Application of Bottom-Trawl Survey Data to Fish Stock Assessments

by

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ABSTRACT

Applications of bottom-trawl survey data to fish stock assessment work are reviewed. Techniques developed at NEFC to estimate recruitment, total biomass, fishing mortality, and other parameters based on bottom trawl survey data are presented and evaluated using examples from past and current assessments. The potential application of these techniques to other stocks is also considered.

INTRODUCTION

The need for accurate analytical assessment work has greatly increased in recent years. This is particularly true for the Northwest Atlantic region adjacent to the USA coast, which during the 1960's and early 1970's was heavily exploited by large distant water fleets. Analyses by Brown et al. (1976) reveal that during the 1961-1972 period a six-fold increase in standardized effort occurred, and landings during the same period more than tripled. By 1973, all major stocks had become fully exploited and some,

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notably the Georges Bank haddock (Melanogrammus aeglefinus) and herring (Clupea harengus) stocks and the southern New England yellowtail flounder (Limanda ferruginea) stock had become seriously depleted.

Increased exploitation levels have focused the need on improved analytical assessment work. Accurate estimates of recruiting year-class strength, trends in stock abundance, current levels of instantaneous fishing mortality (F), age composition of stocks, and other parameters have become increasingly important in recent years, particularly in the case of stocks which have been heavily fished. It has not been possible to obtain unbiased estimates of these parameters solely from commercial (or recreational) catch data. This has stimulated the development and use of a number of predictive assessment techniques at the Woods Hole Laboratory of the Northeast Fisheries Center (NEFC) based largely on bottom trawl survey data. While these techniques were developed in response to specific assessment problems, the methods involved have application to a much wider range of situations.

This document reviews selected assessment techniques developed and used by NEFC scientists which utilize bottom trawl survey catch data. It is hoped that the following material will not only prove useful to researchers in other organizations, but will also stimulate criticism and suggestions for improvement.

BOTTOM TRAWL SURVEY PROCEDURES

Autumn bottom trawl surveys have been conducted by the National Marine Fisheries Service since 1963 in continental shelf waters between 27 and

365 m between Nova Scotia and Hudson Canyon utilizing the R/Vs ALBATROSS IV and DELAWARE II. The survey was extended south to Cape Hatteras in 1967, and a spring survey was initiated in 1968; several summer and winter surveys were also conducted. In all the autumn surveys and in the spring surveys conducted during 1968-1972, both vessels used the standard "36 Yankee" trawl with a 1.25 cm stretch mesh cod end lining. The trawl measures 24 m along the footrope, averages 3 m in height along the headrope, and is equipped with rollers to make it suitable for use on rough bottom. Beginning in 1973, a modified high-opening "41 Yankee" trawl was used during the spring survey which measures 30 m along the footrope and averages 4-5 m in height along the headrope. Coefficients have been calculated for many commercially important species to adjust for differences in fishing power between the two trawls (Sissenwine and Bowman, MS 1977).

Sampling has been based on a stratified random design (Cochran 1953), with the survey area stratified into geographical zones (Figure 1) primarily on the basis of depth and latitude (Grosslein 1969). During 1963-1966, only strata from the New Jersey coast northward (1-42, Figure 1) were sampled; additional strata (61-76, Figure 1) were added in autumn 1967 to cover the mid-Atlantic region.

Approximately 300 stations are sampled during each survey. In all surveys, stations are allocated to strata roughly in proportion to the area of each stratum and are then randomly assigned to specific locations within strata. Following collection of hydrographic data, a 30-minute tow is taken at each station at an average speed of 3.5 knots. The catch from each tow is sorted, weighed, and measured by species, various pertinent data are

recorded, and materials (e.g., scales or otoliths) are collected for ageing and other purposes. The basic catch data are transferred to magnetic tape following completion of each survey. Thus, a considerable time-series of data now exists for all species captured which can be used directly in assessment work. Grosslein (1969; MS 1969a, MS 1969b) presents further details concerning procedures used in these surveys.

Numerous joint surveys have been conducted by the NEFC since 1969 in cooperation with and using research vessels from the USSR, Poland, the FRG and GDR, France, Canada, and Japan. These have proven highly valuable in a number of instances, but lack the continuity and standardized nature of the USA surveys with respect to vessel, gear type, and procedures used. Consequently, NEFC assessment work requiring analysis of time-series data has primarily been based on the USA surveys.

The statistical basis for the survey design and accuracy and precision of the results obtained have been considered by Grosslein (1971) and Grosslein and Pennington (MS 1978) and will not be considered further in this document.

USES OF SURVEY DATA IN ASSESSMENTS

The survey data base has proven essential to NEFC assessment needs. For many stocks, particularly those for which analytical assessments have been prepared only recently, biological sampling of the commercial catch has been limited or nonexistent and catch/effort data are inaccurate and consequently survey data provide the only basis for determining age structure

of the population, growth and mortality rates, relative changes in population abundance, and the like. Even for stocks for which a substantial commercial data base exists, survey data have still been necessary. The validity of the survey data base has been demonstrated repeatedly for demersal species, e.g., survey abundance indices tend to mirror trends in stock size estimates calculated from commercial data (virtual population analysis or VPA) for Georges Bank haddock (Figure 2) and Georges Bank and Gulf of Maine silver hake (Anderson MS 1977a, Anderson and Almeida MS 1978, Figures 3 and 4) while commercial catch/effort and research vessel survey abundance indices correspond closely for Georges Bank yellowtail (Sissenwine et al. MS 1978, Figure 5). Age composition data derived from the surveys also tend to agree closely with commercial sampling data if allowance is made for differences in net selectivity (Figure 6). Similar patterns appear to hold true for pelagic species, e.g., trends in spring bottom trawl survey catch/tow data appear to accurately reflect trends in mackerel stock biomass determined from commercial data (cohort analysis) (Anderson MS 1977b, Figure 7). Consequently, it would appear that a number of predictive applications would be feasible utilizing the bottom trawl survey data base.

The following material reviews predictive techniques which have been developed for stock assessments by NEFC scientists including estimation of recruiting year-class strength, stock abundance, quota levels corresponding to varying levels of fishing mortality, and current fishing mortality levels. Applications of survey data for routine calculations (e.g., relative abundance indices, growth and mortality rates, etc.) will not be considered here.

Prediction of Recruitment

One obvious requirement in assessing the current and future status of a stock is to predict the strength of recruiting year-classes. In practice, this often involves development of a mathematical relationship between survey catch per tow at age data and stock size at age calculated from virtual population or cohort analysis.

Anderson (MS 1977b) has predicted mackerel year-class strength based on power curve relationships between year-class size and spring survey catch per tow data (Figures 8 and 9). Similar relationships were developed using autumn survey data, thus providing additional estimates of a particular year-class. Linear regression analysis may also be used, e.g., Anderson and Almeida (MS 1978a) have used linear regression to predict year-class strength for Gulf of Maine silver hake (Figure 10) using survey catch/tow at age 0 versus VPA year-class size at age 1. Estimates from such analyses appear quite precise provided that an adequate time-series is available and that catch per tow at age data are reasonably consistent, e.g., Anderson (MS 1977b) obtained mackerel year-class size estimates for the 1974 year-class of 2,104, 2,447, and 2,516 million fish at age 1 based on spring and autumn survey data. The estimates for the 1975 year-class at age 1 were 614, 898, and 915 million fish.

Stock abundance and Total Biomass Levels

For some stocks it may be desirable or necessary to predict levels of stock abundance based on estimates of recruiting year-class strength.

Such an approach has been used for Georges Bank haddock (Hennemuth, MS 1969; Clark and Palmer, MS 1978) for which commercial sampling has been somewhat limited in recent years (and thus determinations of stock size based on age composition data may not be very meaningful). Consequently, recruitment estimates calculated from linear regression analysis, removals estimated from commercial catch data, and the assumed instantaneous natural mortality rate (M) for this stock have been used to calculate stock size estimates for recent years using the equation:

$$C_i = N_i \, {}^{F_i}/_{Z_i} \, (1-e^{-Z_i}) \qquad (1)$$

where C_i = catch in year i;

N_i = stock size in year i;

F_i = the instantaneous fishing mortality rate in year i; and

Z_i = the instantaneous total mortality rate in year i ($=F_i+M$, the instantaneous natural mortality rate)

The calculations can readily be performed if N_i can be determined for an initial year from virtual population or cohort analysis. Results have been consistent both with survey abundance indices (kg) and commercial data indicating an increase in abundance in recent years.

An analogous procedure has been developed for the southern New England yellowtail flounder stock by Brown and Hennemuth (1971). This entails calculation of a "survey population index" based on the fact that yellowtail flounder first enter the commercial fishery in significant numbers at age 2 and are almost fully recruited by age 3; most of the commercial catch

consists of age-groups 2-5. Stratified mean catch of pre-recruit (age 1) yellowtail flounder in autumn surveys is taken to represent the relative abundance of the year-class in question at the beginning of the following year (i.e., age 2). The abundance index of this year-class at the beginning of the next year (age 3) is calculated by multiplying the pre-recruit (age 2) index by the survival rate during the first year of exploitation. The age 4 abundance index of this year-class is calculated by multiplying the age 3 index by the survival rate during the second year of exploitation, etc. (Survival rates may be determined from commercial or survey catch per tow data.) The survey population index for a given year is then calculated by summing indices at age over all year-classes in the fishery, i.e.,

$$N_i = n_{ij} + e^{-Z_1} (n_{i-1,j} + n_{i-2,j} e^{-Z_2} + n_{i-3,j} e^{-2Z_2}) \qquad (2)$$

where N_i = relative abundance at the beginning of year i;

$n_{i,j}$ = relative abundance of age-group j in year i;

Z_i = instantaneous total mortality rate during the first year in the fishery, and

Z_2 = instantaneous total mortality rate during the remaining years in the fishery.

An index in terms of weight can be calculated by multiplying each year-class contribution by the appropriate mean weight at age value.

The utility of the procedure is that if (1) survival rates are known with reasonable accuracy and (2) the age 2 contribution can be approximated from recent recruitment trends, the index for a succeeding year can be calculated prior to the autumn survey. This is useful in

predicting future catch levels. Trends in calculated survey population indices are in agreement with trends in abundance as indicated by commercial catch/effort data (Sissenwine et al. MS 1978, Figure 11).

In addition to providing a basis for evaluating trends in abundance for individual species-stocks, survey data have also been used to calculate trends in total biomass. Clark and Brown (1977) calculated biomass estimates by adjusting data for individual species-stocks in terms of catchability; the adjustments are necessary because individual species vary greatly in vulnerability to the survey gear. (For example, herring and mackerel apper to have accounted for as much as 50% of the total finfish biomass during the early years of the survey yet accounted for less than 1% of the weight taken in autumn bottom trawl surveys during the same period). Estimates of trends in total biomass for a given area may, therefore, not be very realistic unless adjustments for differences in catchability are made.

To compensate for this source of bias, Clark and Brown (1977) calculated catchability coefficients by dividing survey catch/tow in autumn of year i by stock size estimates at the beginning of year i+1 (stock size estimates were taken from virtual population or cohort analysis or were calculated from commercial data and available mortality estimates). Resulting values were then averaged over all years to obtain weighting coefficients, viz.

$$W_j = \sum_{i=1}^{n} \frac{(C_{i/S_{i+1}})}{n} \qquad (3)$$

Annual biomass estimates were then calculated by applying these coefficients to each stock and summing over all stocks, viz.

$$\sum_{j=1}^{k} (C_{ij}/W_j) \qquad (4)$$

where C_{ij} refers to stratified mean catch per tow for the jth stock in the ith year and W_j refers to the weighting coefficient for the jth stock, summation being over k stocks. Total biomass at the beginning of any year can thus be predicted knowing the autumn bottom trawl survey abundance indices from the preceding year and the calculated weighting coefficients (Figure 12).

Prediction of catch levels

Brown and Hennemuth (1971) developed a procedure to estimate catch levels for the southern New England yellowtail flounder stock based on the above mentioned survey population index. The method utilizes the relationship between this index, commercial catches, and past levels of fishing mortality and allows determination of future catch levels corresponding to a given mortality rate.

The necessary information for 1978 is summarized in Figure 13 (Sissenwine et al., MS 1978). The vertical line represents the locus of possible points for 1978; the slope of the line from any point through the origin indicates fishing mortality relative to other years and relative to the reference lines provided.

The instantaneous total mortality rate (Z) for southern New England yellowtail flounder for 1963-1969 was estimated as 1.25 by Penttila and

Brown (1973); assuming M = 0.2, then the instantaneous fishing mortality rate (F) was 1.05. By fitting a straight line through the origin to the data points in Figure 13 contained within this time interval, the line corresponding to F = 1.05 was obtained. The slope of the line corresponding to any other F value can be determined by substituting a point from the line of known F into an equation which relates catch to the survey population index (u) and solving for an unknown constant (q), viz.

$$C_i = F_{i/Z_i} \frac{1}{q} u (1-e^{-Z_i}) \qquad (5)$$

Once obtained, q is then substituted back into (5) together with the appropriate survey population index value and the desired F value to obtain the corresponding catch. Catches for 1978 corresponding to the F_{max} and $F_{0.1}$ levels have been calculated by this technique (Figure 13). Essentially the same procedure can be used based on survey catch-per-tow data if the autumn survey point is available. Accordingly, the same calculations have been made for the Georges Bank stock using survey catch-per-tow values in place of survey population indices (Figure 14).

Estimation of Fishing Mortality

The estimation of fishing mortality during the most recent year of the fishery (i.e., the "terminal" or "starting" F value in virtual population/cohort analysis) is an extremely important and critical parameter in stock assessments. Stock sizes immediately prior to or during this year cannot be determined with any degree of confidence unless the terminal F estimate is reasonably accurate. Provided that fishing effort is constantly

proportional to fishing mortality, it is possible to estimate fishing mortality from effort data. However, changes in vessel efficiency often preclude such analyses as found by Anderson (1976) for the Northwest Atlantic mackerel stock. Consequently, a technique was devised for the mackerel assessment to calculate fishing effort in terms of survey catch-per-tow data which are not subject to efficiency biases inherent in commercial data (Anderson et al., MS 1976). This procedure involved calculation of an annual fishing effort index by dividing total catch by the spring survey catch-per-tow values. Because of year-to-year variability in the survey time-series, it was smoothed by calculating an exponential curve through the actual points (Figure 15) (Anderson et al. MS 1977b) and the predicted values from the curve were used in place of the actual values to determine the fishing effort index for each year. A linear regression between indices for preceding years and the corresponding fishing mortality rates determined from cohort analysis were used to predict an F value for the current year (Figure 16). The method may be refined by using this value as the starting F value in a second cohort analysis to get improved estimates of F in earlier years, which may be used in a second regression to determine a new starting F value, etc. This procedure can be continued until the predicted F value and the terminal F value used agree. In addition to mackerel, this technique was also used to determine an F value in 1976 for the southern New England - Middle Atlantic red hake stock (Anderson and Almeida, MS 1978b).

SUMMARY AND CONCLUSIONS

The above procedures provide a basis for evaluating recruitment, trends in stock abundance, and fishing mortality as well as for determining quotas corresponding to desired fishing mortality levels. In most cases the methods are dependent upon both survey and commercial data and are therefore subject to bias from anomalous survey catch per tow values, inconsistencies in VPA or cohort analysis resulting from inadequate commercial sampling, etc. Serious anomalies should usually be obvious and may be excluded from the analyses as was done in the above recruitment prediction calculations (Anderson, MS 1977b, Figures 8 and 9; Anderson and Almeida, MS 1978a, Figure 10). In any case the general consistency observed between the two data bases in depicting trends in abundance, size and age composition, etc. (Figures 2-7) would appear to support the general validity of these techniques.

The above procedures would obviously be most dependable when the time series involved is reasonably long. For stocks for which the available data base is more limited, predictive accuracy should improve substantially as additional data become available. Considerable refinement may also be possible by compensation for day-night differences in availability to the survey gear, selection of strata sets to minimize bias from changing migration patterns, or actual modification of existing survey procedures. Further analyses to provide a basis for such refinements are of primary importance and have been given high priority at the Northeast Fisheries Center.

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Figures

Figure 1. Northwest Atlantic area from Nova Scotia to Cape Hatteras, delineated into strata for survey purposes.

Figure 2. Comparison between stock size estimates calculated from virtual population analysis for Georges Bank haddock and abundance indices from USA autumn bottom trawl surveys, 1964-1972.

Figure 3. Comparison between stock size estimates calculated from virtual population analysis for Georges Bank silver hake and abundance indices from USA autumn bottom trawl surveys, 1964-1977.

Figure 4. Comparison between stock size estimates calculated from virtual population analysis for Gulf of Maine silver hake and abundance indices from USA autumn bottom trawl surveys, 1964-1977.

Figure 5. Comparison between commercial catch per day (tons) and abundance indices from USA autumn bottom trawl surveys for Georges Bank yellowtail, 1964-1977.

Figure 6. Length-frequency distribution of Georges Bank and Gulf of Maine haddock in (A) commercial length-frequency samples for July-November 1977, and (B) catches during the R/V Delaware II bottom trawl survey, autumn, 1977.

Figure 7. Comparison between stock size estimates calculated from cohort analysis and research vessel survey abundance indices for Atlantic mackerel, 1968-1977.

Figure 8. Power curve relationship between mackerel year-class size at age 1 and spring survey catch-per-tow at age 1 (1968 point not used in calculating the curve).

Figures (cont'd)

Figure 9. Power curve relationship between mackerel year-class size at age 2 and spring survey catch-per-tow at age 2 (1967 point not used in calculating the curve).

Figure 10. Relationship between year-class size at age 1 from VPA and USA autumn survey catch-per-tow at age 0 for Gulf of Maine silver hake.

Figure 11. Comparison between survey population indices derived from USA autumn bottom trawl surveys and commercial catch/effort data for southern New England yellowtail flounder, 1967-1977.

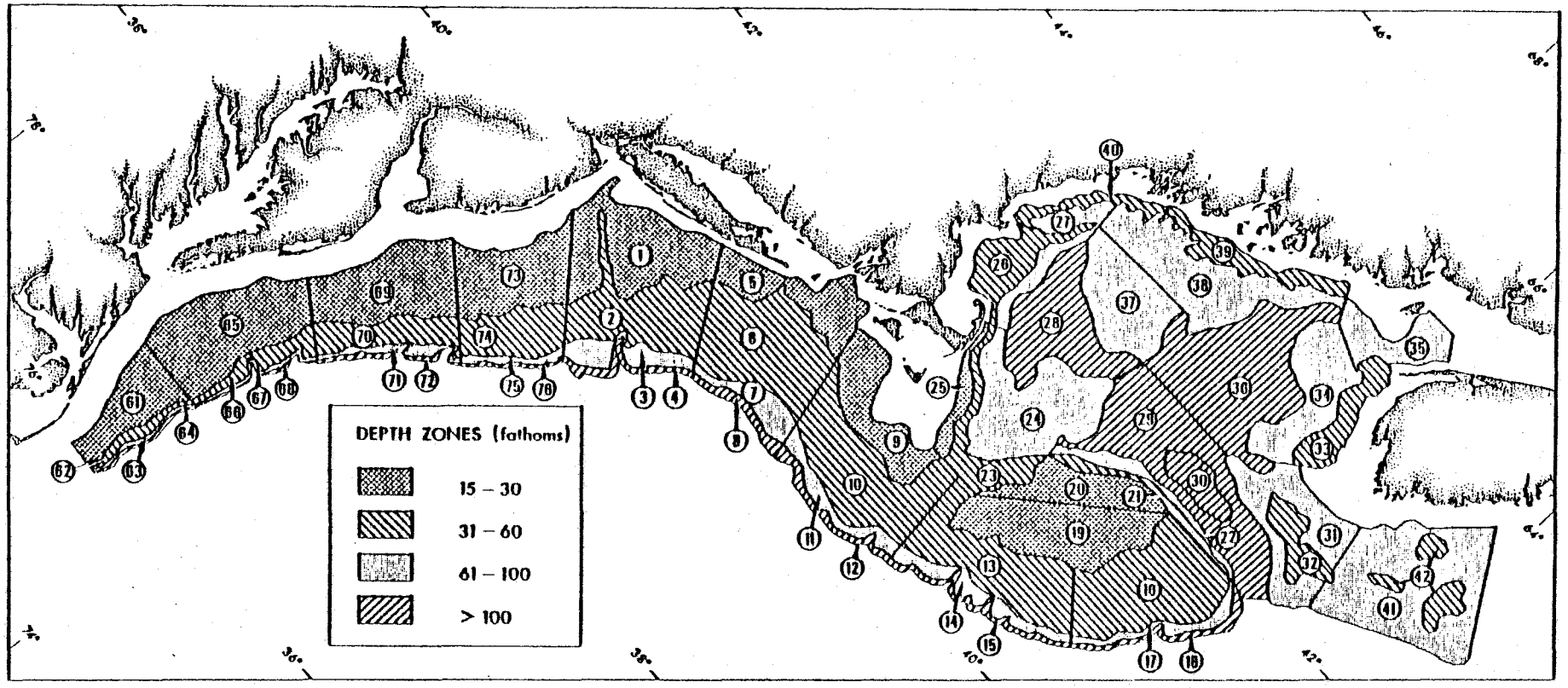
Figure 12. Estimates of fishable biomass from the Gulf of Maine to Cape Hatteras, 1964-1977, calculated from USA autumn bottom-trawl survey data.

Figure 13. Population size index based on the USA autumn bottom trawl survey versus catch during the following year for the southern New England yellowtail stock.

Figure 14. Stratified mean catch-per-tow from USA autumn bottom trawl surveys versus catch during the following year for the Georges Bank yellowtail stock.

Figure 15. Exponential curve calculated through the 1968-1977 time series (1969 point omitted) of spring survey catch-per-tow (kg) indices for Atlantic mackerel.

Figure 16. Relationship between fishing mortality from cohort analysis and fishing effort for Atlantic mackerel derived from spring survey catch-per-tow and total catch.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31 – 60
61 – 100
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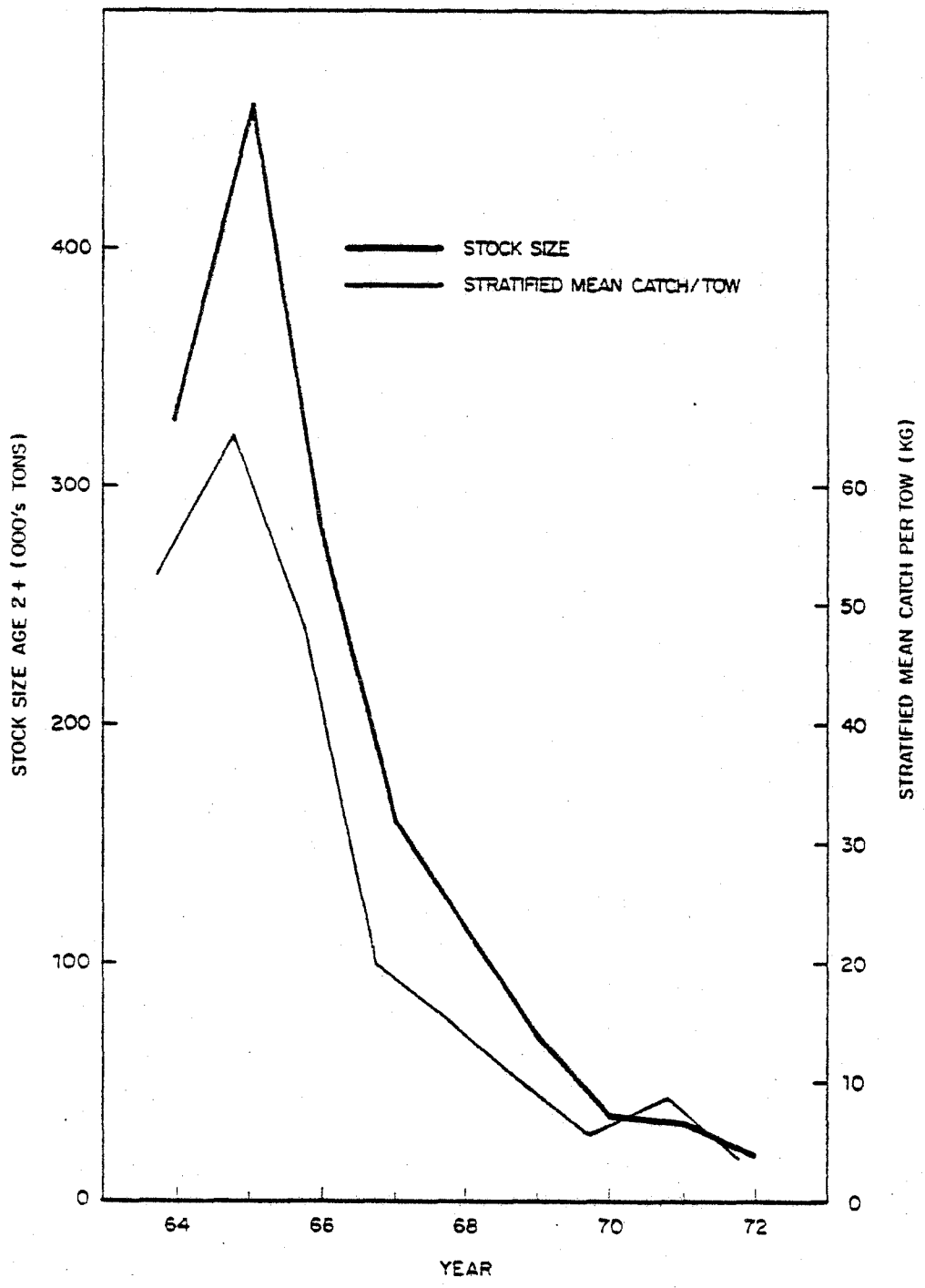
2


STOCK SIZE
STRATIFIED MEAN CATCH/TOW
STOCK SIZE AGE 2+ (000's TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
YEAR
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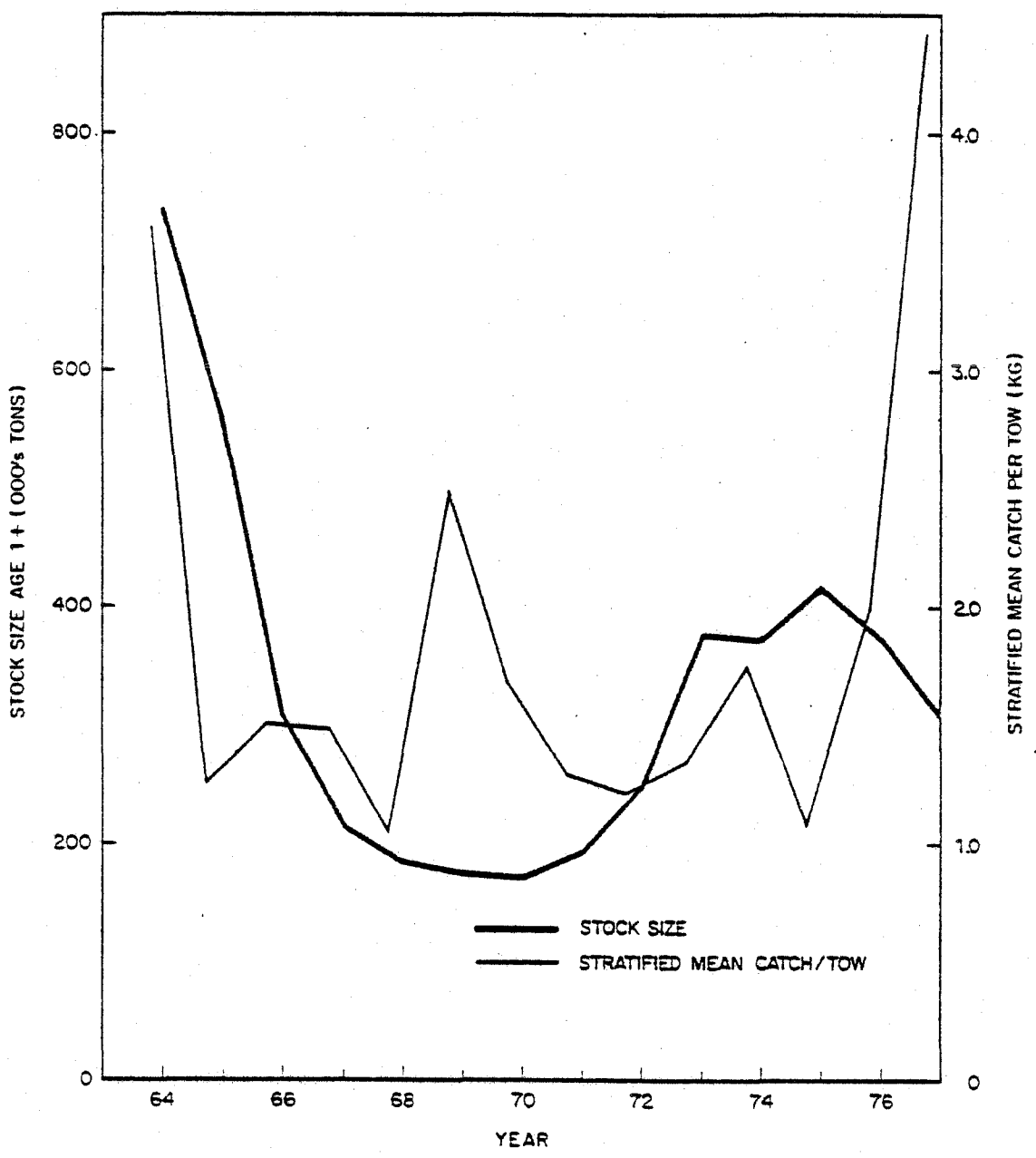
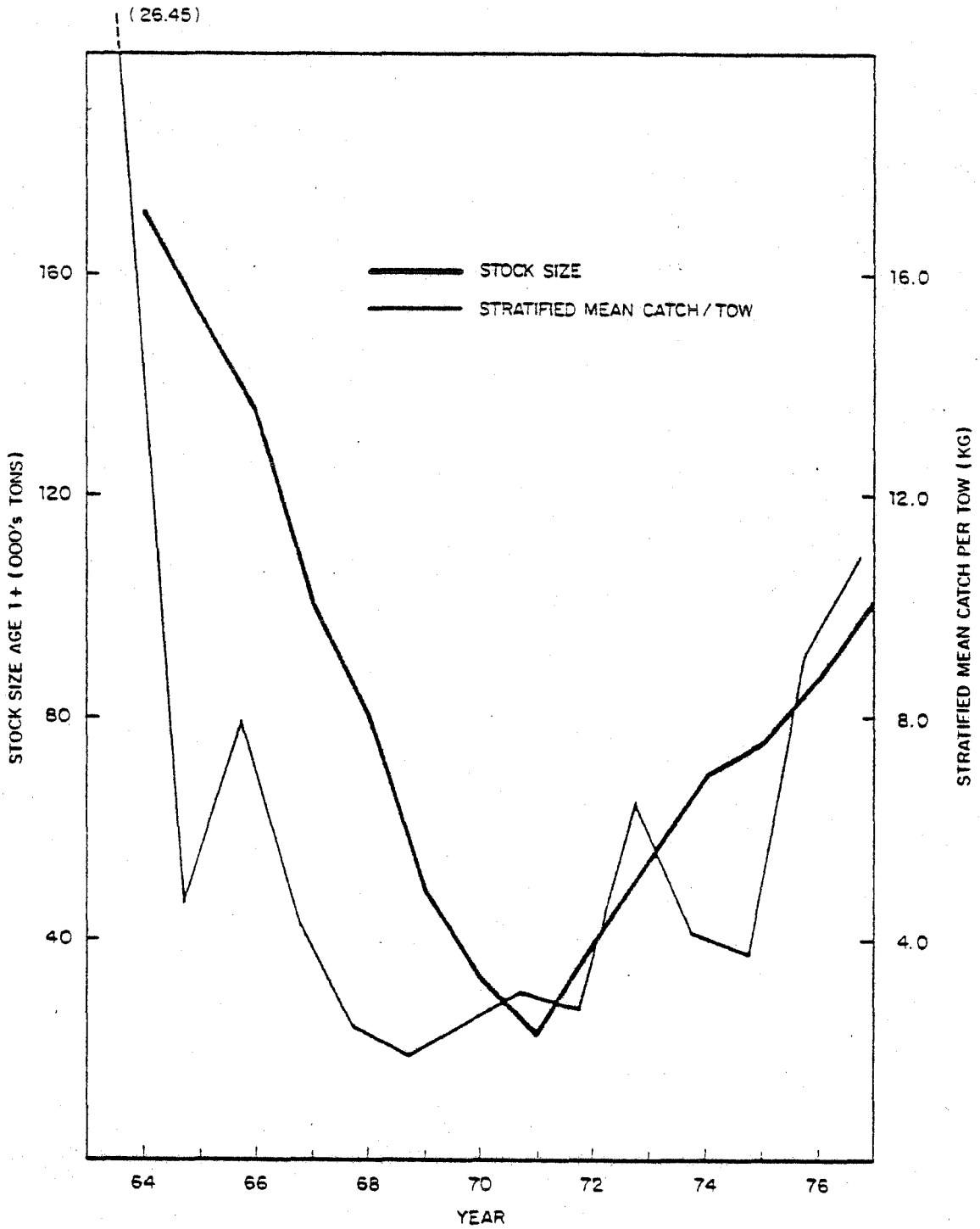
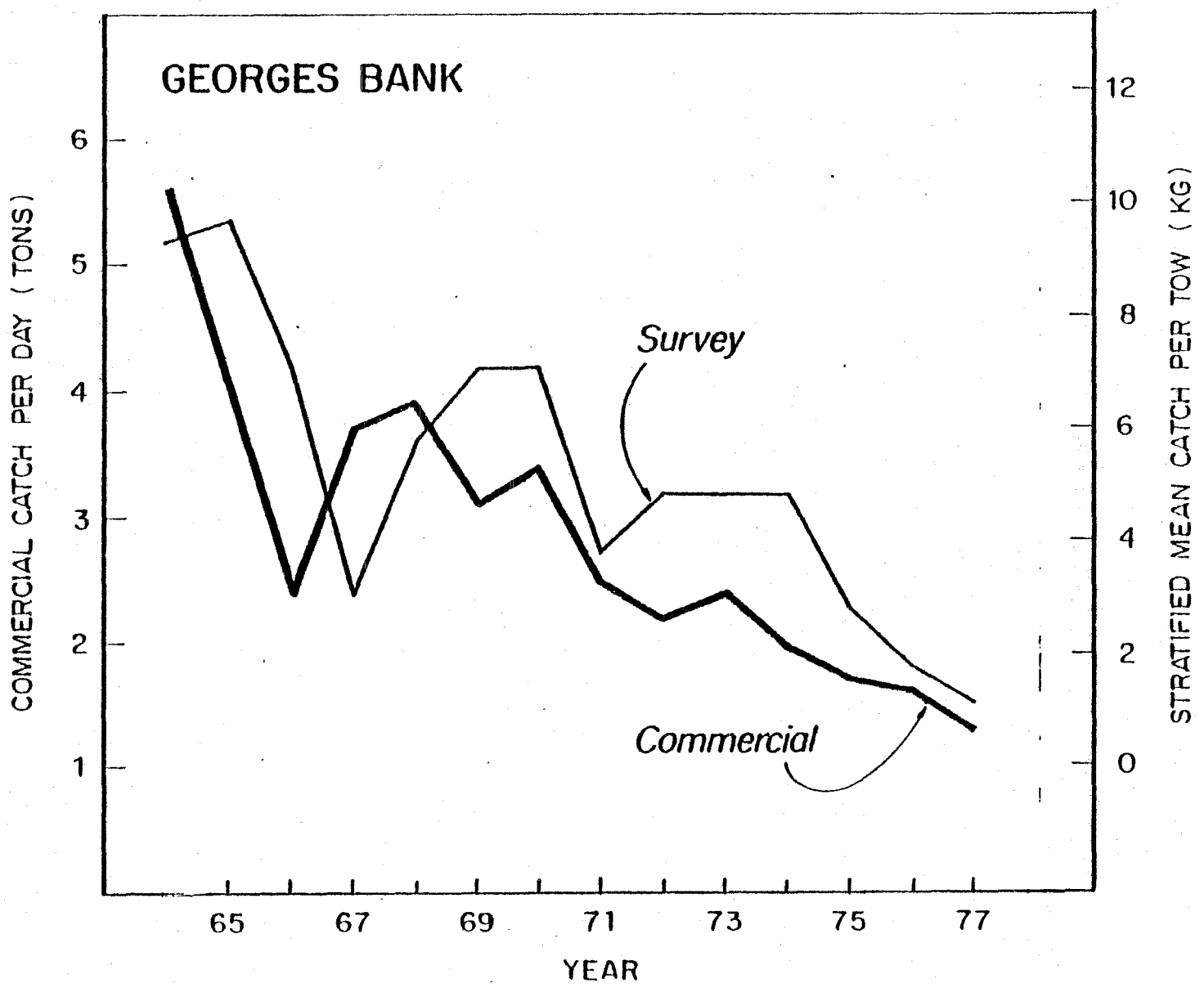
100
200
300
400
0
10
20
30
40
50
60
64
66
68
70
72

3


800
600
400
200
0
4.0
3.0
2.0
1.0
0
STOCK SIZE AGE 1+ (000's TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
STOCK SIZE
STRATIFIED MEAN CATCH/TOW
64
66
68
70
72
74
76
YEAR


(26.45)
STOCK SIZE
STRATIFIED MEAN CATCH / TOW
160
120
80
40
16.0
12.0
8.0
4.0
STOCK SIZE AGE 1+ (000's TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
64
66
68
70
72
74
76
YEAR


GEORGES BANK
COMMERCIAL CATCH PER DAY (TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
YEAR
Survey
Commercial
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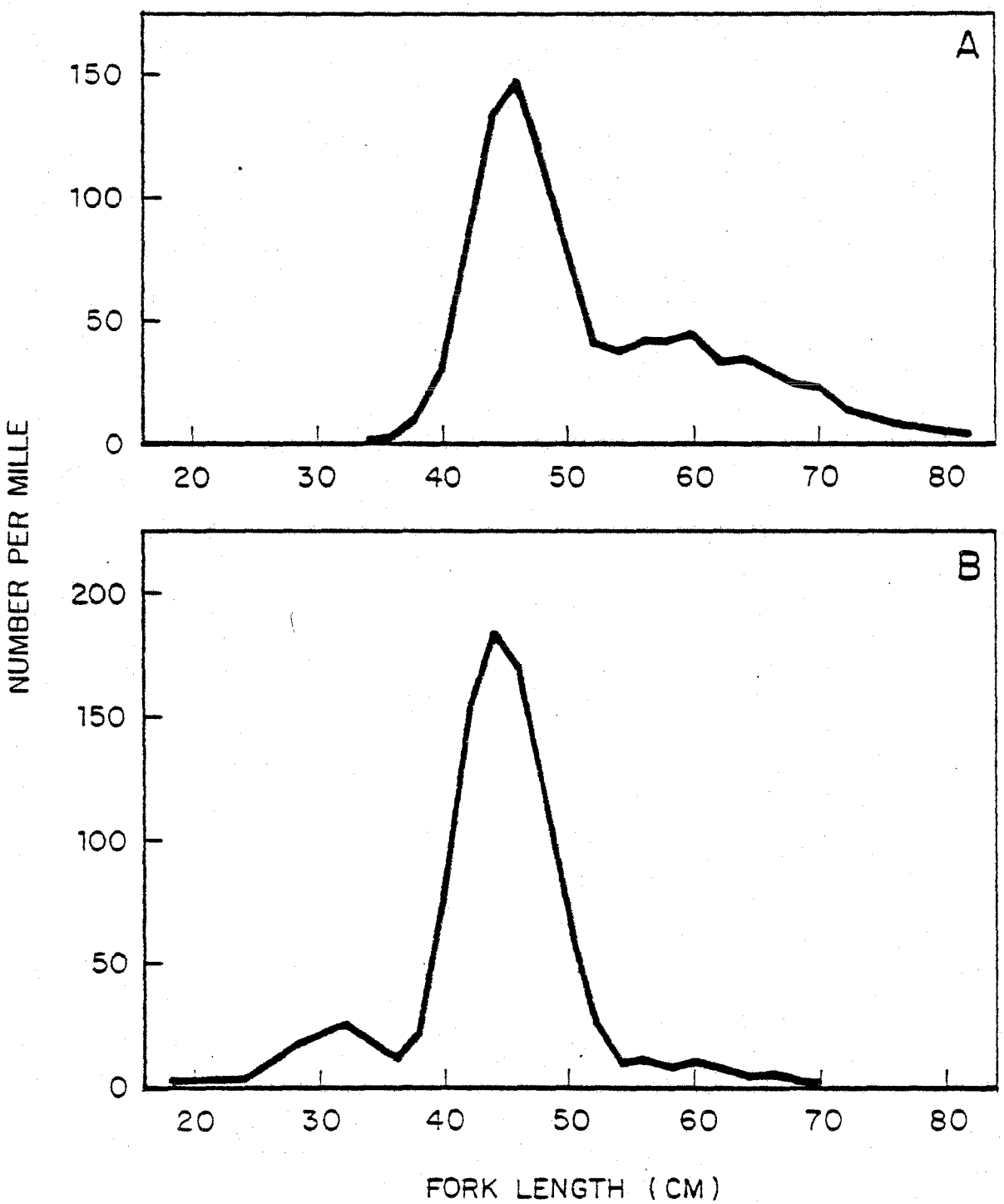
2
3
4
5
6
0
2
4
6
8
10
12
65
67
69
71
73
75
77


A
B
150
100
50
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200
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100
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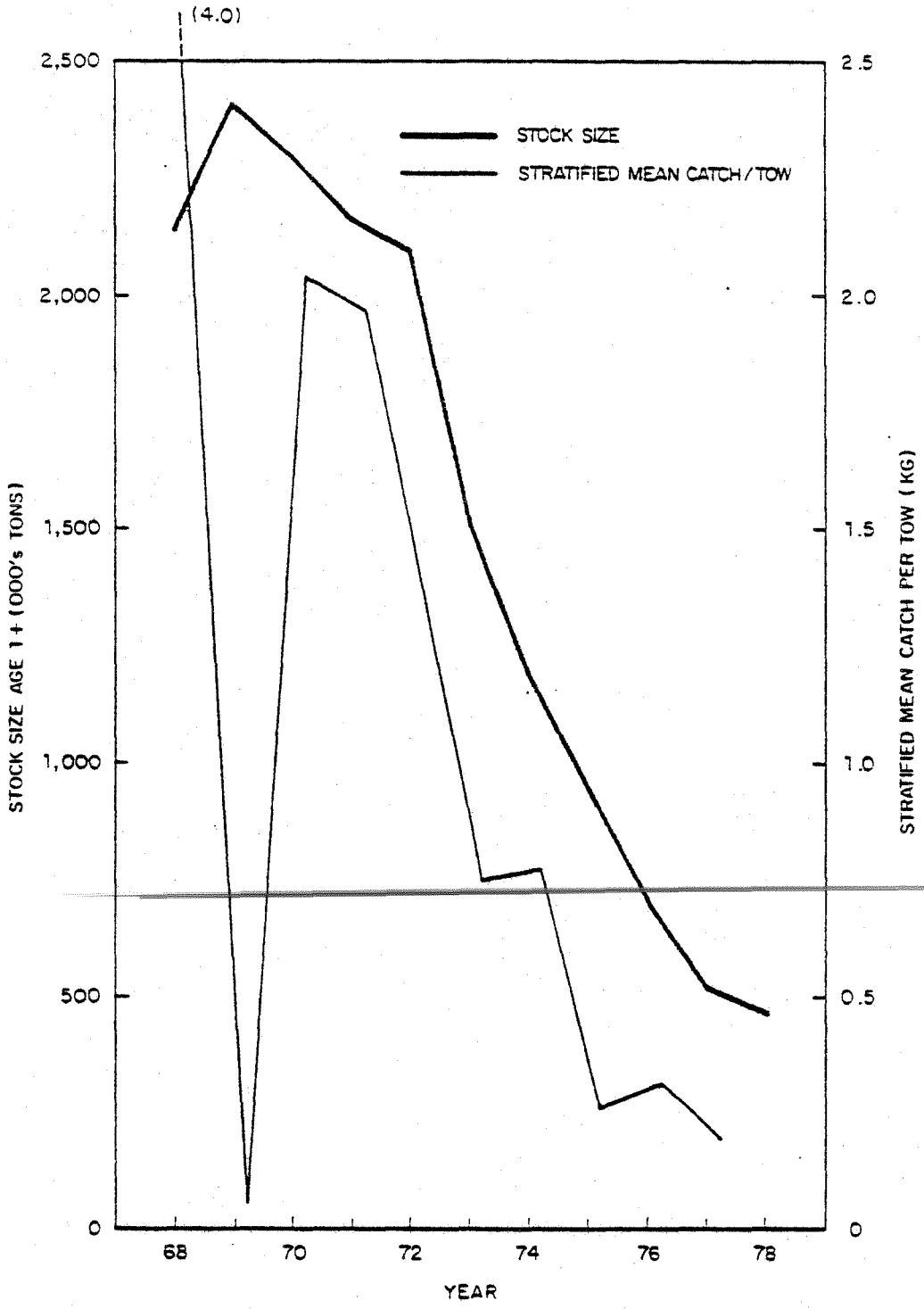
0
20
30
40
50
60
70
80
NUMBER PER MILLE
FORK LENGTH (CM)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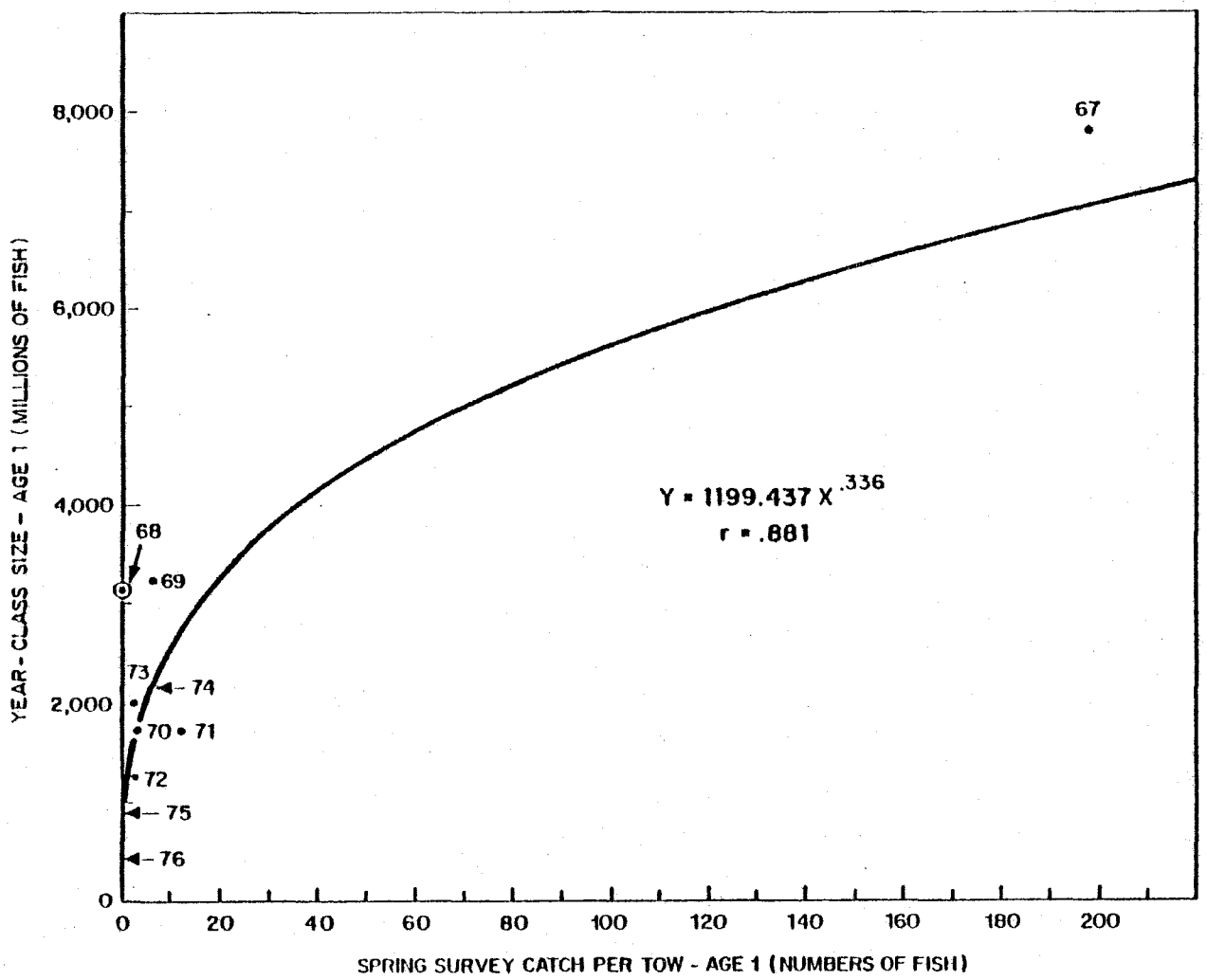
2,000
1,500
1,000
500
0
2.5
2.0
1.5
1.0
0.5
0
STOCK SIZE
STRATIFIED MEAN CATCH/TOW
STOCK SIZE AGE 1+ (000's TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
68
70
72
74
76
78
YEAR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2,000
0
YEAR-CLASS SIZE - AGE 1 (MILLIONS OF FISH)
0
20
40
60
80
100
120
140
160
180
200
SPRING SURVEY CATCH PER TOW - AGE 1 (NUMBERS OF FISH)
Y = 1199.437 X .336
r = .881
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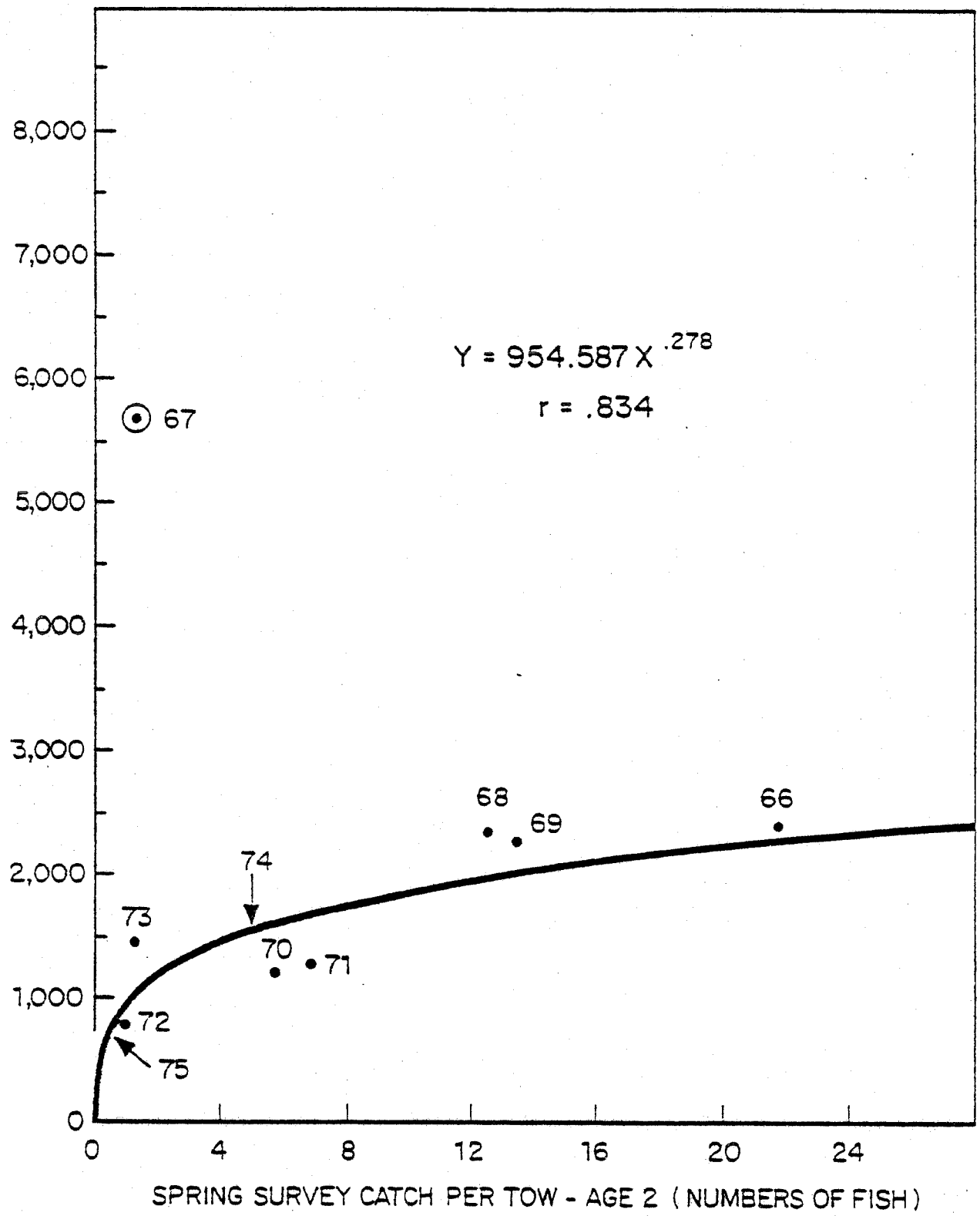
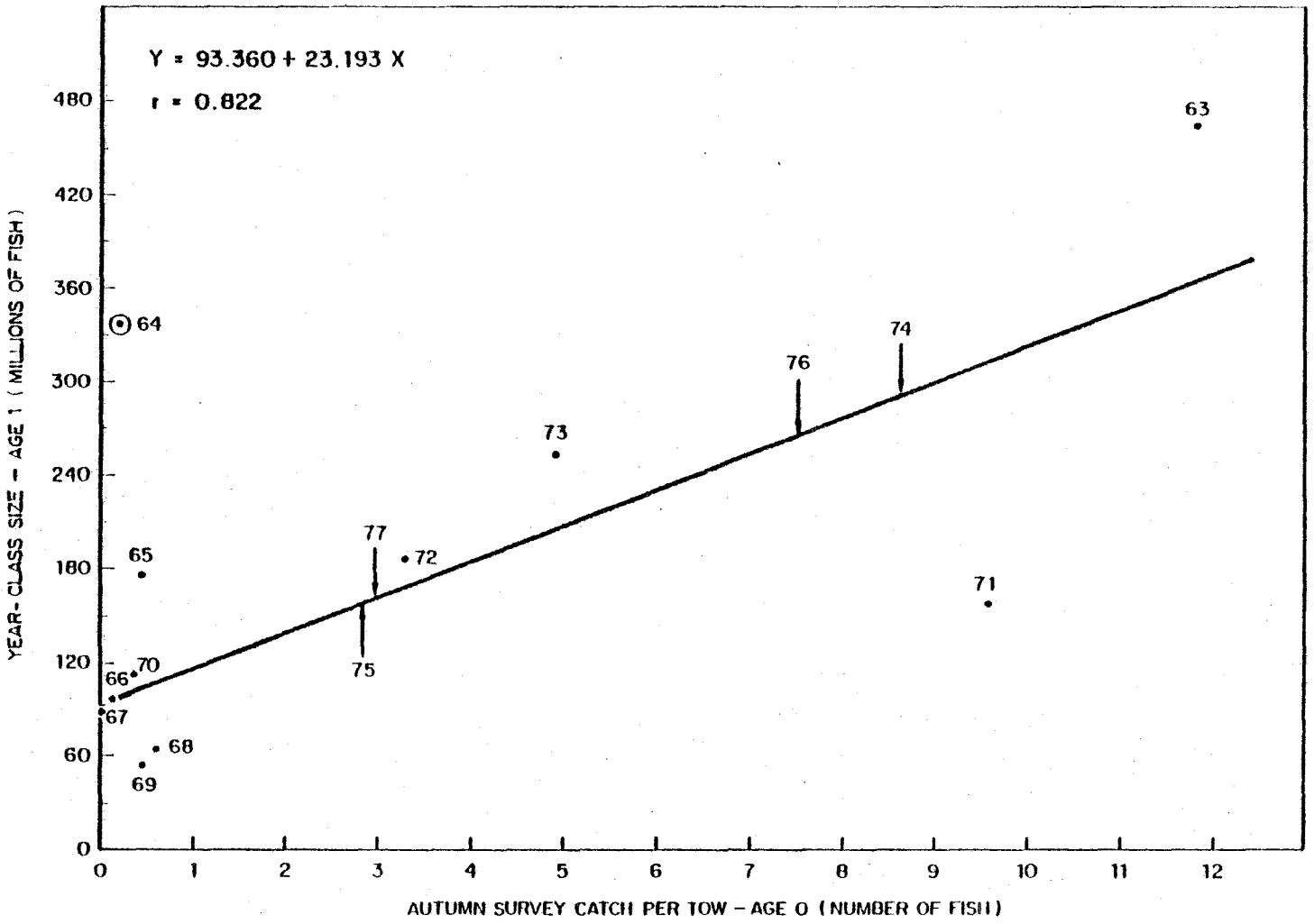
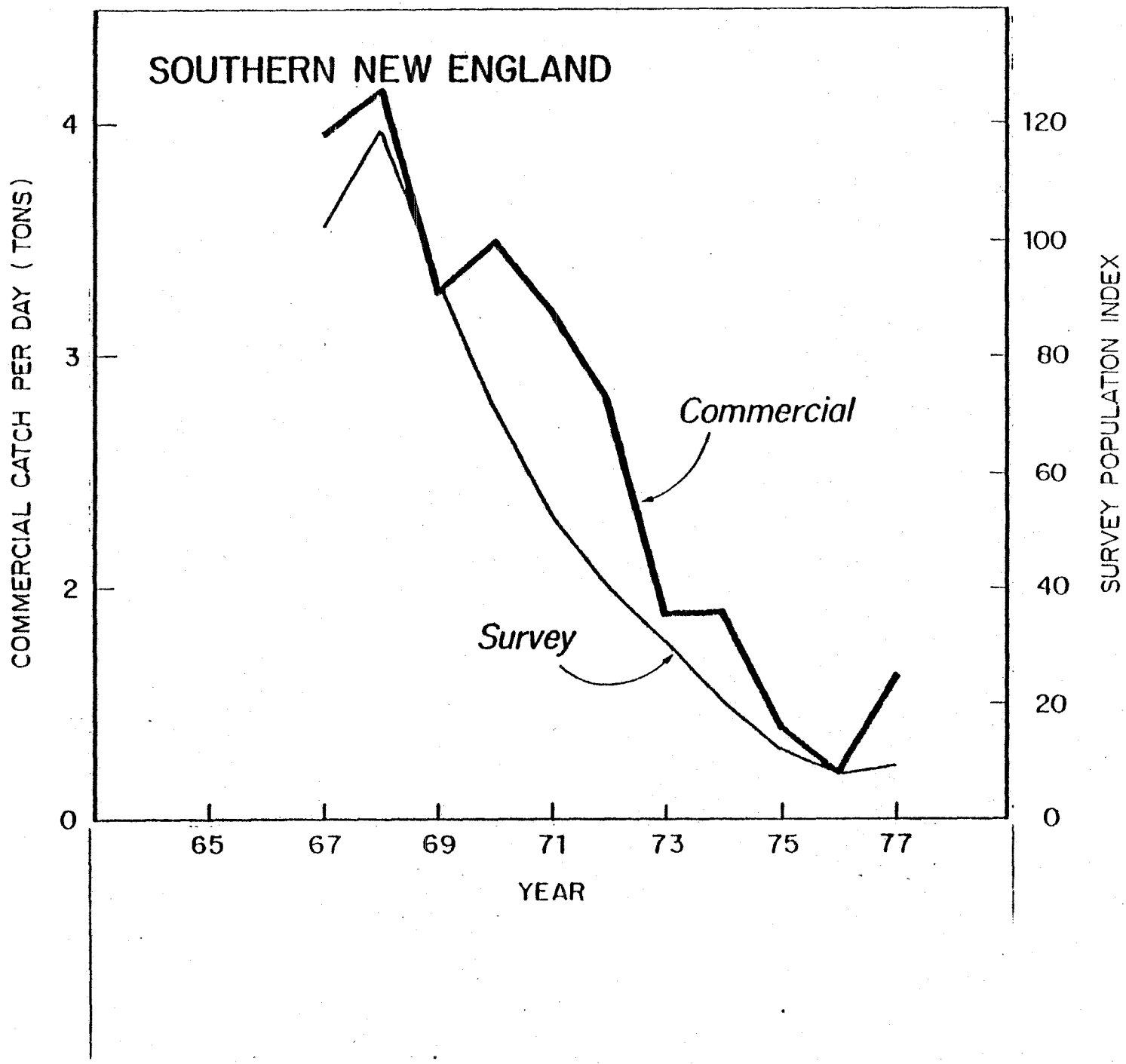
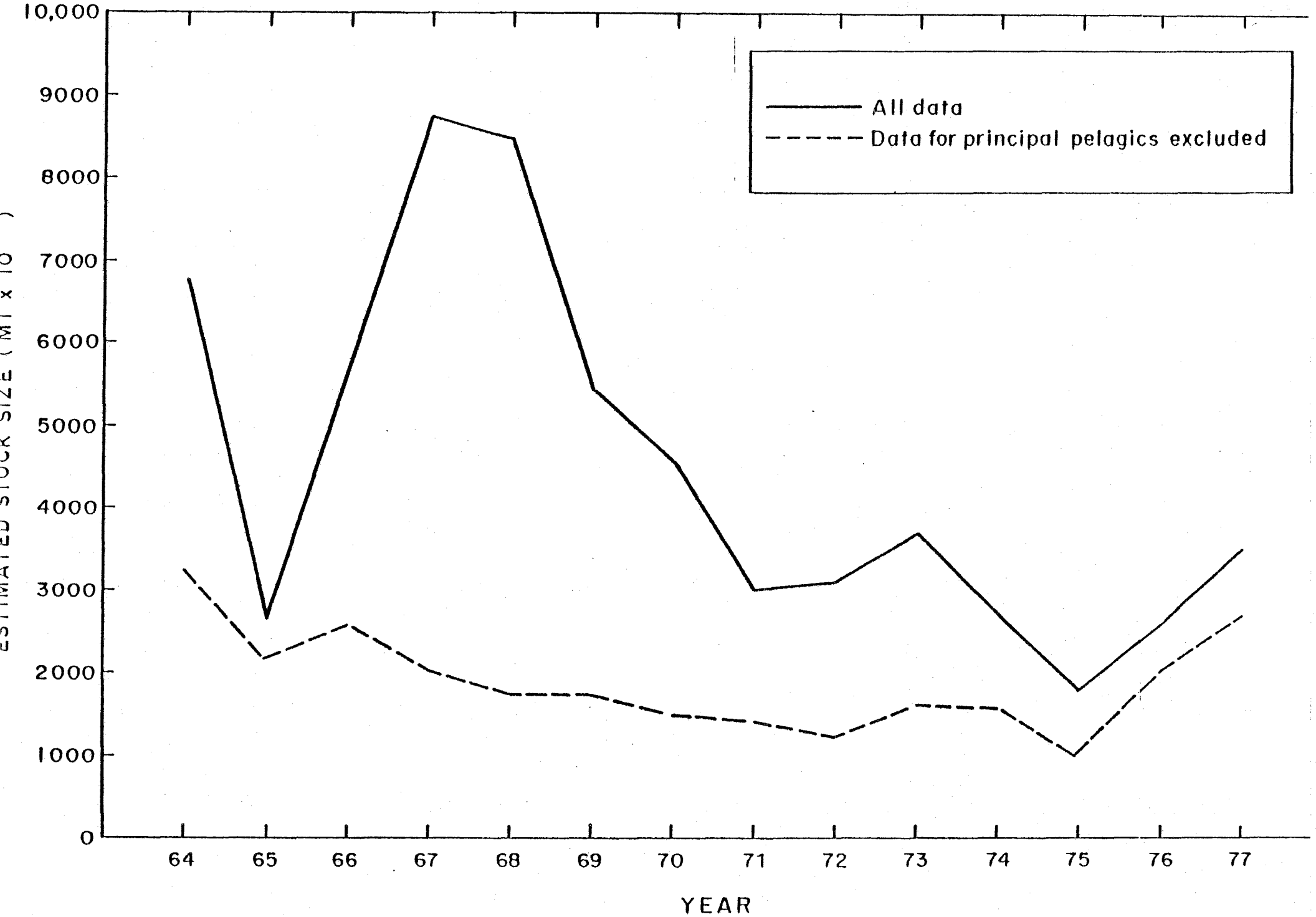
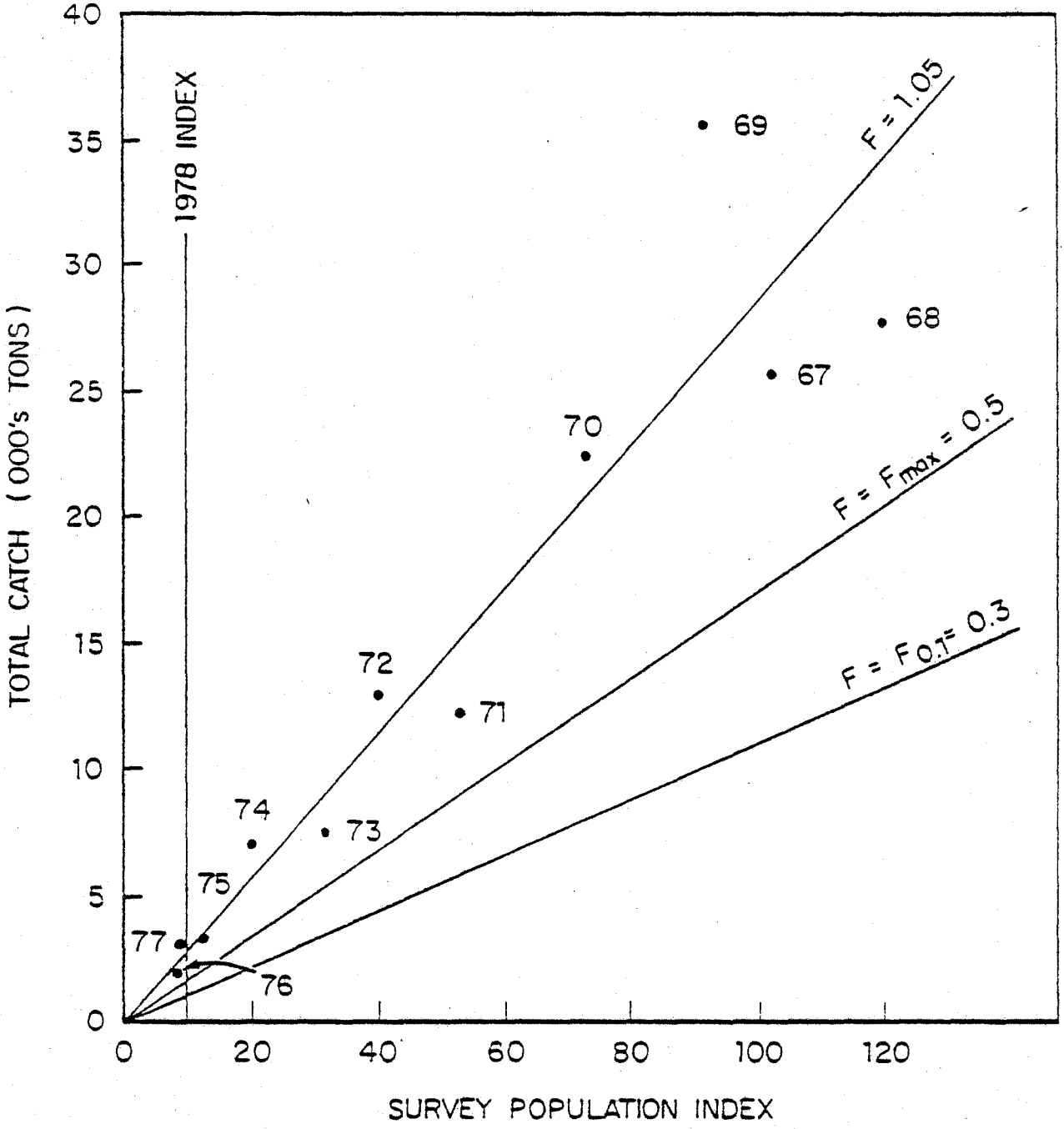
68
69
73
74
70
71
72
75
76

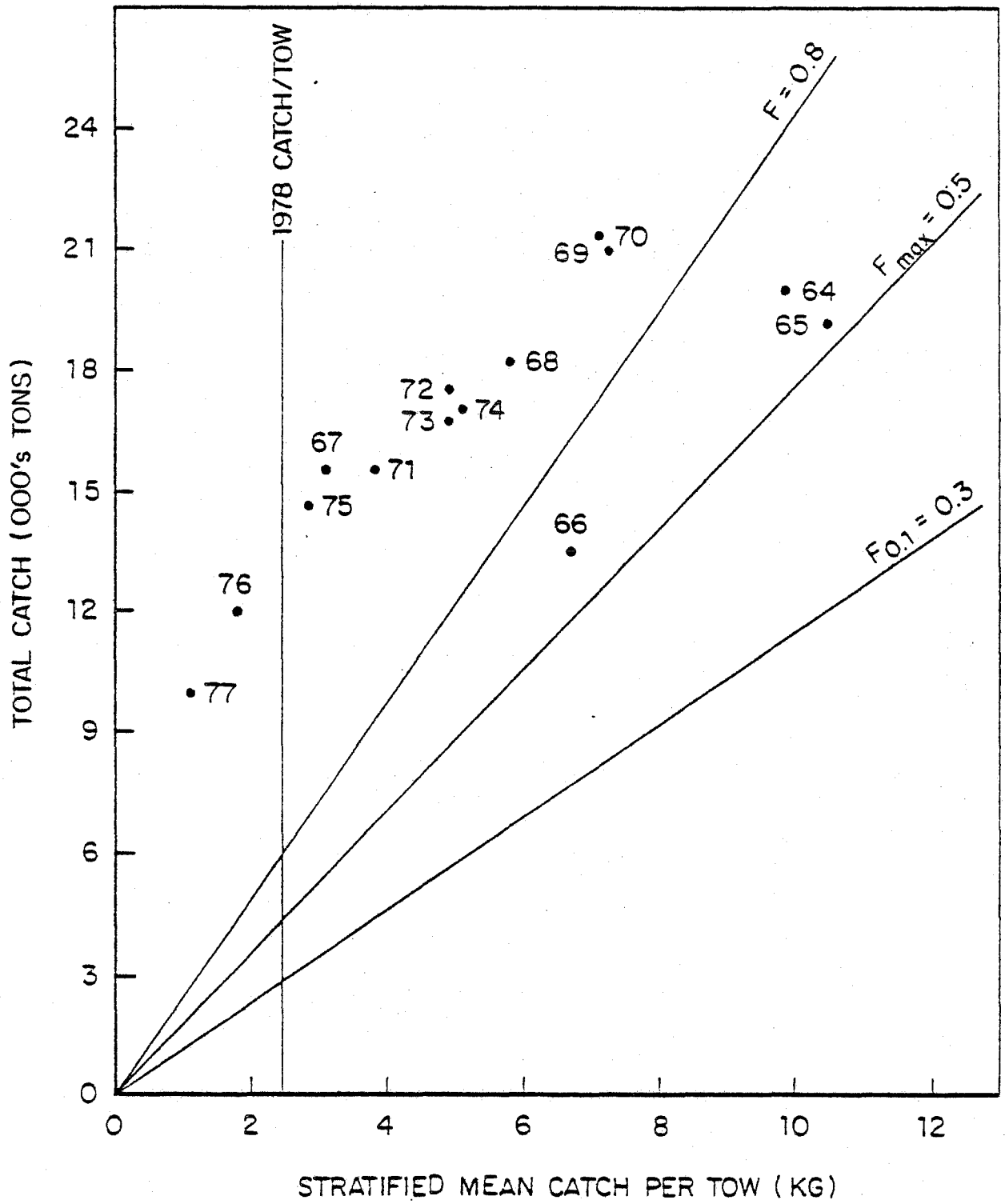

8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
4
8
12
16
20
24
Y = 954.587 X .278
r = .834
67
68
69
66
74
73
70
71
72
75
SPRING SURVEY CATCH PER TOW - AGE 2 (NUMBERS OF FISH)

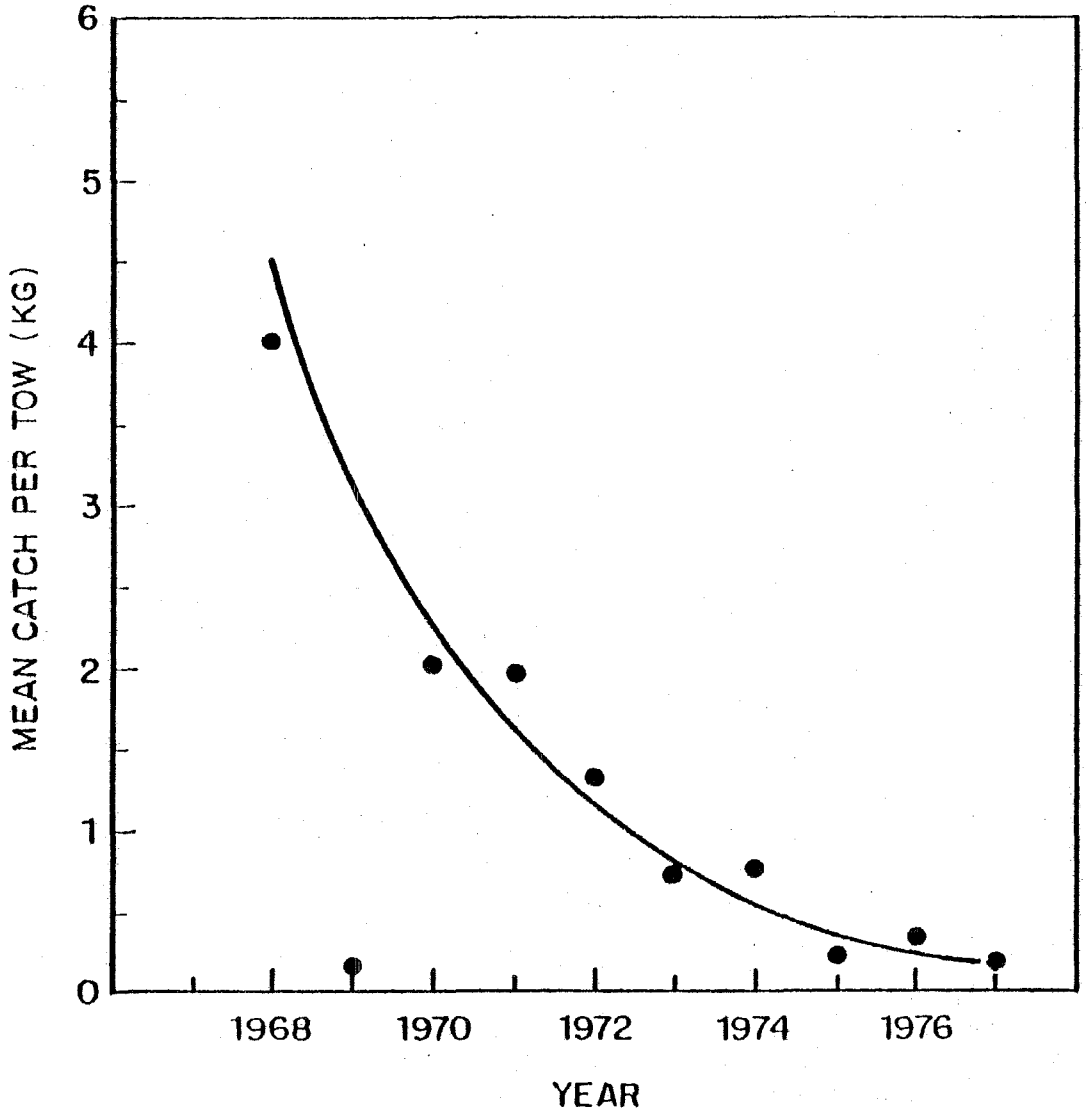

Y = 93.360 + 23.193 X
r = 0.822
YEAR-CLASS SIZE – AGE 1 (MILLIONS OF FISH)
AUTUMN SURVEY CATCH PER TOW – AGE 0 (NUMBER OF FISH)
0
60
120
180
240
300
360
420
480
0
1
2
3
4
5
6
7
8
9
10
11
12
63
64
74
76
73
77
72
65
71
75
70
66
67
68
69

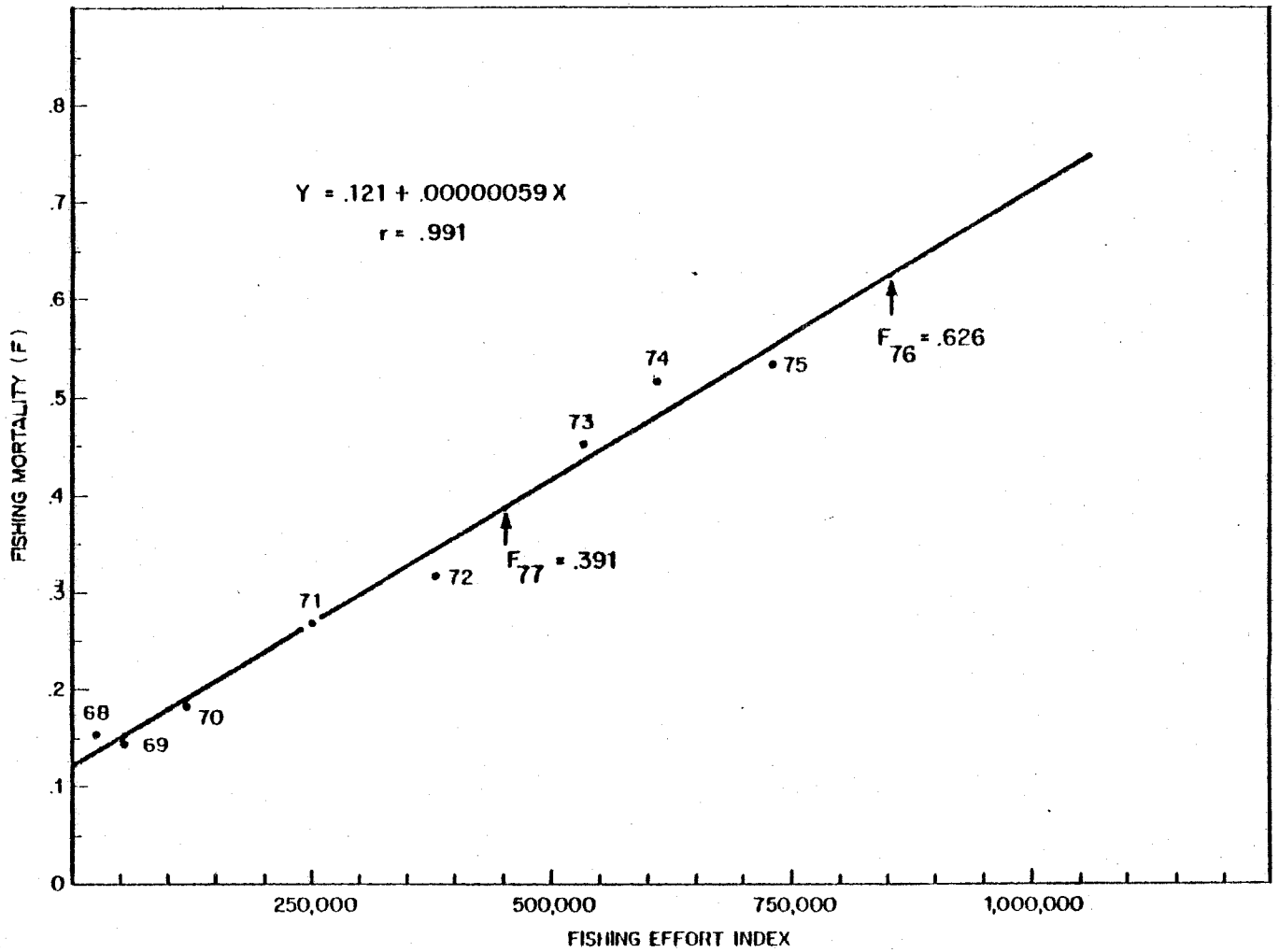

SOUTHERN NEW ENGLAND
COMMERCIAL CATCH PER DAY (TONS)
SURVEY POPULATION INDEX
Commercial
Survey
YEAR
0
2
3
4
0
20
40
60
80
100
120
65
67
69
71
73
75
77


10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
ESTIMATED STOCK SIZE (MT x 10)
All data
Data for principal pelagics excluded
64
65
66
67
68
69
70
71
72
73
74
75
76
77
YEAR


TOTAL CATCH (000's TONS)
SURVEY POPULATION INDEX
1978 INDEX
F = 1.05
F = Fmax = 0.5
F = F0.1 = 0.3
69
68
67
70
72
71
74
73
75
77
76
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120


1978 CATCH/TOW
F = 0.8
F max = 0.5
F0.1 = 0.3
TOTAL CATCH (000's TONS)
STRATIFIED MEAN CATCH PER TOW (KG)
0
3
6
9
12
15
18
21
24
0
2
4
6
8
10
12
64
65
66
67
68
69
70
71
72
73
74
75
76
77


MEAN CATCH PER TOW (KG)
6
5
4
3
2
1
0
1968
1970
1972
1974
1976
YEAR


Y = .121 + .00000059 X
r = .991
FISHING MORTALITY (F)
FISHING EFFORT INDEX
0
.1
.2
.3
.4
.5
.6
.7
.8
250,000
500,000
750,000
1,000,000
68
69
70
71
72
73
74
75
F77 = .391
F76 = .626