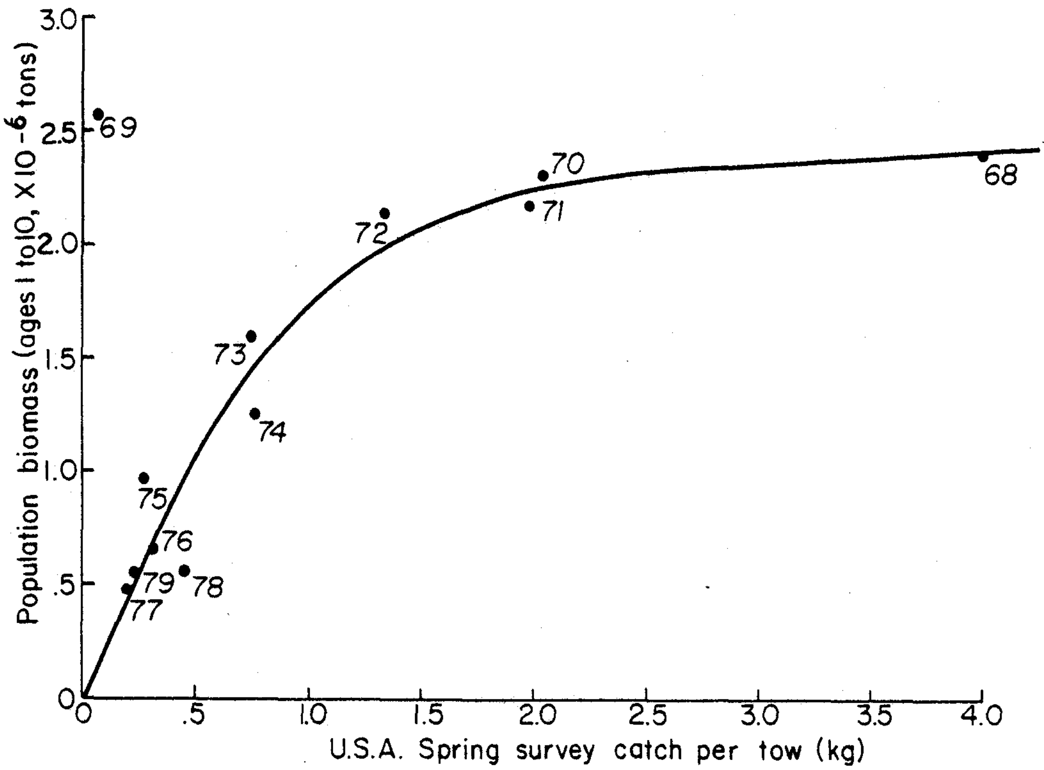

Figure 3. Mackerel age one and older biomass ('000 tons) versus the U.S.A. spring survey stratified mean catch per tow (kg) (line fitted by eye).

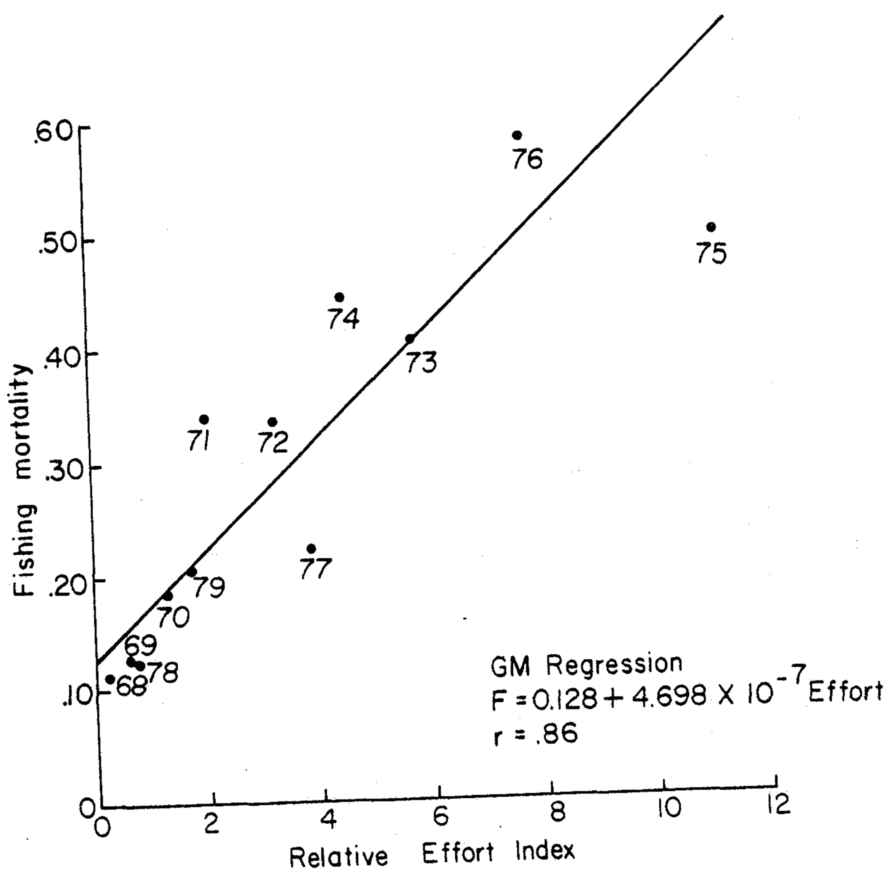

Figure 4. Relationship between mackerel average (4+) weighted F and relative exploitation index from the USA spring bottom trawl survey. Fully recruited F in 1979 is 0.25.

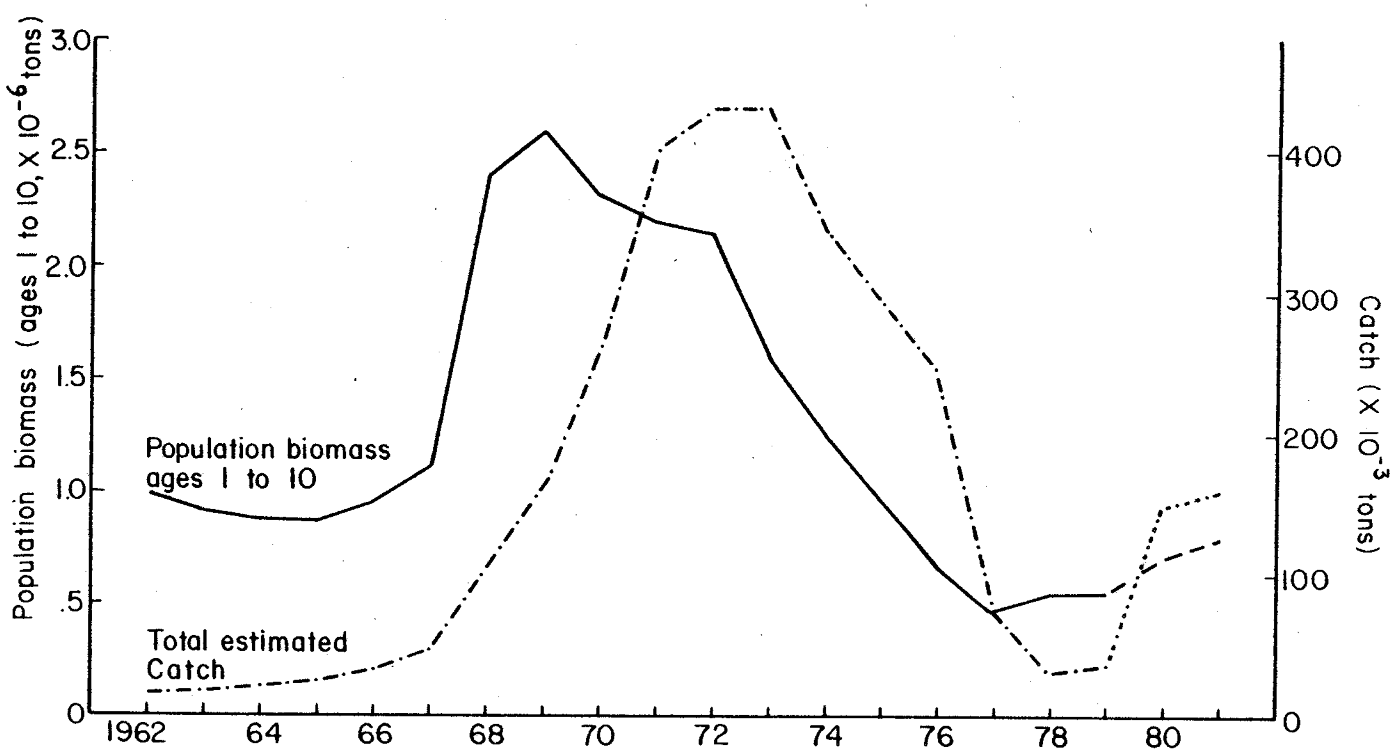

Figure 5. Mackerel 1+ biomass and catch since 1962 with projections to 1980 and 1981.

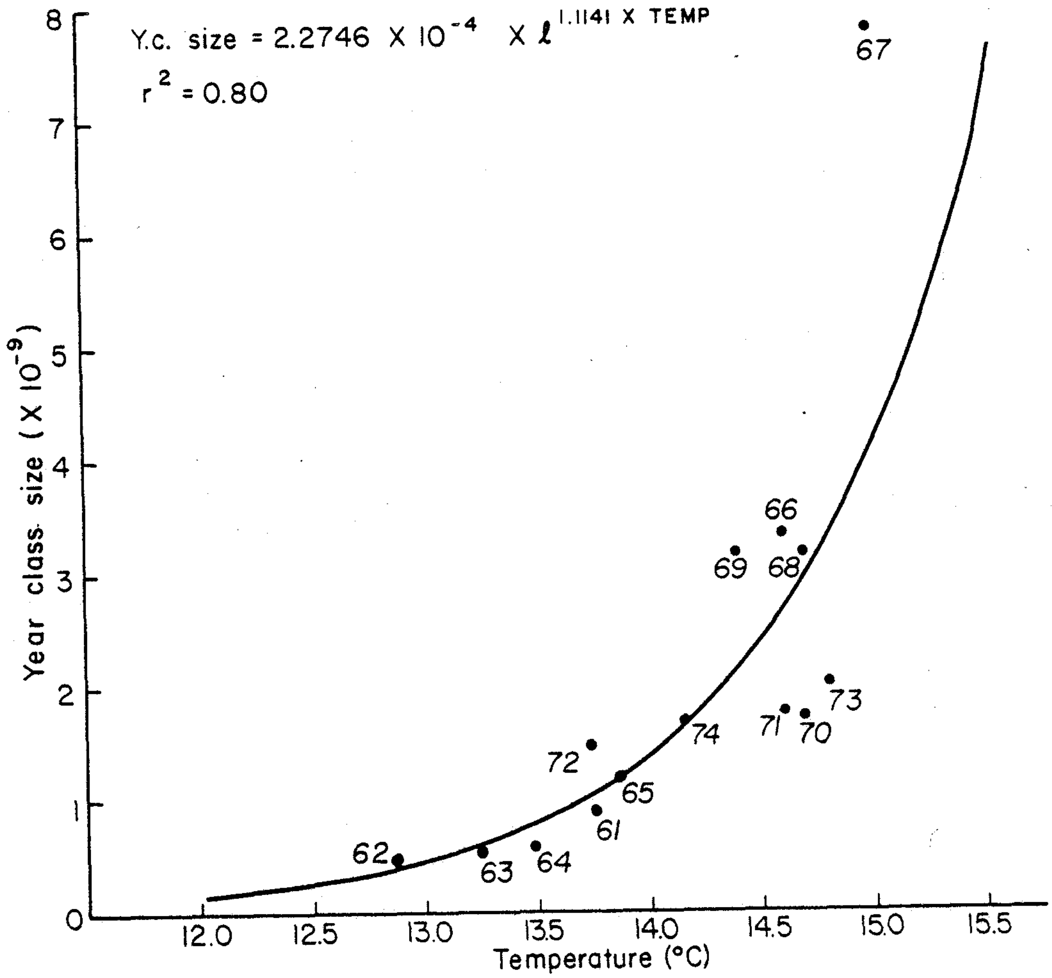

Figure 6. Relationship between mackerel year-class size and average summer temperature (June-September) at Entry Island, Quebec.

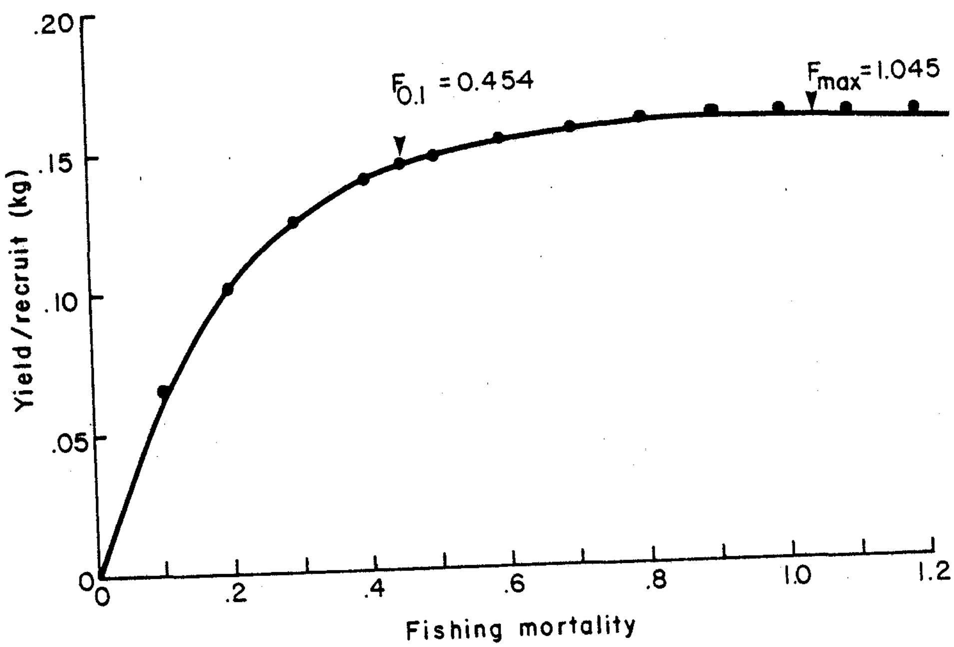

Figure 7. Mackerel Yield-per-recruit analysis with M = 0.3 and partial recruitment multipliers and weights at age of Table 8.