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An analytical assessment of SA 3-6 mackerel with information from egg and larval survey

by

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Introduction

The methods most currently used for stock assessment purposes are based on virtual population techniques. The historical population abundance estimates based on these methods will converge towards the real stock abundance level depending on the historic levels of exploitation (Pope 1972) but the initial stock abundance level will vary in proportion to 1/F (Pope 1972). When there is a good relationship between effort (f) and fishing mortality (F), the fishing mortality for the initial year and the inital stock abundance can be estimated with some confidence but when there is a trend in catch this can give spurious correlation. This is especially true in a case like mackerel where the effort data which is most used is derived from research vessel surveys representing a very small proportion of the total effort and using a gear which is not necessarily representative of the fishery's total removals. The rapid expansion of the fishery in the late 60's involving learning factors, implies that if commercial effort data is to be used it will have to be corrected. These corrections are delicate because it is very difficult to differentiate between variations in availability (q) and learning factors. The need for an assessment procedure independent of any effort measure is thus apparent in the case of mackerel.

Egg and larval cruises have been initiated on both sides of the Atlantic and in the Pacific to investigate the spawning areas and time of commercially important fishes, their recruitment mechanisms and also to provide an index of stock abundance (Smith and Richardson 1977; Saville 1977; Coombs et al. 1977; Zweifel 1973; Ciechoniski and Capezzani 1973; Seriebryakov 1965; Berrien and Anderson 1976; Berrien, Naplin and Pennington 1979). The estimates of stock abundance levels derived from these surveys are especially important for species like mackerel in the Northwest Atlantic where only one other abundance index has been successfully used in recent years. The purpose of this paper is to present an assessment of Northwest Atlantic mackerel based on egg data together with conventional methods.

I. Catch statistics:

Mackerel landings in the northwest Atlantic since the early 1800's show wide fluctuations (Fig. 1) probably influenced by variations in abundance, in fishing methods and in market conditions (Sette, 1950). There was a period of relatively high exploitation between 1830 and 1885 with landings averaging 47,000 metric tons and peaking at 106,038 t in 1884. Although the USA were the main harvester of the resource at that time both the northern and southern population were exploited since the American fishermen were following the fish in the Gulf of St. Lawrence (Sette and Needler, 1934). A period of low landings followed between 1886 and 1924. The catches during that period averaged 18,000 t with the lowest one being 5835 t in 1910. The catch level increased slightly to an average of 35,000 t between 1925 and 1949, only to decrease again to an average catch of 13,000 t between 1950 and 1966. Subsequently, a period of high exploitation occurred during the late 1960's and early 1970's with catches peaking at 420,000 t in 1973 and averaging 236,000 t for the period 1967-1978.

Most of these variations in landings remain to be explained. However, Sinderman (1966) talking about an epizootic fungus disease that affected herring in the mid-50's mention that "mackerel were also heavily infected, mortality occurred and landings decreased during the post epizootic years" (p. 43). Both the Canadian and American landings decreased in the mid to late fifty's and if the northern population was at that time an important component of the stock, the disease may partially explain the low landings.

The Northwest Atlantic mackerel fishery was first regulated in 1973 when ICNAF established a total allowable catch (TAC) at 450,000 t for SA 5-6 to limit the rapidly expanding fishery in those areas. The fishery was managed at that time on the belief that two different stocks were exploited, one in SA 5-6 and the other in SA 3-4. However, tagging data by Beckett _et al_. (1974) Parsons and Moores (1974) and ancillary ecological and biological data (Moores _et al_., 1975) showed that the two population were intermingling on the overwintering grounds. Anderson (1975) demonstrated that assessing these two populations as two different stocks would lead to setting the TAC's much too high and would mean overexploitation of the stock. Since then the stock(s) fished in SA 3-6 have been assessed as a single unit. Table 1 gives the catches since 1962 and the associated TAC's since 1973.

II. Abundance indices:

Four abundance indices are considered in this paper. The first one is in fact the spawning stock assessment based on ichthyoplankton data and the remaining three are the catch per tow on the Canadian and American research surveys (Gulf of St. Lawrence and Scotian Shelf for Canada and spring for the USA).

II-I Spawning stock estimates from ichthyoplankton surveys:

The method used to estimate the spawning stock from egg data has been described in detail in Maguire (1979). That paper also includes an analysis of the influence of different factors on the population estimate obtained. The method will only be summarized here.

By combining data from two sampling gear types (the surface Meter net and the Miller samplers) a value for the abundance of eggs per m^2 of water surface area can be calculated. But these eggs represent several days of spawning activity thus the survey data were corrected as follows: when sorted, the eggs were classified in four stages, the first one lasting for about one day. Spawning activity can vary from day to day and from place to place due to hydrographic conditions, thus there may be very few stage one eggs in some surveys. Given information on the mortality rate of eggs and incubation time, the number of stage one eggs can be back calculated from each stage. The average value calculated from these four estimates gives the best estimate of daily egg production at each station. The daily egg production per m^2 at each station is then multiplied by the suface area of the station and the stations are added together to give the total daily egg production for the entire Gulf of St. Lawrence. Analysis by Ware (1977), Lett and Marshall (1978) and Maguire (1979) have demonstrated that the mackerel spawning cycle is about 40 days long, has a normal shape, and that the optimal spawning temperature is in the order of 12.0-13.0°C. From the regression of cruise temperature on Entry Island temperature the day corresponding to peak spawning can be determined as well as the day having the temperature corresponding to the average cruise temperature. The egg production previously calculated is assumed representing the daily egg production of the date corresponding to the average cruise temperature. From a standard normal probability curve the probability of the average day of catch (ADC) can be calculated. Knowing that this probability represents the daily egg production of ADC, the daily egg production for each day of the spawning cycle can be calculated and summed to get the total egg production for the whole spawning cycle.

The analysis of the importance of the input parameters showed that the two single most important factors are 1) the length of time between peak spawning day and average day of catch and 2) the variability associated with the gonad-weight/fecundity relationship. The conclusion was that the real population abundance should be between ± 50% of the population estimated.

Having calculated the total egg production, the spawning stock abundance can be computed from the following formula:

$$1.\quad \text{Spawning stock} = \frac{E}{PixMixFi} \times R$$

where
E = total egg production

R = sex ratio

Pi = population abundance at age i

Mi = maturity at age i

Fi = fecundity at age i

The sex ratio of the mackerel sampled by the St. Andrews Biological Station from 1965 to 1967 and from 1973 to 1977 is 0.96 male to every female. This is close enough to use a 1:1 sex ratio. It is assumed that the Canadian catch is representative of the 2+ population and the percent catch at age in the second quarter of the year is taken as the spawning stock age structure. Maturity at age can be calculated from maturity at length (Hunt pers. comm.) and mean length at age. Fecundity estimates are available from three sources: MacKay (1976), Maguire (unpublished data) and Morse (1978). Morse's study is the most complete but deals with the so-called southern population while MacKay's study is based on the examination of only 4 fish. Maguire's data was thus used. The relationship is:

(2) Fecundity = -19817 + 5215 x GONAD WEIGHT

($r^2 = .74$, $F_{1,21} = 59.95$ significant at 99%)

Gonad weights have been taken during regular commercial sampling since 1973. These values are smoothed over age by fitting a von Bertalanffy curve.

The spawning stock estimates calculated from equation (1) with input parameters given in Table 2 are 5247 x 10^6 individuals in 1969, 2484.3 x 10^6 in 1976, 3666.3 x 10^6 in 1977 and 2358 x 10^6 in 1978. This suggest that the population decreased between 1969 and 1976, had a small increase in 1977 and would be in 1978 at its lowest abundance.

II-2 Abundance index from Canadian research cruises

Groundfish research cruises were initiated in 1970, in the Gulf of St. Lawrence and on the Scotian Shelf, and have become standard survey cruises. Although mackerel catches are rather low during these groundfish cruises, abundance indices from similar surveys have been used for mackerel by Anderson (1976; 1977), Anderson and Paciorkowski (1978) and Anderson and Overholtz (1978). Winters (1978) also found a good correlation between catch per unit effort for herring in the Gulf of St. Lawrence Groundfish Research cruise and biomass from cohort analysis. The average catch per tow (numbers) and total number caught are give in Table 3a.

In an attempt to normalize the data and to have an index directly comparable to the American index a ln (X + 1) transformation was applied to individual catches and the average calculated. The derived mean was retransformed to linear scale using the equation (Finney, 1941).

$$(3)\ \bar{Y} = \mathrm{EXP}\ (\bar{X} + \frac{S^2}{2}) - 1$$

where

Y = linear average catch per tow

$\bar{X}$ = ln average catch per tow

S^2 = variance (ln scale).

The variance of abundance indices from research cruise surveys is very high and it is well accepted that the trend in the data is more meaningful than individual values. To identify such a trend both a 3 and 2 year running average were applied to the data. These data for the Canadian surveys are given in Table 3a and Fig. 2. For the 3 year running average a value is obtained for the first and last year by taking 2/3 of the value to which the average applies and 1/3 of the following or preceeding value respectively. A rapid examination of Fig. 2a shows that the Scotian Shelf research survey average catch per tow does not seem to reflect the fluctuations observed in the abundance of this stock. This index is thus discarded as being meaningless. The average catch per tow during the Gulf of St. Lawrence surveys would, however, seem to agree more closely with the current belief concerning the fluctuations in the stock. The abundance reached a peak (Fig. 2b) in the early 1970's then decreased steadily to start to increase in 1977-78. A preliminary analysis showed that the highest correlation was between the 2 year running average and the 4+ biomass.

II-3 Abundance index from American research cruises

Data from the American spring groundfish survey is also shown (from Anderson and Paciarkowski (1978) and Anderson and Overholtz (1979a). This shows an exponential decline in the population abundance since 1968 with an increase to about 50% of the 1973 abundance level in 1978 (Table 3b, Fig. 3).

III - Current catch composition

Catch at age data from ICNAF SA 3-6 were taken from Anderson and Paciarkowski (1978) for 1962-1977 while the 1978 catch at age was taken from Hunt (per. comm.) for the Maritimes Region, from Moores (pers. comm.) for Newfoundland catches and from Anderson and Overholtz (1979b) for the American commercial and recreational fisheries. Canadian catches (Maritimes, Quebec and Newfoundland) represented about 73% of the total international catch. Removals at age from the Canadian and

American sources were prorated to include the total SA 3-6 catch. The 1978 catch at age is detailed in Table 4 and catch at age since 1962 in Table 5. The average lengths and weights of fish caught in the Canadian fishery are given in Table 6.

IV - ASSESSMENT PARAMETERS:

IV-1 Fishing mortality

The input parameters for cohort analysis are: catch at age, natural mortality, fishing mortality at age for the last year and for the last age and each year for the whole time period. 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 (D. Gray, pers. comm.) to drop that age-group and use only the catch that is specifically attributed to a given year-class. Thus the cohort analysis were run with catch at age from age 1 to 10 only.

Starting F can be derived from the three previously mentioned abundance indices. Knowing the catch, the stock abundance calculated from egg and larval surveys and assuming a value for natural mortality, starting F can be found directly. The spawning stock abundance previously calculated results in an average F for age 3 to 10 of 0.028. Considering the 50% confidence interval associated with this method as estimated in Maguire (1979) this means that F_{78} should be between 0.014 and 0.042.

There is great difficulty in using commercial catch per unit effort data due to fleet composition variation, learning factor, gear changes etc. Because of these difficulties it has become very popular among fisheries scientists to use what some of them call "manufactured effort". This effort index is obtained by dividing the total catch by the research cruises average catch per tow. This index of effort is then regressed against average F to obtain starting F. There is growing concern about the use of that technique, the argument being that since $F = C/\bar{N}$ and the index of effort is C/catch per tow the model is auto correlated and if there is a trend in catches, one is bound to get a good correlation (W.G. Doubleday, pers. comm.). However, it would be very legitimate to do a regression of biomass on average catch per tow. The data was thus analysed following that rationale for both the Canadian and American research cruise surveys data. A cohort analysis was run with an aribtriarily choosen starting F, the biomass calculated from average weights at age and a regression of biomass on average catch per tow was made. The process was repeated until the best fit was found. Figure 4 shows the result for the Canadian survey. The best fit was found for a starting F_{3-10} equals to 0.030 (r^2=.92) at a 1978 4+ biomass level equals to 907×10^3 t.

A plot of biomass against the American research surveys catch per tow (Fig. 5) shows a plateau for the earlier years of the surveys (68 to 72). When a linear regression is done on the whole series the best fit is found for a rather high starting F (F_{78} = 0.40). But this series can be broken in two parts: from 1968 to 1972 the cruises utilized a No. 36 Yankee trawl while from 1973 onwards a larger, high opening No. 41 Yankee trawl was used. The data given in Anderson and Overholtz (1979b) is corrected for that gear change but the shape of the curve suggests that the correction factor used was much too high. If for consistency sake the earlier part of the series is dismissed the results become more consistent with previous estimates. The highest correlation between biomass and average catch per tow is then obtained for a starting F_{3-10} of 0.029 (r^2=.77) and the 1978 3+ biomass level would be 1080×10^3 t, (Fig. 6).

The three estimates of starting F are thus 0.028, 0.030 and 0.029. Considering the very low 1978 catch these are very realistic. When the 50% confidence interval on the estimate based on egg surveys is considered it becomes F_{78}=0.042. An examination of the 1974 year-class contribution to the fishery since 1975 suggest that the 1974 year-class is of average strength. The average year-class size at age 1 between 1962 and 1973 is 2424×10^6 fish. It can thus be stated with a fair degree of confidence that the 1974 year-class abundance at age 1 is close to 2400×10^6 fish. An F of 0.042 at age 4 in 1978 results in a 1974 year-class abundance at age 1 of 2406×10^6 individuals indicating that $F_{4,78}$ = 0.042 is fairly accurate.

IV-2 Natural mortality

Estimates of natural mortality for mackerel in the Northwest Atlantic range from 0.2 to 0.6. This has led to a number of options when projections were made and the ICNAF Mackerel Working Group at its January 1974 meeting adopted M=0.3 to reduce the number of options. This is the value that has been most often used since then even though, studies by Rikther and Efanov (1976) and Winters (1978) estimated M=0.35. Rikther and Efanov's study was based on a relationship between M and the age of sexual maturity and Winter's was based on relationship between Z and effort. Only M=0.30 is used in the projections made in this analysis even if it is felt that an accurate estimate of M for mackerel is yet to be found.

IV-3 Recruitment estimates

An examination of the population abundance at age table from cohort analysis (Table 7) shows that mackerel recruitment is highly variable. Recruitment has varied from 545 x 10^6 fish for the 1963 year-class to 8087 x 10^6 for 1967 year-class with a 1961-74 average of 2423 x 10^6 fish at age 1. This variability shows that a sound management of the fishery cannot be achieved without an accurate prediction of recruitment.

Several authors (MacKay, 1976; Ware, 1977; Lett and Marshall, 1978; Maguire, 1979; Winters, 1975) have shown that mackerel egg production is strongly influenced by temperature. Since recruitment is very likely to be dependent on the egg production, a relationship between recruitment and temperature is not unexpected. This relationship might also be expected because mackerel is in the northern part of its distribution. A plot of year-class 1 abundance from cohort analysis versus the average summer months (June, July, August and September) temperature at Entry Island shows that the relationship seems to be an exponential one (Fig. 7 and Table 9). A regression of the natural logarithm of recruitment from 1961 to 1974 versus average temperature gives the following results.

(4) $\text{Recruitment} = 0.00023723 \; e^{1.12117\text{TEMP}}$

(r^2=.78, F=43.44 significant at 1% ($F_{1,12/9.33}$))

The American research surveys catch at age per tow have been used by Anderson and Overholtz (1979b) to predict recruitment. Three relationships were used: the autumn survey catch per tow at age 0 versus year-class size at age 1 from cohort analysis, the spring survey catch per tow at age 1 versus year-class size at age 1 and the spring survey catch per tow at age 2 and year-class size at age 2. Anderson and Overholtz (1979b) fitted a power curve to their data. The result is a curve with an intercept close to zero, the rationale being that the year-class size should be zero when the average survey catch is zero. An underlying assumption would be that the American research survey sample the whole population at all ages. If it is not the case a search for an intercept close to zero would thus seem unjustified. Furthermore, an analysis of the American survey catch at age data shows that the best fit is a linear relationship and not a power one. The results of the linear and power curve fit are given below:

	linear fit	power fit
Autumn survey Catch at age 0	YC1=1601. + 3641 r^2=.83	$YC1=5449.61X^{0.47833}$ r^2=.58
Spring survey Catch at age 1	YC1=2277 + 143. r^2=.84	$YC1=2240.31X^{0.30920}$ r^2=.60
Spring survey Catch at age 2	YC1=838.88753+742.57584X r^2=.80	$YC2=1645.37X^{0.48079}$ r^2=.78

The year class sizes at age 1 and age 2 are from a cohort analysis run with F derived in the partial recruitment section. The year-classes 1963 to 1974 were used for the autumn survey catch at age 0, year-classes 1967 to 1974 excluding 1968 for the spring survey catch at age 1 and year-classes 1966 to 1974 excluding 1967 for the spring survey catch at age 2. Year-class sizes at age 1 can be found directly from the research surveys catch at age 0 and catch at age 1. However further calculations are necessary to compute year-class size at age 1 from the research surveys catch at age 2. Knowing the year-class size at age 2, from the relationship between research surveys catch at age 2 and year-class size at age 2, and the catch at age 2, a F value can be calculated from the catch equation for the 1975 and 1976 year-classes at age 2 in 1977 and 1978. When there are used in cohort analysis the year-class size at age 1 is found. A slightly different procedure must be followed for the 1977 year-class size. The fishing mortality exerted on the 1977 year-class in 1978 can be calculated by the following formula:

$$\frac{N^2}{C_1} = \frac{Z.1^{-Z_1}}{F_1}(1-e^{-Z_1}$$

where N_2=1977 year-class abundance at age 2 in 1979.

This F used in cohort analysis gives the 1977 year-class size at age 1.

The predicted year-class sizes at age 1 from these equations and from equation 4 are given below:

Year-class	Year-class vs temperature	Autumn survey 0 linear	Autumn survey 0 power	Spring survey 1 linear	Spring survey 1 power	Spring survey 2 linear	Spring survey 2 power	Ave.
1975	2253	1645	657	2306	1370	1271	785	1470
1976	1904	1601	0	2280	678	1225	972	1443
1977	600	1678	859	2295	1186	965	200	1112
1978	3153	3386	3874	2281	750			2689

The recruitment relationship are shown as Fig. 7 and Fig. 8 (a, b, c).

The predictions for a given year show important variations and are sometimes contradictory. However the interpretation might be easier if a few facts are remembered. First it should be noted that the linear relationship between year-class size and average catch per tow on the American research survey cannot predict small year-class since the intercept for average catch at age 0, 1 and 2 are respectively 1601, 2277 and 839 x 10^6 individuals. A predicted year-class size close to the intercept would however be indicative of a small year-class. Two out of three predictions with the linear relationships are close to the intercept for the 1975, 1977 and 1976 year-classes suggesting low recruitment for these years. However it is difficult to decide what their exact values are. Since the power curve relationship can predict small year-classes it is tempting to use the values it predicts. But these low predicted values are misleading and give a false sense of precision since it has already been shown that a linear relationship gives a much better fit and the hypothesis that the American research surveys may not sample the whole population raise doubts about the legitimacy of a power curve fit. Thus this fit should not be accepted only on the basis that it can predict small year-classes. It is also not certain what the smallest year-class has been in the past. Cohort analysis shows that the year-classes 1962-1963 and 1964 are the smallest observed with the lowest value being 545 x 10^6 individuals, more than one order of magnitude smaller than the highest observed. However the catches in those years were rather small and the sampling was not intensive either so it is not known how accurate these figures are. However examination of the average of the predicted recruitment shows that the 1975 and 1976 year-classes are of approximately equal value while the 1977 year-class appears smaller. Given the aforementioned uncertainties the 1975 and 1976 year-classes were set equal to 800 x 10^6 individuals at age 1 and the 1977 at 650 x 10^6 individuals. All indices, except the spring survey catch at age 1, indicate that the 1978 year-class is above average. Anderson and Overholtz (1979b) believe that the 1978 year-class size is underestimated by the spring survey catch at age 1 due to availability change in the 1979 spring survey, thus the spring survey catch at age 1 is not used. The average for the other predictions is 3471 x 10^6 individuals and the 1978 year-class is thus taken equal to 3000 x 10^6 individuals.

IV-4 Partial recruitment rates:

An analysis of the fishing mortality at age table from cohort analysis (Table 8) shows that partial recruitment rates have varied widely since 1962. This is probably due to both year-class abundance variability as well as fishing effort and fishing pattern changes. In 1969-73 inclusive, and 1975 even age 0 fish were partially recruited to the fishery. However these fish were taken by the distant water fleet and age 0 fish are not likely to be recruited in a Canadian or American fishery. Partial recruitment rates defined as age specific F divided by the average 3+ F varied for age 1 from 1% in 1969 to 80% in 1975 while partial recruitment rates for age two varied from 14% in 1970 to 100% in 1975. It seems that the partial recruitment rates in 1978 are rather low. The 1978 F values at age 1, 2 and 3 necessary to produce the 1975, 1976 and 1977 year-classes abundance previously estimated are 0.000178 at age 1, .0003525 at age 2 and 0.01314 at age 3. Because a good part of the 1978 catch was made in Newfoundland, where mainly older fishes are caught, the age of full recruitment might be older than the one observed in previous years. If it is assumed that age 4 fish and older are fully recruited to the Maritime area fishery then age specific F can be calculated by comparing the total percentage catch at age to the Maritimes area percentage catch at age. This results in the following age specific F's:

Age	4	5	6	7	8	9	10	11+
F	.042	.056	.071	.075	.053	.037	.067	.155

Although maximum F is at age 11+, for convenience age 6 is taken as age of full recruitment and the resulting partial recruitment rates are used for 1978:

Age	1	2	3	4	5	6	7	8	9	10	11+
P.R.	.25	.50	18.5	59.2	78.9	100	100	74.6	52.1	94.4	100

This set of partial recruitment will be called PROBS.

IV-5 Yield per recruit:

In addition to the previously derived set of partial recruitment rates, another more "conventional" set is used to calculate yield per recruit by the Thompson and Bell method. Because the 1978 year-class appears to be quite abundant the partial recruitment rates at age 1, 2, and 3 are likely to be higher in future years than they were in 1978. Anderson and Overholtz (1979b) examined the Canadian fishery partial recruitment rates and taking the average for 1968 to 1978, excluding the highest and lowest values, arrived at the following results which will be called PRCALC.

Age	1	2	3	4	5	6	7	8	9	10	11+
P.R.	15	33	70	100	100	100	100	100	100	100	100

Similarly, two set of mean weights at age were used. Those adopted by ICNAF (1974) (ICNAF WT) and those observed in the 1978 Canadian fishery (OBSWT). With the natural mortality rate equal to M=0.30 the resulting $F_{0.1}$ are:

	PROBS	Yield $F_{0.1}$ as a % of Yield F_{max}	PRCALC	Yield $F_{0.1}$ as a % of Yield F_{max}
OBSWT	.710	69%	.487	84%
ICNAFWT	.597	79%	.387	90%

The Y/R curves are shown in Fig. 9 (a, b, c, d)

Results of assessment

A cohort analysis was run with the age specific F's empirically determined in the partial recruitment section to obtain the 1978 population abundance at age (Table 7) to start the projections. There is no index of the future year-classes sizes and when projecting more than one year ahead values for recruitment in future years must be assumed. Two basic options are available: chose a fixed constant value, that might be equal to the average observed recruitment values for preceeding years or some other value or generate a set of year-class size from the observed mean and standard deviations of observed recruitment. The latter option incorporate some of the natural variability shown in the data and has no optimistic or pessimistic bias. A combination of these two options was used: to be conservative a low 1979 year-class size was selected (650 x 10^6 fish) and the 1980 to 1984 year-classes were selected from the observed geometric mean of recruitment (7.379) and standard deviation (.724). Year-classes size at age 1 (x10^6) for projections are thus:

1978	1979	1980	1981	1982	1983	1984
3000	650	2180	1746	1985	2740	1745

A number of projections were made, corresponding basically to the four $F_{0.1}$ resulting of the two vectors of partial recruitment rates and weights at age. Two categories of catch options were also considered: first, fishing at $F_{0.1}$ from 1979 to 1985 and second, 1979 catches of 30, 50, 100 and 150 thousands mt and fishing at $F_{0.1}$ thereafter until 1985. The results of these are given in Table 10. All these projections are resulting from the uncertainty about the exact nature of the fishery in future years. If in coming years the Newfoundland fishermen take the same proportion of the catch as in 1978 PROBS and OBSWT should be used in projections. However if the catch by Maritimes and Quebec fishermen is by far the more important PRCALC and OBSWT should be used while if catches on overwintering grounds are the largest, PRCALC and ICNAFWT would be more appropriate. Even if the combination PROBS-ICNAFWT would not correspond to any real situation, the results of the projections are given here as a minimal reference point. It should be noted however that although the projections are numerous, they do not include all the possibilities. They rather represent extreme situations. Fishing at $F_{0.1}$, the maximum catch is predicted when OBSWT and PRCALC are used (1979 catch of 301,000 mt and 1979 to 1985 average of 272,000 mt) while the lowest catch is predicted when ICNAFWT and PROBS are used (1979 catch of 186,000 mt and 1979 to 1985 average of 157,000 mt). It thus appears that a 1979 TAC of 150,000 mt could be taken and still allow for rebuilding of the stock even when the worst situation is considered (PROBS-ICNAFWT).

However the 1979 catches, given the present market conditions, is not likely to be as high as 150,000 mt and the projections with 1979 catches smaller than 150,000 mt indicate that a smaller 1979 catch means higher potential catch in subsequent years.

Conclusion and Discussion

The cohort analysis presented in this assessment shows that the 1+ biomass of the northwest Atlantic mackerel stock has decreased continuously since 1972 (Fig. 2). This decrease was believed to result of a period of overexploitation between 1970 and 1976. However the average 3+ F, weighted by the population abundance, do not suggest that overexploitation took place and the highest F, in 1976, did not even reach $F_{0.1}$. The decrease in biomass is real but it may be due to the passage of the big 1967 year-class through the fishery and to the fact that the 1975 to 1977 year-classes seem to be weak compared to the average 1961-1974 recruitment. It thus seems that the situation has never been as bad as some earlier assessment suggested and that even with extremely low 1975 to 1977 year-classes the biomass has now begun to increase. The 1978 year-class is predicted higher than average and thus a good potential yield for the next 3 or 4 years seems almost guaranteed.

The spawning stock assessment based on egg surveys appears to give a fairly accurate estimate of what is happening in the population although the correlation with cohort analysis is not perfect. There are only four data points for spawning stock estimate from egg surveys but it is felt that as more points are added the validity of this method will be established. Some of the variations between cohort analysis and the spawning stock estimate based on egg surveys may also be removed when a fecundity study presently being conducted is completed.

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Table 1. Mackerel Catch (tons) from SA 3-6 During 1962-78 and TAC During 1973-78

Year	U S A		Canada	Other Countries	Total	TAC
	Commercial	Recreational				
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	450,000
1974	1042	7640	16701	321837	347220	359,000
1975	1974	5968	13544	271719	293205	355,000
1976	2712	4202	15746	223275	245935	310,000
1977	1376	522	22477	53745	78120	105,000
1978	1604	6571	24444	831	33450	105,000

Table 2. Population Parameters for Stock Assessment from Egg Production

AGE	Spawning Population Age Structure 1969[1]	1976[2]	1977[2]	1978[2]	Maturity at Age[3] 1969	1976	1977	1978	Fecundity at Age[4] 1969	1976	1977	1978
2	4	14.5	14.6	.24	.644	.790	.703	.891	111497	142891	87090	39269
3	28.1	27.1	42.3	8.4	.921	.920	.908	.959	210477	211729	242497	251259
4	7	15.7	22.2	36.3	.970	.950	.962	.970	277959	262836	342625	295534
5	3	19.5	6.5	25.1	.985	.970	.979	.970	323998	300384	407291	328076
6	3	5.1	4.4	10.2	.989	.980	.987	.985	355355	328023	449011	367136
7	3	3.8	2.8	6.9	.992	.989	.990	.990	376732	348883	476234	397018
8	2	9	3.4	4.9	.994	.992	.992	.992	391308	364007	493860	416418
9	33	3.8	1.8	4.0	.994	.992	.993	.992	401237	374958	504812	424605
10	17	1.4	1.9	4.1	.994	.992	.994	.994	408006	383302	512113	438425

YEAR	DAILY EGG PRODUCTION	AVERAGE DAY OF CATCH	PEAK SPAWNING DATE	TOTAL EGG PRODUCTION	TOTAL SPAWNING POPULATION
1969	1.08×10^{13}	167	181	8.28×10^{14}	5247.3×10^{6}
1976	2.05×10^{13}	178	180	3.066×10^{14}	2484.3×10^{6}
1977	2.29×10^{13}	178.5	184	4.94×10^{14}	3663.4×10^{6}
1978	1.66×10^{13}	180	174	3.81×10^{14}	2358.4×10^{6}

1 - from MacKay, 1976
2 - from catch composition in the Maritime fishery during the second quarter
3 - from a maturity vs length relationship from J. J. Hunt (pers. comm.)
4 - from a fecundity - gonad weight relationship (Maguire, unpublished data)

Table 3a. Number caught and average catch per tow for the Gulf of St. Lawrence and Scotian Shelf research cruises.

	SCOTIAN SHELF				GULF OF ST. LAWRENCE			
	Number	CPUE[1]	CPUE[3]	CPUE[2,4]	Number	CPUE[1]	CPUE[3]	CPUE[2,4]
1970	153	.434	.429		28	.545	.515	
				.427				.500
1971	42	.419	.425		25	.455	.539	
				.420				.536
1972	46	.421	.420		91	.616	.510	
				.420				.538
1973	24	.419	.411		31	.460	.507	
				.406				.452
1974	12	.392	.436		47	.444	.447	
				.444				.441
1975	123	.496	.431		20	.438	.421	
				.451				.410
1976	19	.405	.447		3	.381	.416	
				.422				.385
1977	100	.439	.432		3	.388	.416	
				.455				.418
1978	35	.451	.447		25	.478	.448	

1 retransformation to linear scale of ln (x+1)
2 average weighted by the number caught on each cruise
3 3 years running average
4 2 years running average

Table 3b. Weight caught and average catch per tow on the American spring survey

Year	Average Catch per Tow[1]
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	.477

1 Retransformed of ln (x+1)

Table 4. Mackerel Catch in ICNAF SA 3-6 in 1978.

Catch in metric tons and numbers in thousands

	0	1	2	3	4	5	6	7	8	9	10	11+	TOTAL	CATCH
CANADA-MARITIMES														
Quarter 2	-	-	24	854	3693	2551	1039	701	502	406	223	190	10,183	5,336
Quarter 3	-	2	150	1465	3698	1843	429	121	62	72	12	31	7,885	3,779
Quarter 4	-	-	-	259	710	329	590	153	153	406	145	-	2,745	1,646
CANADA-NEWFOUNDLAND														
SA 4R	-	-	.7	17.0	34.7	22.2	10.1	6.3	2.5	4.6	3.1	4.3	105.5	53
SA 3K	-	-	-	438.7	2530.0	2627.8	1673.4	843.3	345.9	238.4	273.7	483.9	9,455.0	5,720
SA 3L	-	-	-	625.8	3390.5	3696.0	2300.8	1128.7	507.5	221.0	386.3	588.7	12,845.4	7,657
SA 3P	-	-	-	23.4	105.2	58.4	70.1	81.8	11.7	-	11.7	46.8	409.1	253
USA-RECREATIONAL														
SA 6	-	-	8.5	188.8	611.6	442.5	938.5	789.1	225.5	1789.6	188.8	2646.3	7,829.2	4,032
USA-COMMERCIAL														
Div. 5Y (Jun-Jul)	-	96.8	24.3	82.1	148.2	25.0	27.8	-	-	18.6	8.8	8.8	440.4	171
S.Div. 5ZW (Apr)	-	-	2.8	6.1	20.0	10.9	3.2	1.4	0.3	1.5	-	1.7	47.9	20
TOTAL		98.8	210.3	3959.9	14941.2	11605.8	7081.9	3825.6	1810.4	3157.7	1252.4	4001.5	51,945.5	28,667
Unsampled Catch														4,783
Total Catch at Age		115.3	245.4	4620.6	17434.1	13542.2	8263.5	4463.9	2112.5	3684.6	1461.4	4669.1	60,612.4	33,450

Table 5. Mackerel Commercial and Recreational Catch at Age (x 10^{-6}) from ICNAF SA 3-1 for 1962-78

A G E	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
0	0.0	0.0	0.0	0.0	0.0	2.2	1.4	4.5	5.1	2.5	3.6	4.0	2.0	3.7	0.0	0.0	0.0
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	0.1
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	0.2
3	22.1	1.7	5.1	3.5	6.4	24.4	73.6	183.2	556.0	132.0	260.0	284.2	264.4	114.0	272.5	100.7	4.6
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
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
6	2.3	0.4	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
7	2.1	0.2	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
8	1.1	0.2	0.8	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
9	0.6	0.2	1.0	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
10	0.2	0.2	0.3	0.0	0.0	0.0	0.1	9.5	4.0	8.4	3.8	3.8	2.5	2.3	13.4	3.6	1.5
11+	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	3.0	7.5	5.7	1.6	0.8	1.0	1.4	0.6	4.7
Total	63.30	53.5	70.5	64.3	95.0	123.0	409.8	597.3	1069.4	1375.4	1089.6	1405.1	1075.8	1271.3	916.4	225.2	60.6
Observed Weight	16.6	17.3	21.7	24.7	32.4	47.6	109.9	165.1	262.7	403.7	431.6	429.3	347.2	293.2	245.9	78.1	33.4
Calculated Weight[1]	15.3	18.2	23.1	25.5	30.7	48.0	84.0	144.7	276.8	429.2	396.2	435.4	346.9	308.1	271.3	73.1	28.0
Ratio Obs/Calc.	1.085	0.951	0.939	0.969	1.055	0.992	1.302	1.141	0.949	0.941	1.089	0.986	1.001	0.952	0.906	1.068	1.193
Mean Weight	0.262	0.323	0.308	0.384	0.341	0.387	0.268	0.276	0.246	0.293	0.396	0.306	0.348	0.231	0.268	0.347	0.551
Mean Age	2.80	3.93	3.84	4.74	3.86	4.80	2.34	2.80	2.96	3.61	4.23	3.59	3.79	2.83	3.51	3.81	5.77

[1] Applying ICNAF WEIGHTS (1974)

Table 6. Observed Average Weight and Length at Age in Canadian Fishery for 1978

	AGE												AVERAGE
	0	1	2	3	4	5	6	7	8	9	10	11+	
CANADA-MARITIMES													
Weights at Age		176.7	290.7	348.7	428.3	454.8	523.4	564.1	603.9	688.7	668.4	682.6	469.4
Lengths at Age		25.6	29.9	32.9	33.6	34.3	35.8	36.7	37.5	39.0	38.7	38.9	34.5
CANADA-NEWFOUNDLAND													
Weights at Age			464.0	463.0	506.7	549.6	612.8	661.8	701.1	736.4	737.2	782.0	581.9
Lengths at Age			35.0	34.4	35.2	36.1	37.0	38.0	38.6	39.0	39.3	40.1	36.6
CANADA-AVERAGE													
Weights at Age		176.7	291.4	418.0	461.8	509.4	582.7	630.4	657.1	705.9	712.4	765.7	528.3
Lengths at Age		25.6	29.9	33.4	34.3	35.3	36.6	37.6	38.1	39.0	39.1	39.9	35.6
Mean Weights adopted by ICNAF (1974)		95	175	266	350	432	506	564	615	659	693	693	

Table 7. Mackerel stock size (millions of fishes) for SA 3-6 from cohort analysis during 1962-1978

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	961	555	545	587	1269	3654	8087	3372	4372	1910	2007	1727	2472	2406	800	800	650
2	467	692	410	390	425	915	2706	5840	2491	3061	1349	1467	1140	1749	1460	582	591
3	1330	343	508	296	285	303	650	1939	4069	1796	2005	924	844	636	923	777	408
4	54	966	252	372	217	206	204	418	1279	2536	1217	1262	440	398	373	449	489
5	27	35	686	183	271	158	149	110	245	798	1380	742	734	239	208	203	287
6	7	19	19	487	130	196	113	95	76	156	410	682	384	446	126	109	140
7	5	3	14	10	341	88	140	77	67	50	85	227	336	189	272	70	72
8	16	2	2	6	3	230	59	103	55	45	29	42	142	155	95	166	47
9	9	11	1	1	0	2	136	42	73	32	30	18	22	83	72	41	118
10	8	6	8	0	0	0	1	94	29	45	20	15	10	11	51	34	27
TOTAL	2885	2633	2445	2332	2941	5752	12244	12091	12757	10429	8531	7106	6523	6310	4378	3230	2828
1 + Biomass[1]	635	611	628	648	763	1011	2360	2624	2530	2460	2493	1923	1624	1366	1046	936	961

[1] calculated by applying ICNAF weights at age (1974) and corrected multiplying by the ratio of observed catch weight to calculated catch weight calculated in Table 4.

Table 8. Mackerel fishing mortality for SA 3-6 from cohort analysis during 1962-1978

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	.029	.003	.035	.022	.027	.000	.026	.003	.056	.048	.013	.115	.046	.200	.018	.003	.000178
2	.010	.009	.025	.013	.039	.043	.033	.061	.027	.123	.078	.253	.283	.339	.330	.055	.0003525
3	.019	.006	.012	.014	.026	.098	.141	.116	.173	.089	.163	.442	.453	.233	.420	.163	.01314
4	.125	.043	.023	.015	.017	.025	.315	.234	.172	.308	.195	.241	.312	.350	.310	.150	.042
5	.075	.308	.042	.041	.025	.031	.150	.071	.150	.367	.406	.357	.199	.337	.347	.071	.056
6	.460	.025	.366	.058	.090	.038	.088	.043	.122	.309	.289	.408	.412	.195	.289	.112	.071
7	.695	.071	.531	.909	.094	.104	.007	.035	.102	.241	.406	.173	.470	.386	.190	.098	.075
8	.082	.138	.506	-	.269	.225	.024	.040	.251	.100	.189	.359	.237	.475	.551	.045	.053
9	.085	.021	-	-	-	.325	.067	.071	.184	.176	.385	.312	.420	.193	.457	.115	.037
10	.030	.041	-	-	-	.092	.138	.124	.171	.241	.251	.338	.353	.288	.362	.132	.067
Average 3+	.030	.041	.044	.042	.039	.092	.138	.124	.171	.241	.251	.338	.353	.288	.362	.132	.067

Table 9. Data used to calculate relationship between recruitment and temperature and recruitment and catch per tow[3]

Year-Class	Year-Class Size Age 1	Year-Class Size Age 2	Summer Temperature	Autumn[1] Age 0	Spring[1] Age 1	Spring[1] Age 2
1961	961		13.75			
1962	555		12.88			
1963	545		13.25	.08		
1964	587		13.48	.021		
1965	1269		13.85	.114		
1966	3654	2706	14.58	.158		1.726
1967	8087	5840	15.00	1.833	40.24	.198[2]
1968	3372	2491	14.68	.095	.238[2]	2.625
1969	4372	3061	14.38	.690	1.010	2.779
1970	1910	1349	14.68	.023	.929	1.368
1971	2007	1467	14.60	.169	1.894	.787
1972	1727	1140	13.73	.085	.915	.383
1973	2472	1749	14.80	.214	.826	1.277
1974	2406	1460	14.15	.141	3.186	.787
1975			14.33	.012	.204	.109
1976			14.18	.000	.021	.221
1977			13.15	.021	.128	.009
1978			14.63	.490	.029	

[1] from Anderson and Overholtz 1979 b

[2] not used in calculations

[3] see text for results of calculations

Table 10. Projected biomass and catch from 1979 to 1985

YEAR	PRCALC-OBSWT		PROBS-OBSWT		PRCAL-ICNAFWT		PROBS-ICNAFWT	
	Population Biomass	Catch Biomass	Population Biomass	Catch Biomass	Population Biomass	Catch Biomass	Population Biomass	Catch Biomass
Fishing at F0.1 from 1979 to 1985								
1979	1462	301	1462	252	1007	193	1007	186
1980	1225	245	1297	162	867	158	893	124
1981	1305	263	1480	176	903	166	983	124
1982	1291	252	1534	217	917	167	1053	156
1983	1370	259	1635	208	960	169	1114	154
1984	1565	284	1862	235	1077	183	1252	173
1985	1583	303	1909	243	1109	196	1303	180
1979 catch = 30,000 t and F0.1 afterwards								
1979	1462	30	1462	30	1007	30	1007	30
1980	1480	320	1482	235	1024	198	1027	171
1981	1447	308	1559	207	1000	192	1048	147
1982	1362	276	1567	229	973	183	1083	166
1983	1403	270	1647	212	990	177	1127	158
1984	1579	289	1866	237	1091	187	1257	175
1985	1589	305	1910	244	1116	197	1304	180
1979 catch = 50,000 t and F0.1 afterwards								
1979	1462	50	1462	50	1007	50	1007	50
1980	1461	315	1466	229	1005	193	1010	165
1981	1437	305	1552	205	988	188	1040	144
1982	1357	274	1564	228	966	181	1079	165
1983	1401	270	1646	212	986	176	1125	158
1984	1578	288	1866	237	1090	187	1257	174
1985	1589	305	1910	244	1115	197	1304	180
1979 catch = 100,000 t and F0.1 afterwards								
1979	1462	100	1462	100	1007	100	1007	100
1980	1414	301	1424	212	957	180	967	150
1981	1411	297	1534	197	959	180	1019	137
1982	1344	270	1557	226	949	176	1069	162
1983	1395	268	1643	211	977	174	1121	157
1984	1576	287	1865	236	1085	185	1255	174
1985	1588	305	1909	244	1113	197	1303	180
1979 catch = 150,000 t and F0.1 afterwards								
1979	1462	150	1462	150	1007	150	1007	150
1980	1367	287	1382	195	908	168	924	135
1981	1385	288	1516	190	929	173	998	130
1982	1331	265	1549	223	932	171	1059	159
1983	1389	266	1641	210	968	171	1117	155
1984	1573	287	1864	236	1081	184	1254	173
1985	1587	304	1909	244	1111	196	1303	180

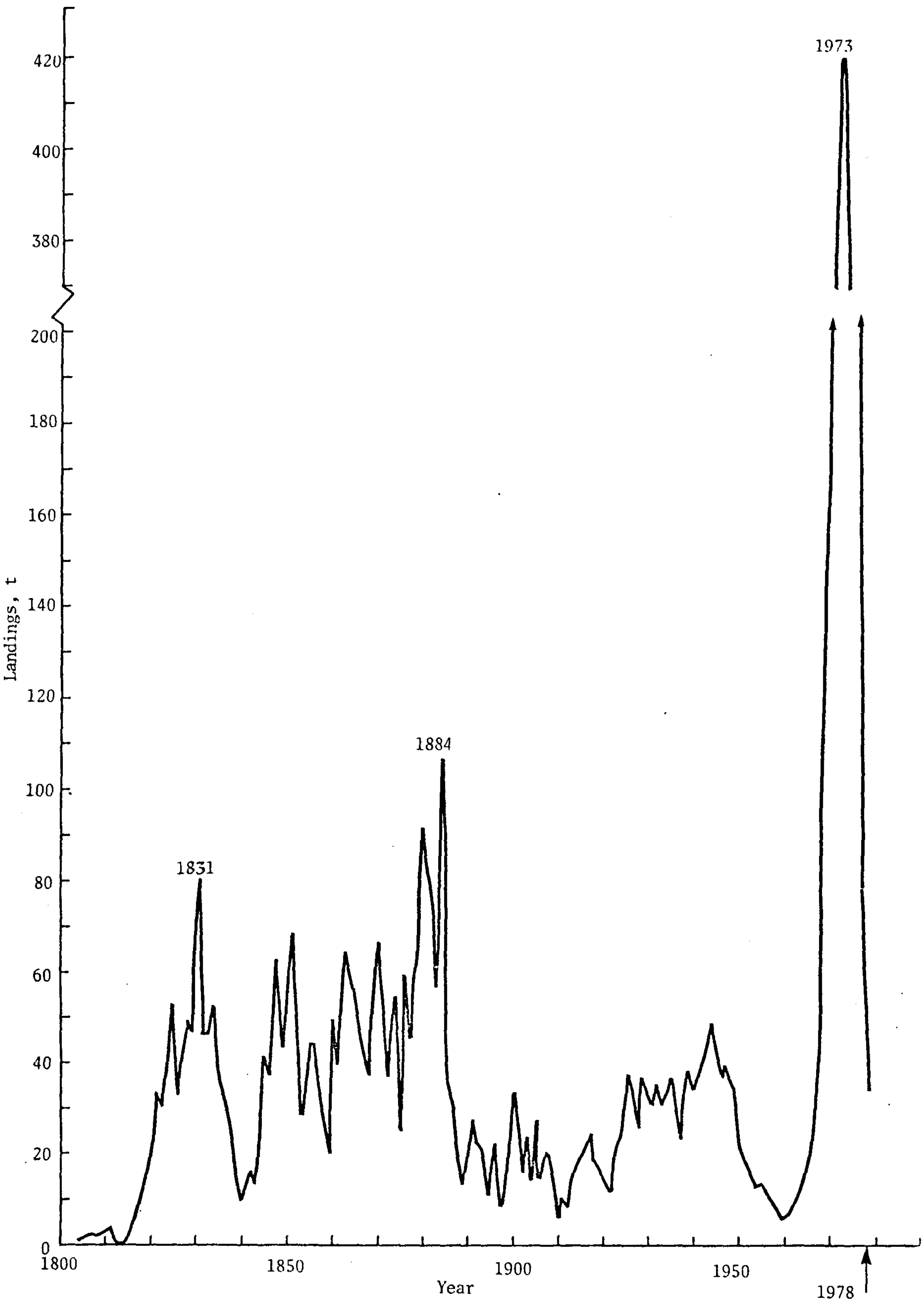

Figure 1: Mackerel Landings Since 1804

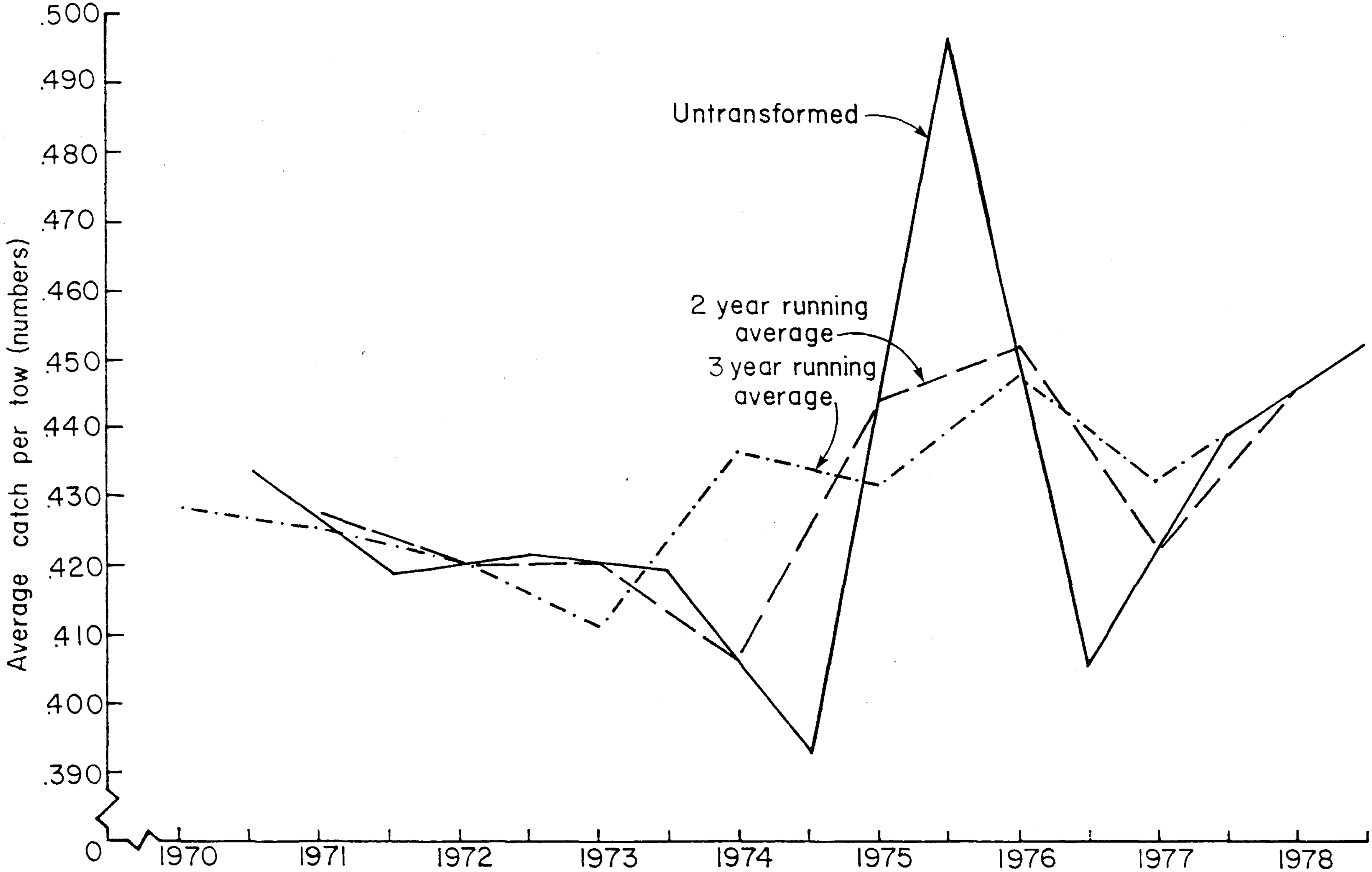

Figure 2a. Scotian Shelf research cruise catch per tow (numbers).

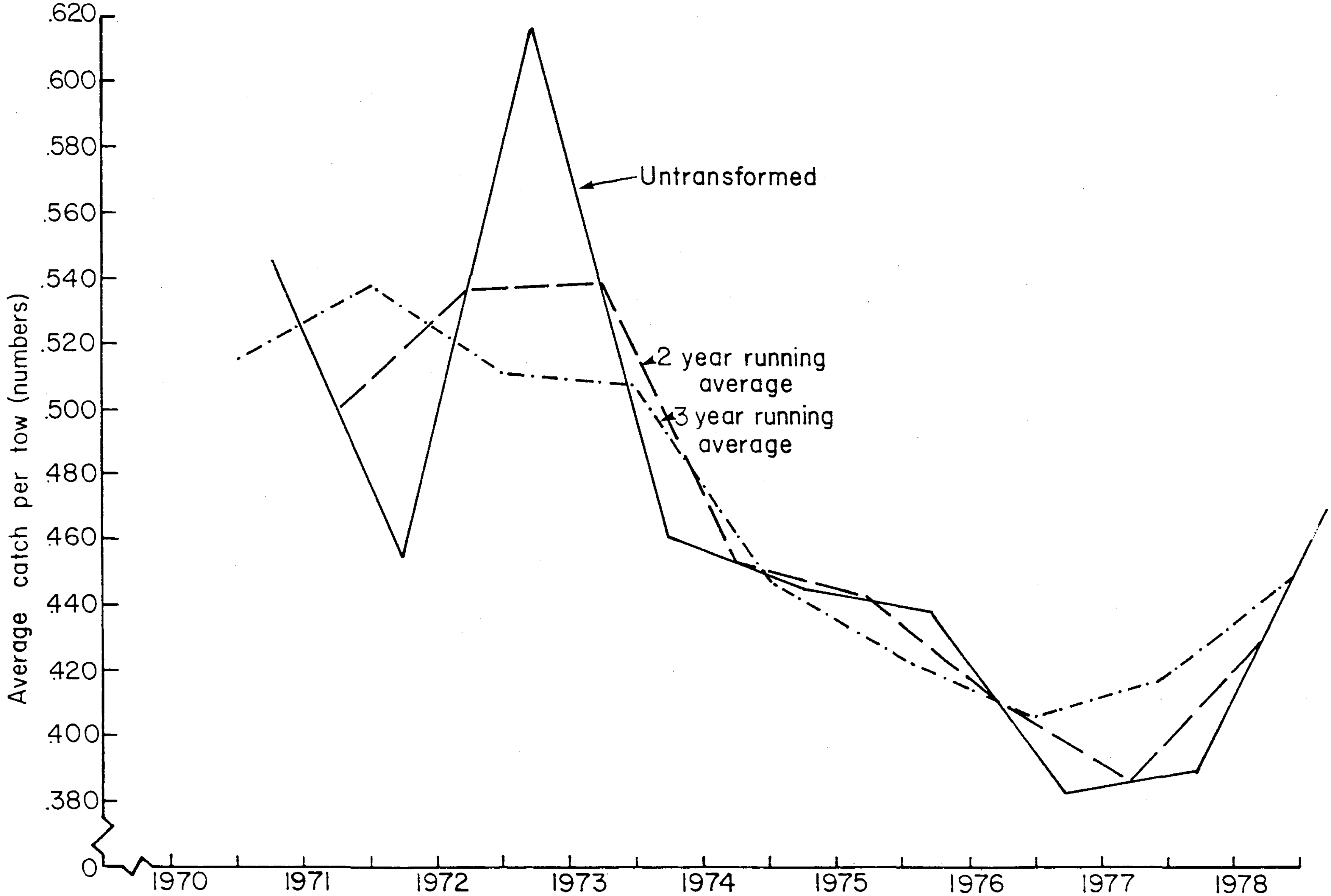

Figure 2b. Gulf of St. Lawrence research cruise catch per tow (numbers).

Figure 3: American spring survey catch per tow (weight)

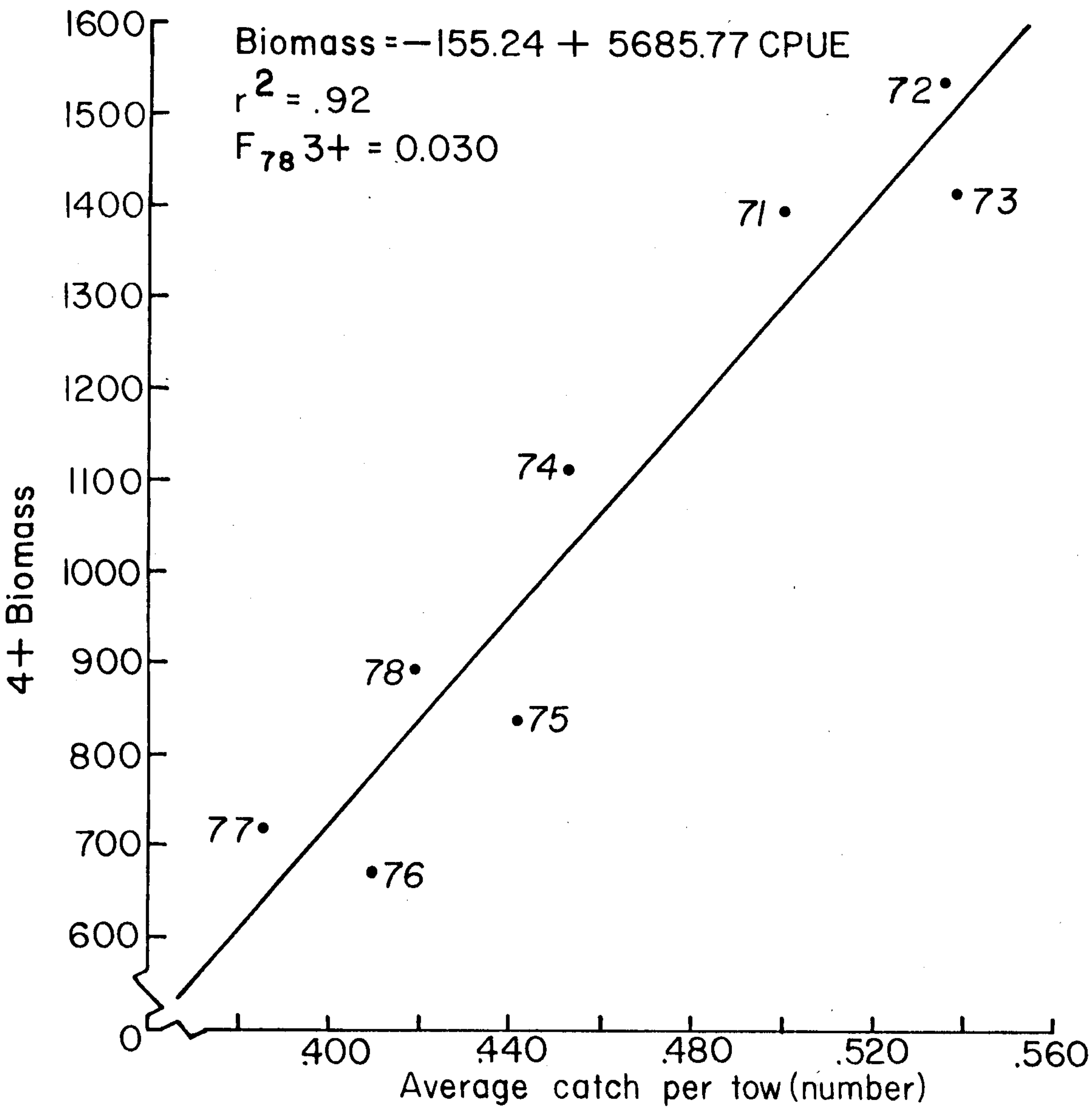

Figure 4. Population biomass (4+) vs Canadian catch per tow (numbers)

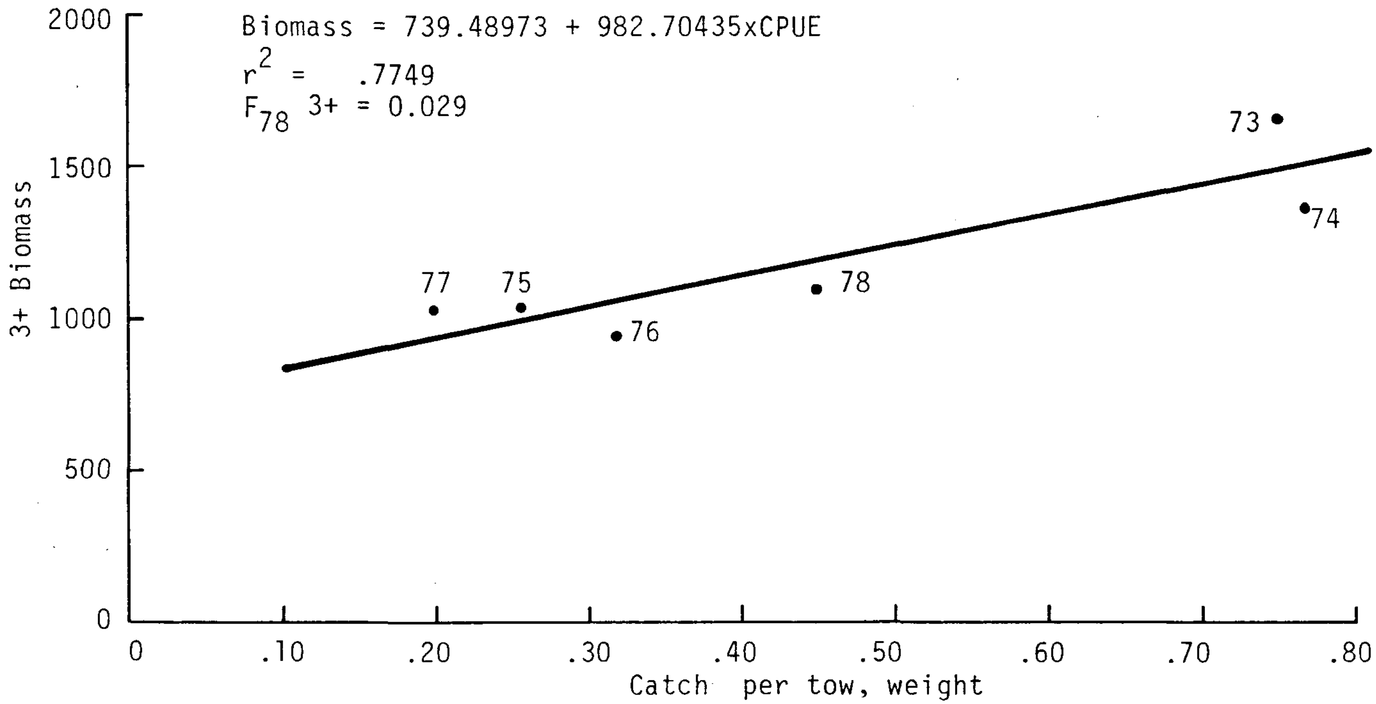

Figure 5: Population biomass vs catch per tow (American)

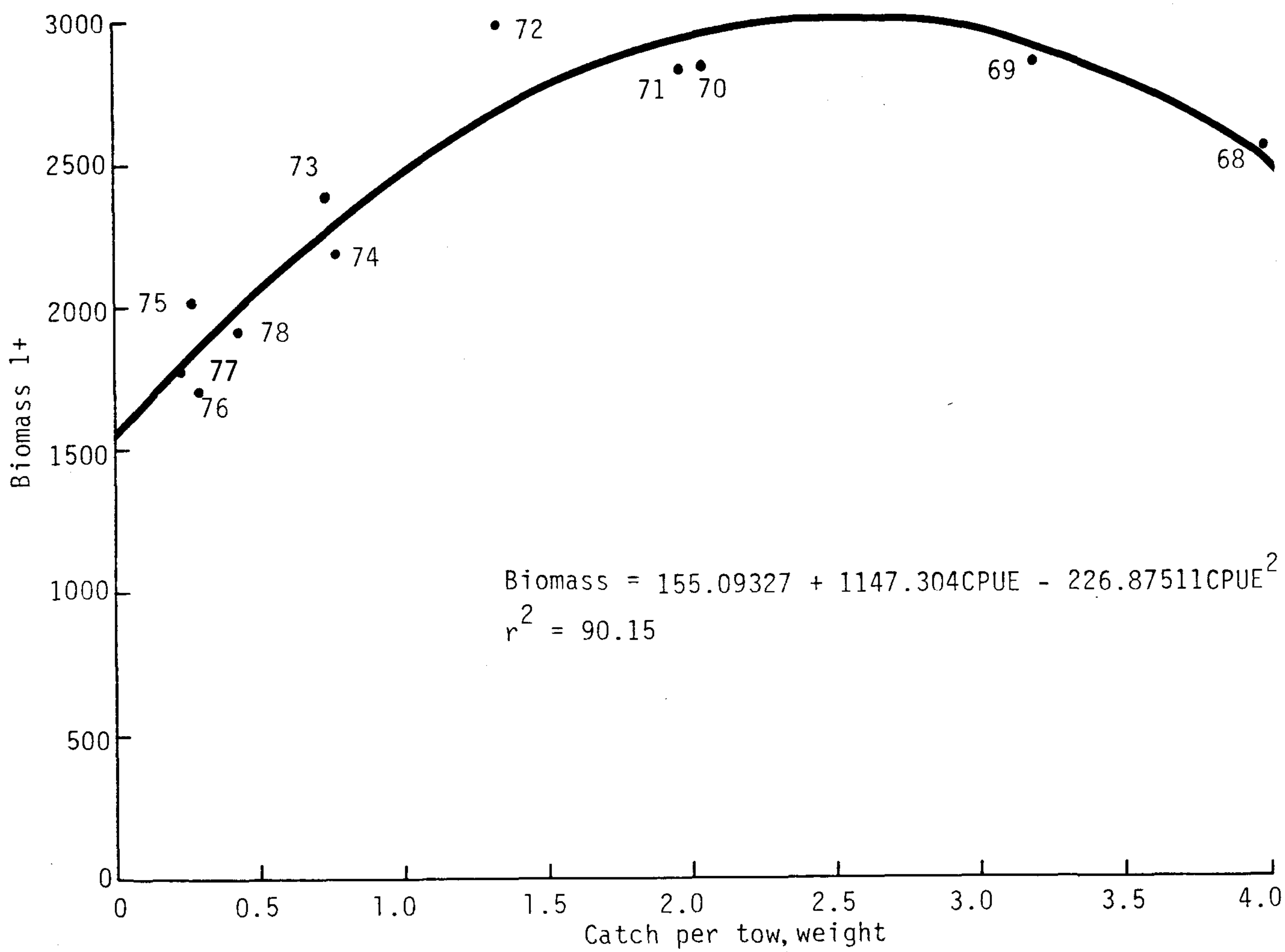

Figure 6: Biomass versus American spring survey catch per tow 1968-1978

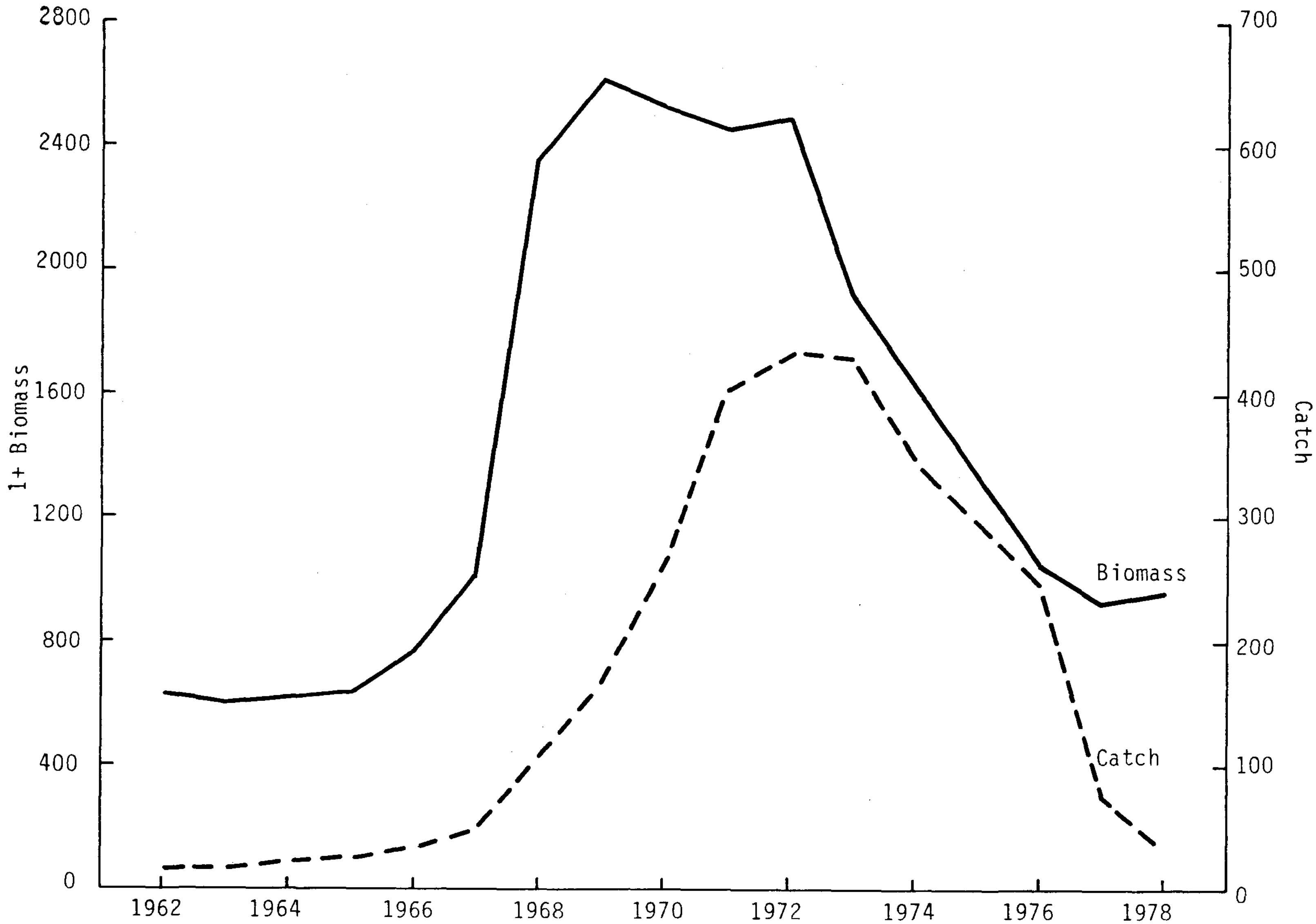

Figure 7: Biomass and catch since 1962

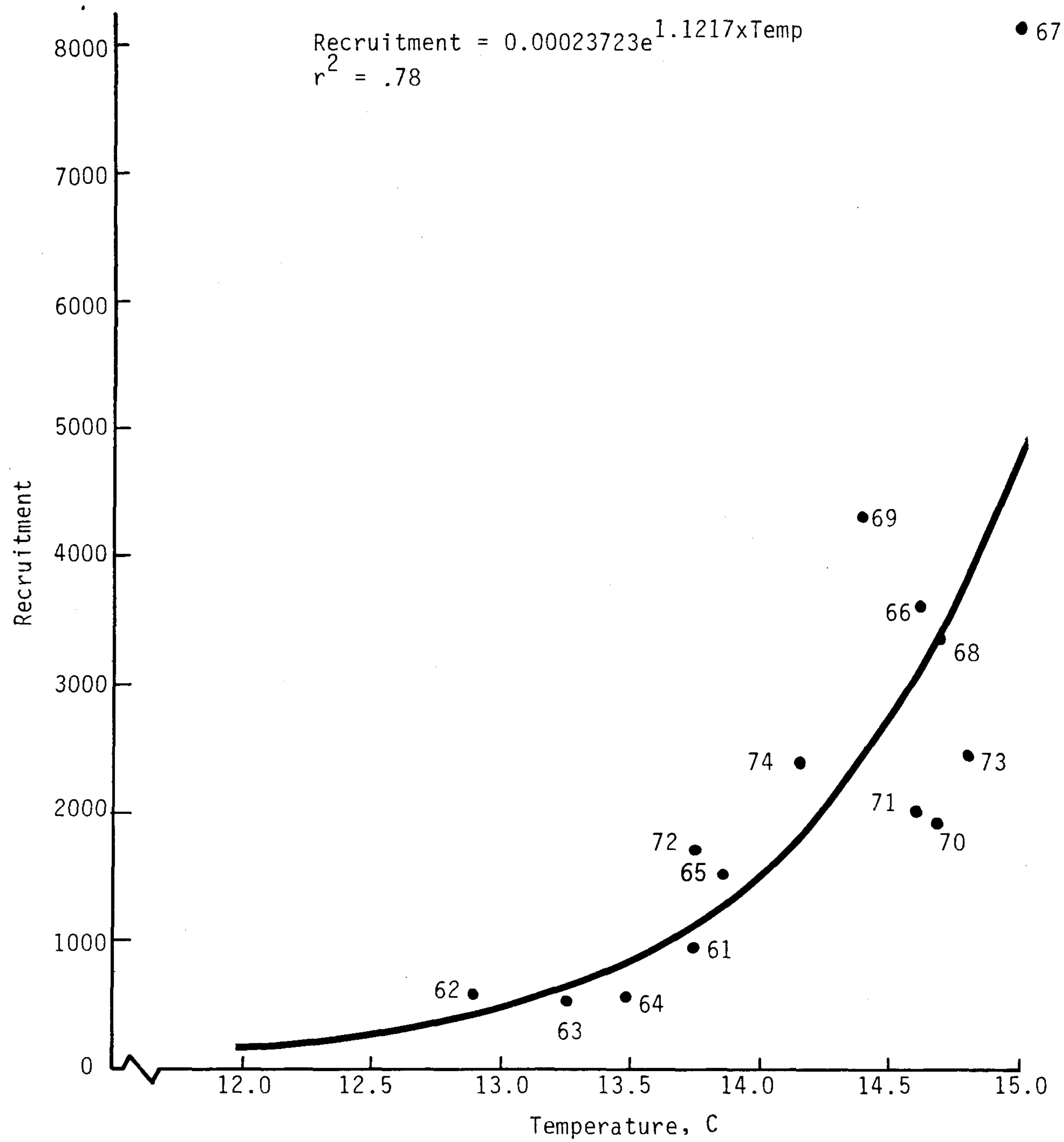

Figure 8 a.: Mackerel recruitment versus average summer months temperature at Entry Island, Quebec

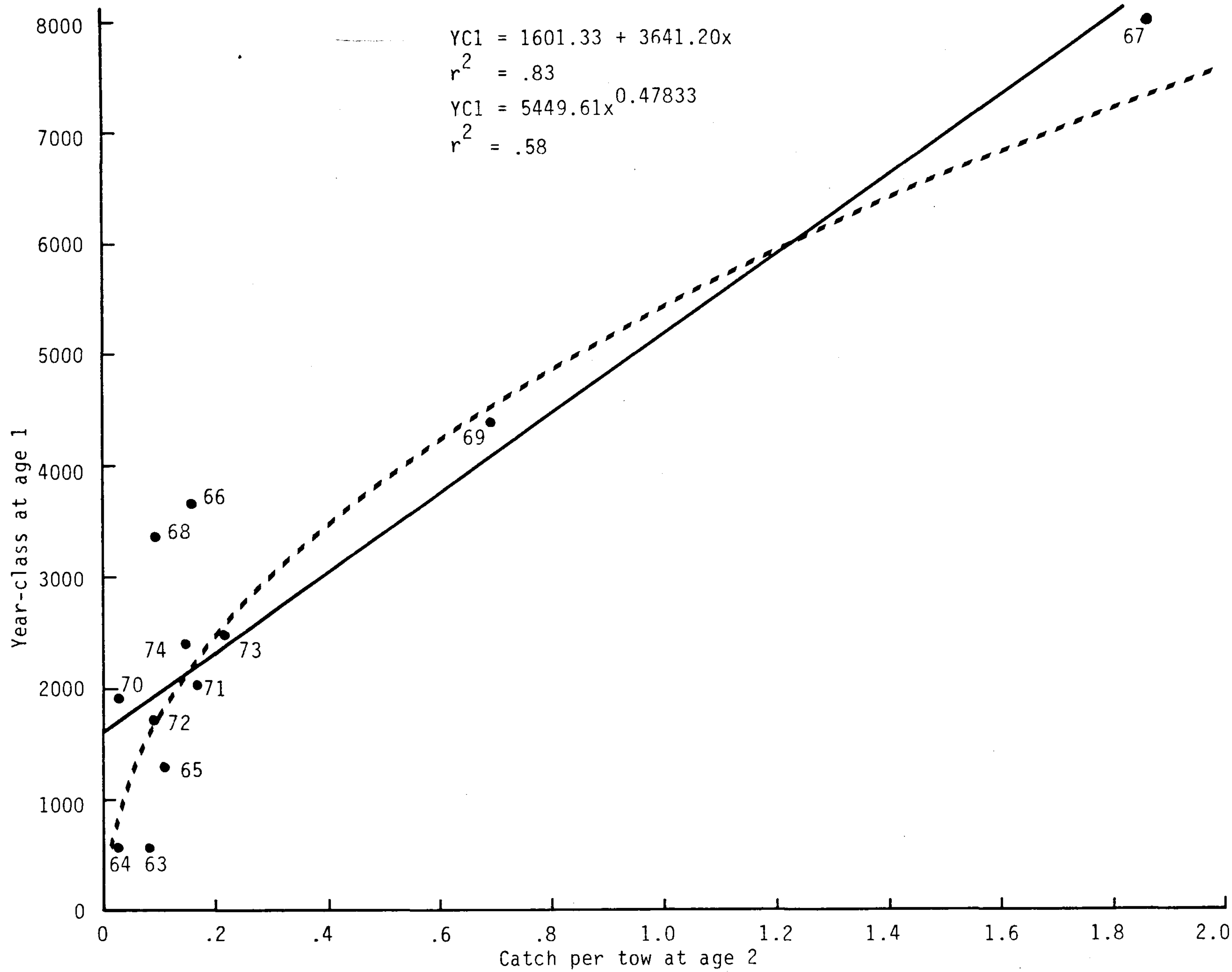

Figure 8 b.: Year-class size at age 1 versus the American autumn survey catch at age 0

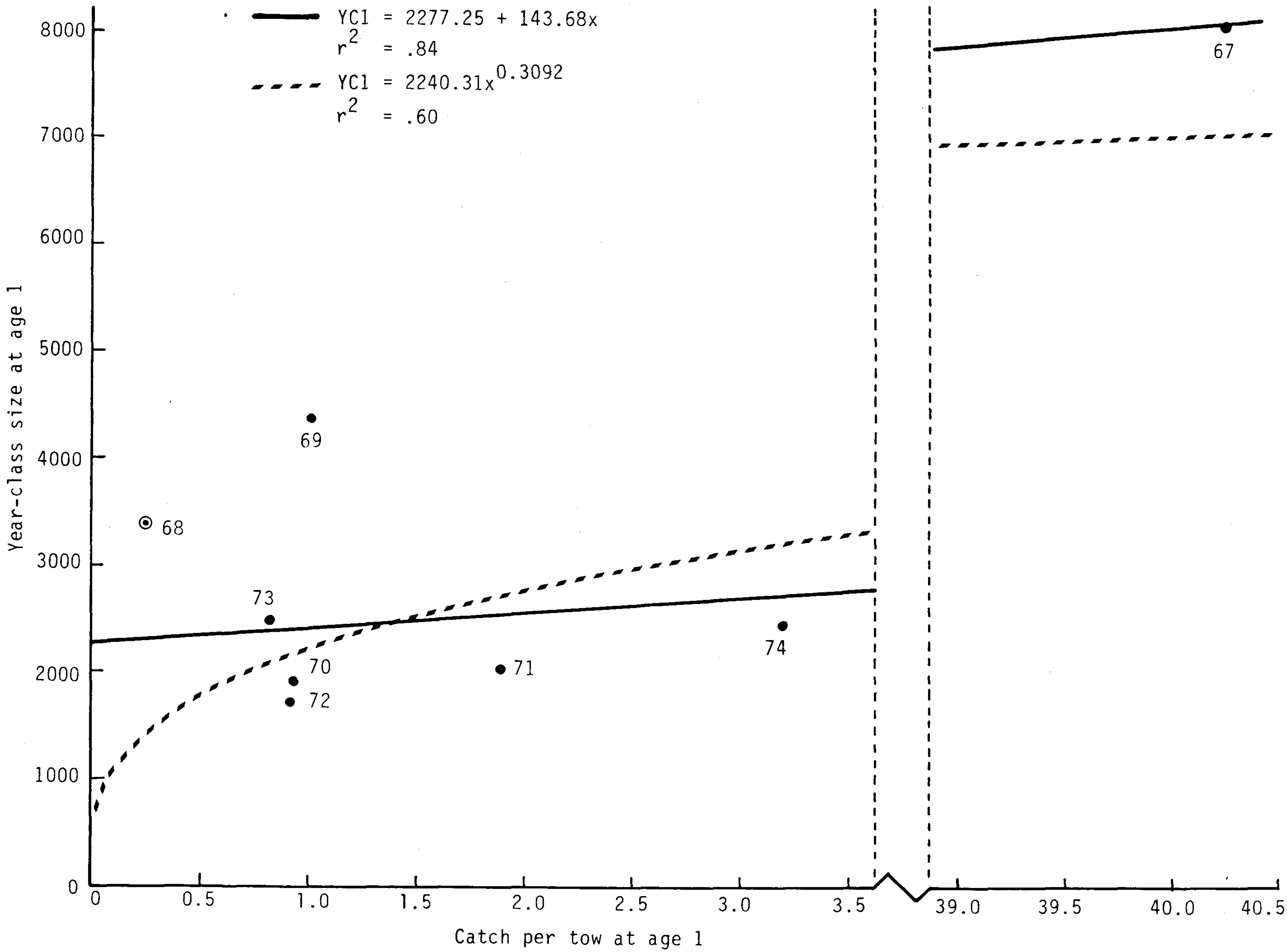

Figure 8 c.: Year-class size at age 1 versus the American spring survey catch at age 1

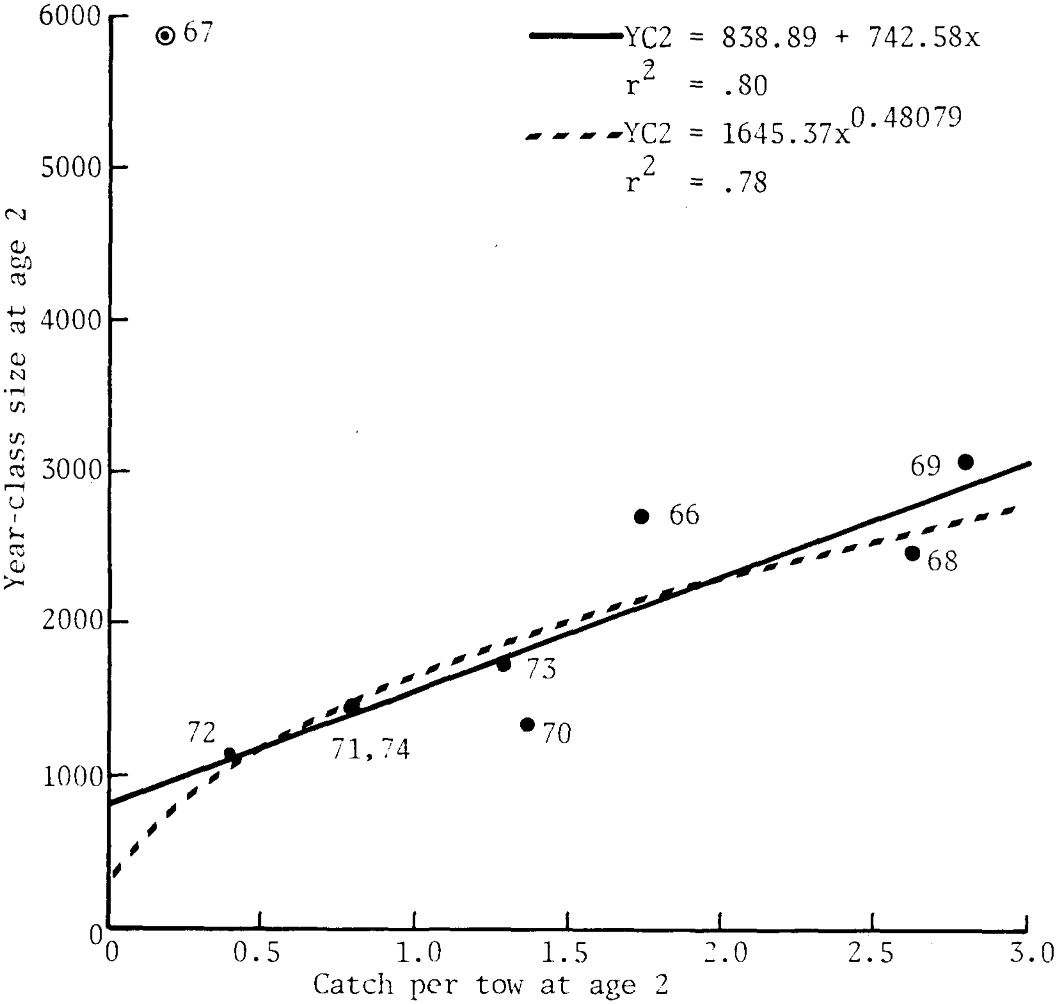

Figure 8 d.: Year-class at age 2 versus the American spring survey catch at age 2

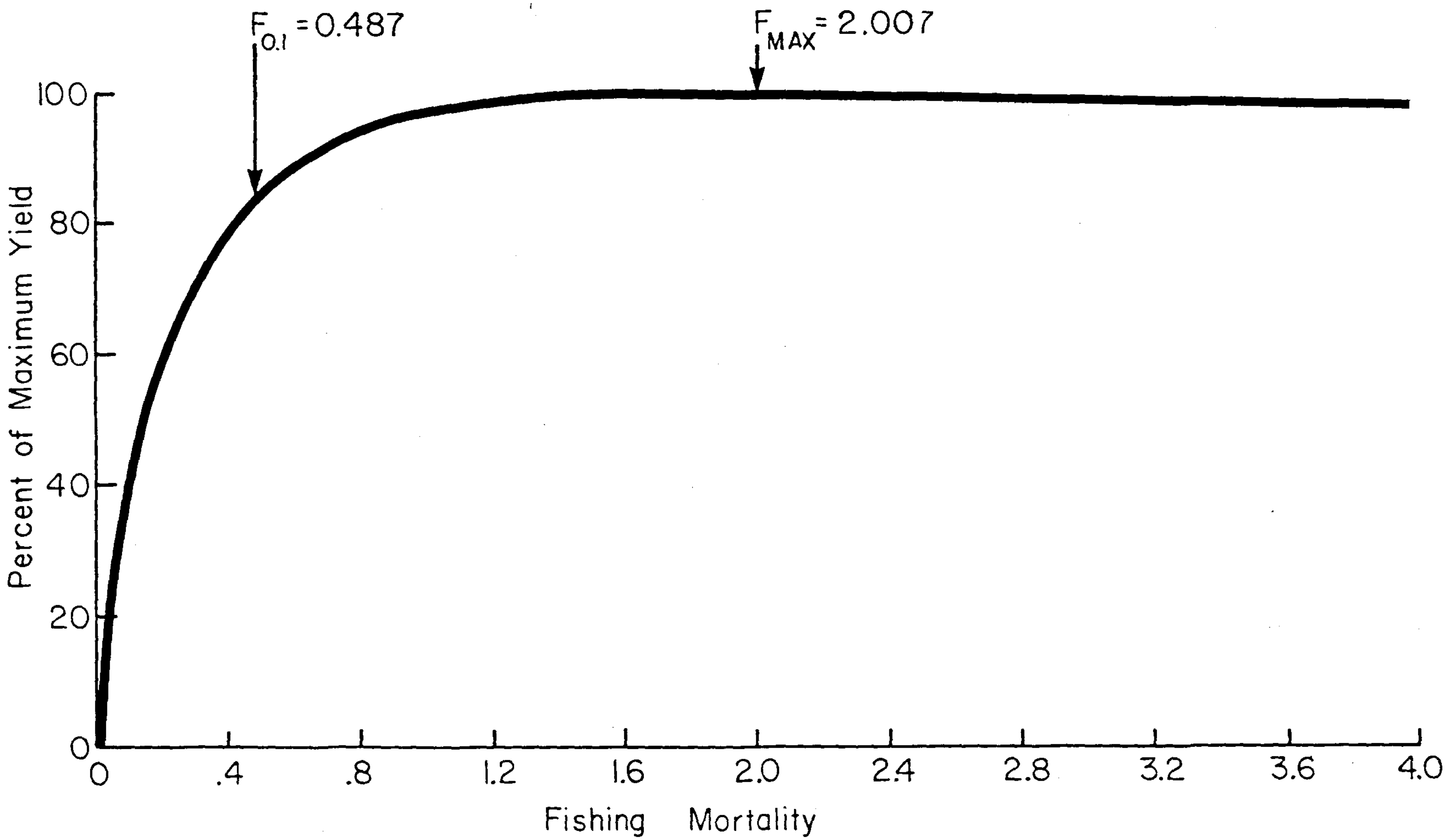

Figure 9 a.: Yield per recruit with observed weights in Canadian fishery and predicted partial recruitment

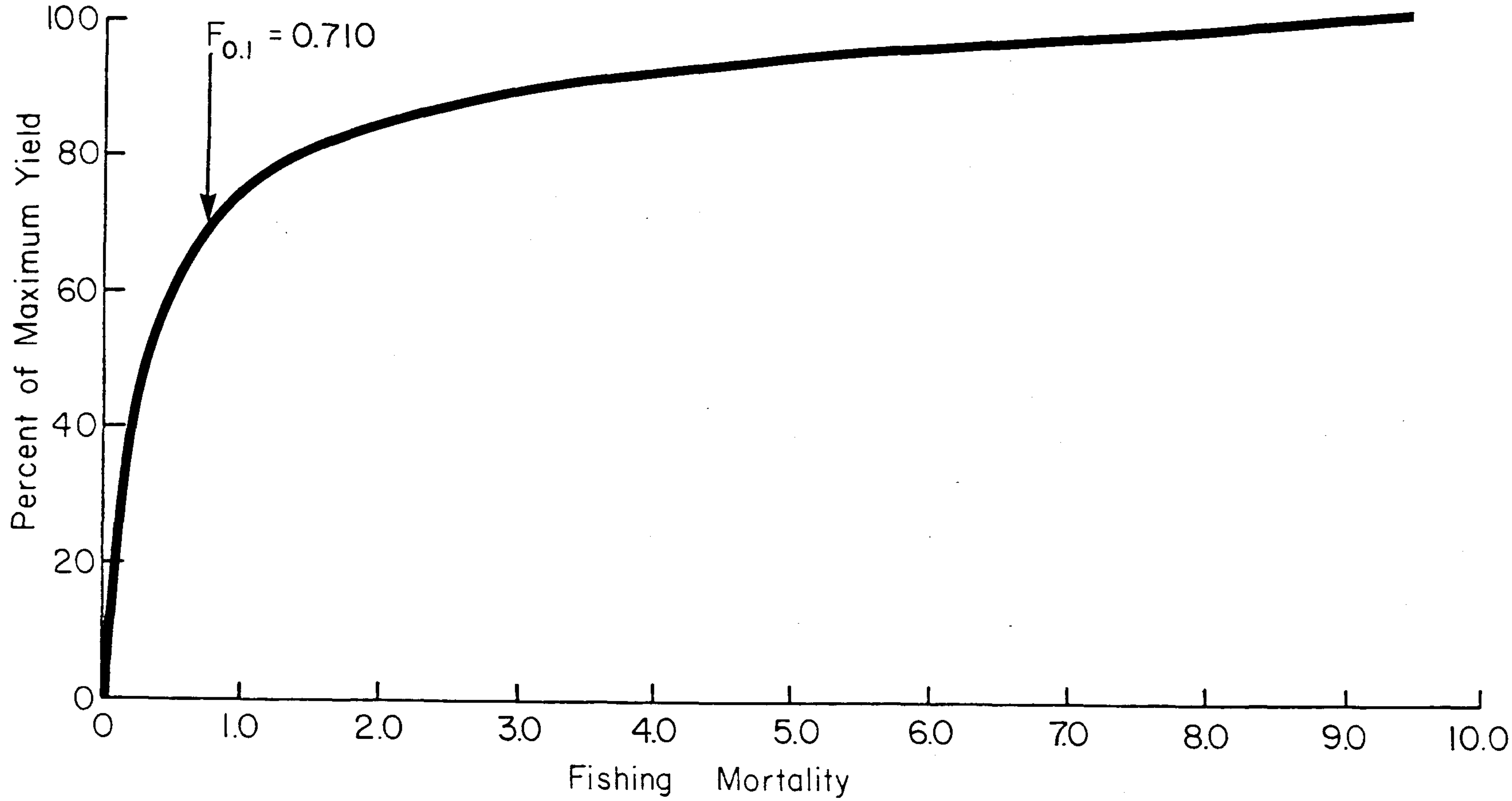

Figure 9 b.: Yield per recruit with observed weights in Canadian fishery and empirical partial recruitment

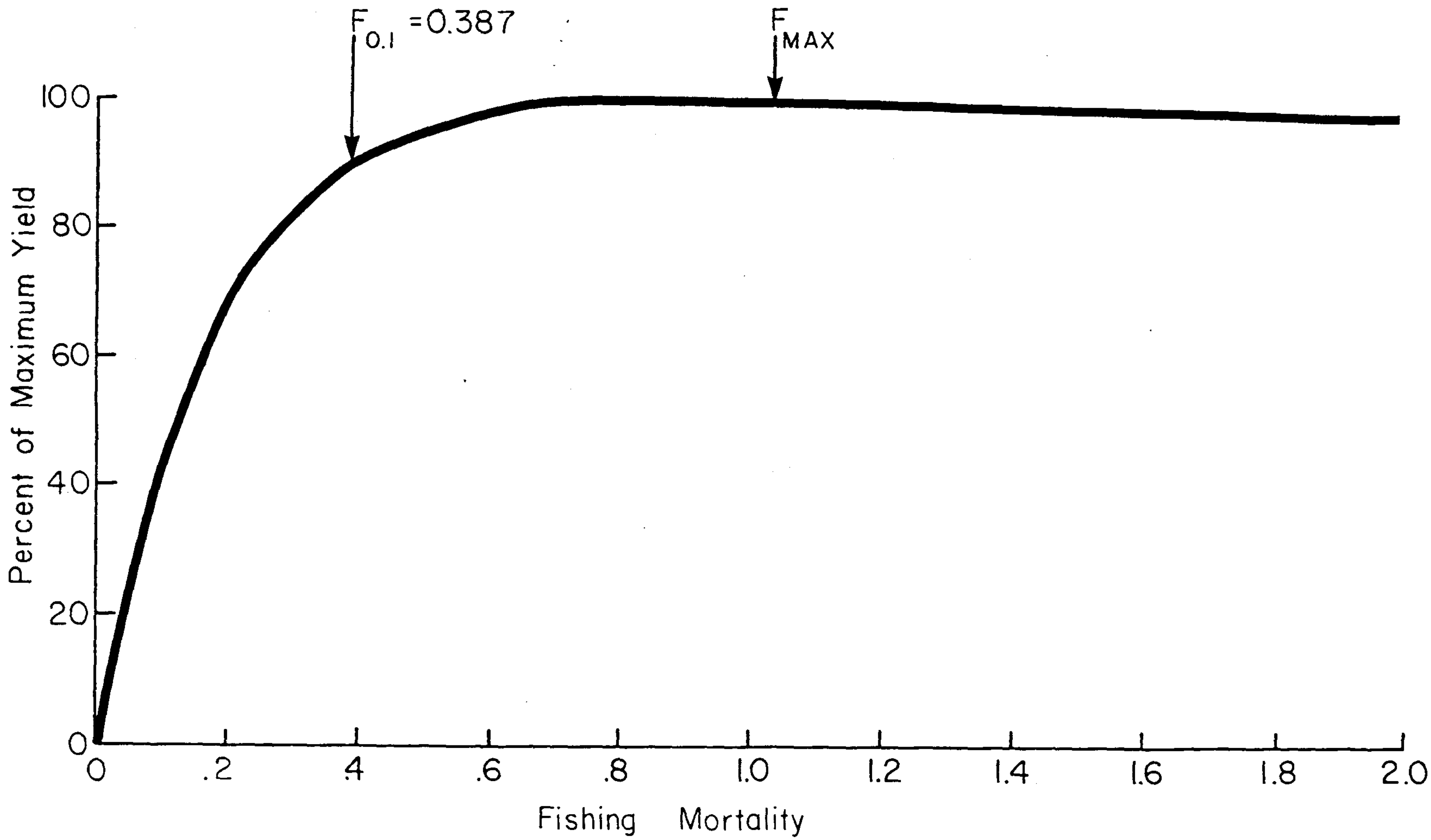

Figure 9 c.: Yield per recruit with ICNAF weights and predicted partial recruitment

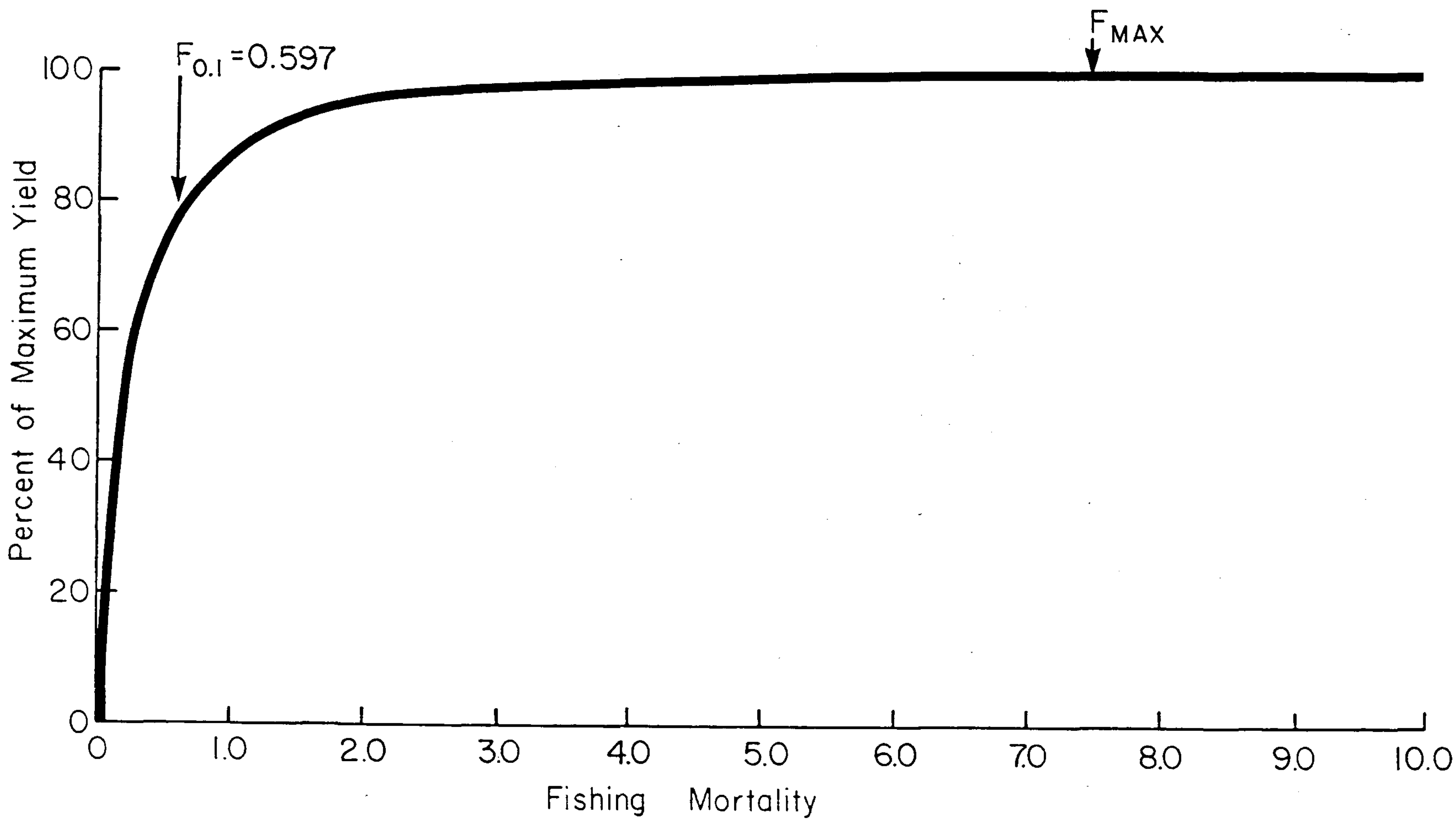

Figure 9 d.: Yield per recruit with ICNAF weights and empirical partial recruitment