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Addendum 1

ANNUAL MEETING - JUNE 1976

Recruitment estimates for the mackerel stock in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 based on US research vessel spring trawl surveys, 1968-1975, with implications for assessment

by

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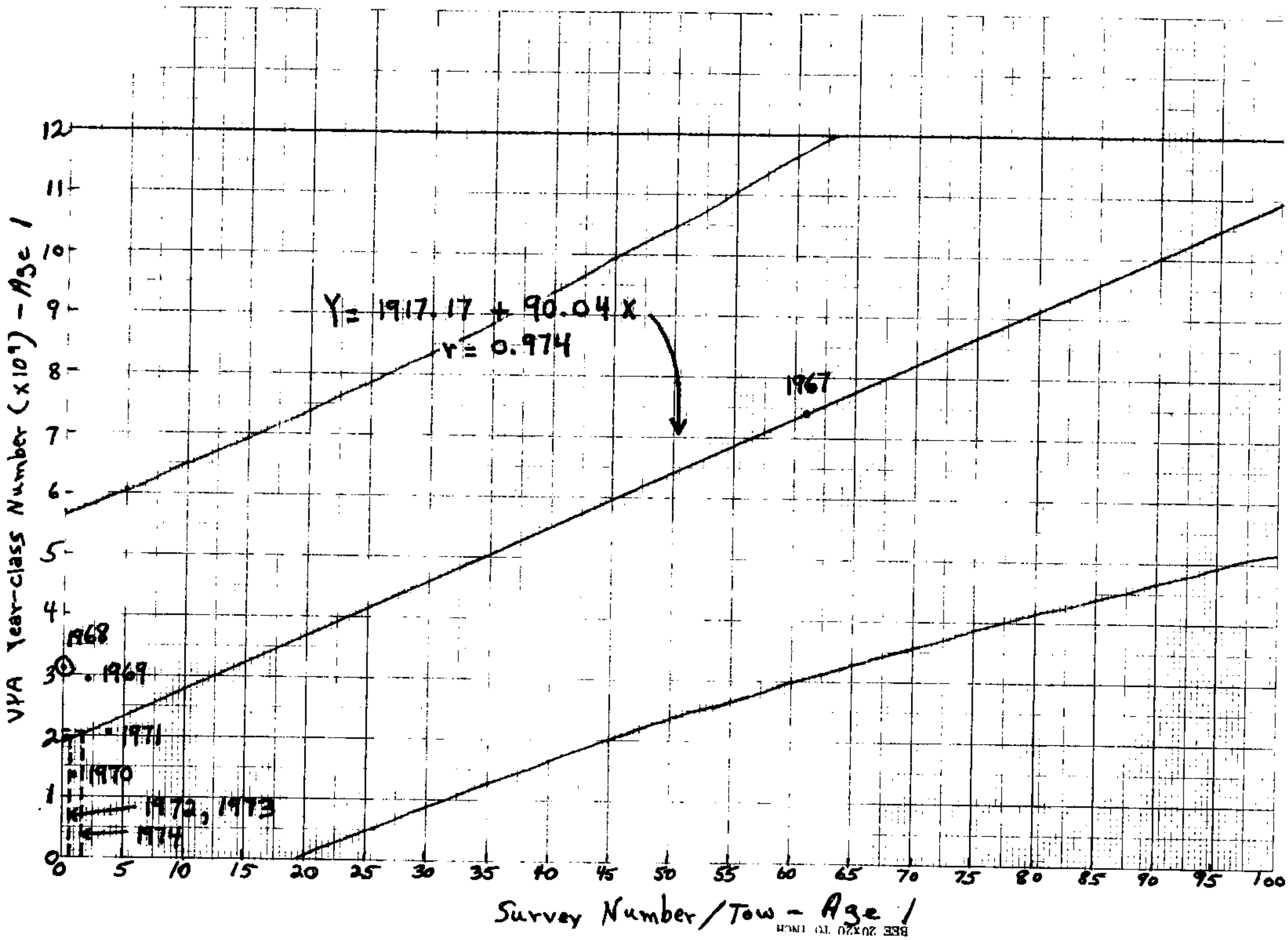

Figure 3A. Relationship between the spring survey number per tow index for mackerel at age 1 and year-class size (number x 10^9) at age 1 calculated by virtual population analysis (VPA) showing 95% confidence limits for predicted values of year-class size. Calendar years refer to year-classes; 1968 is not included in the analysis.

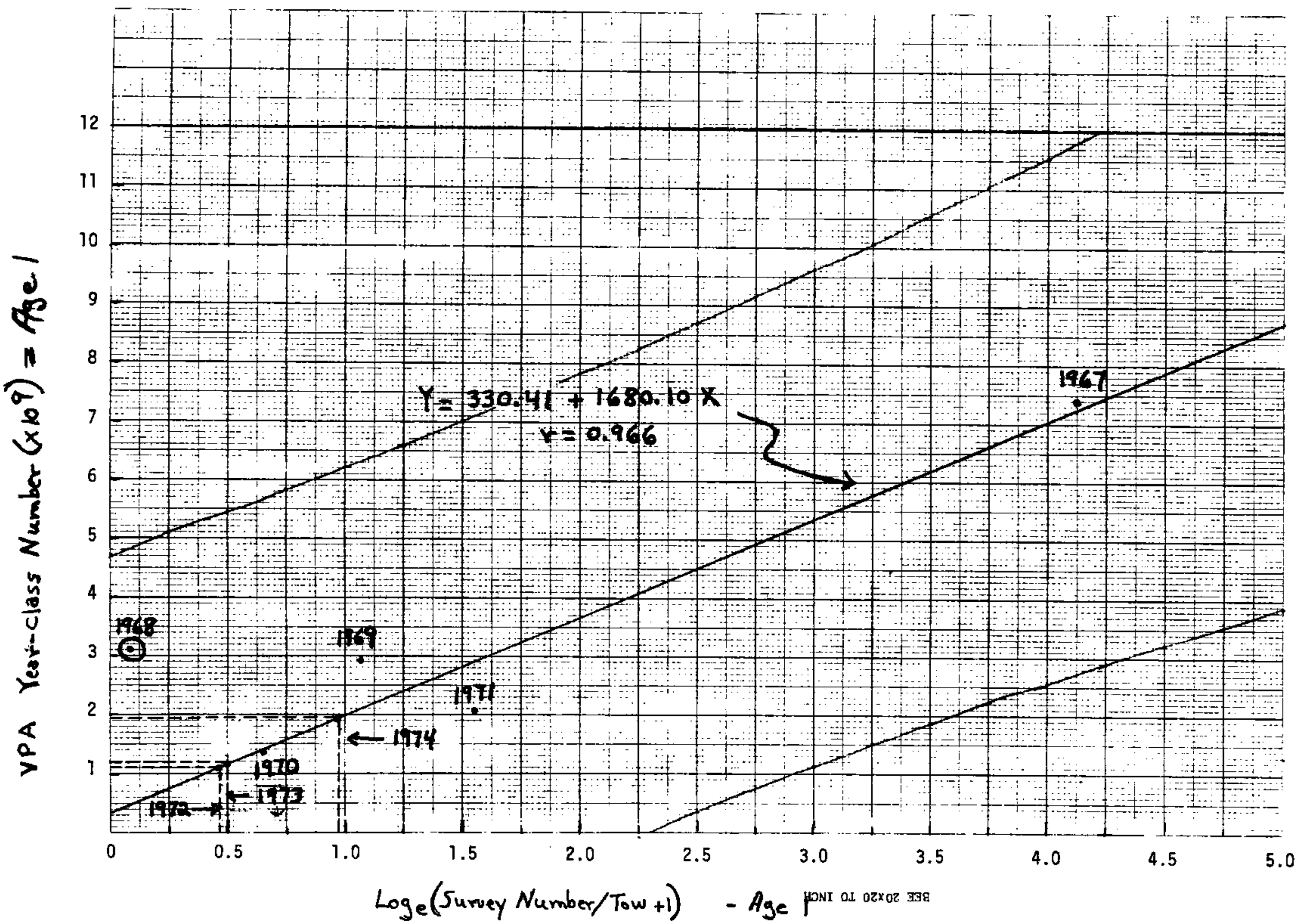

Figure 4a. Relationship between the spring survey $\log_e$ (number per tow +1) index for mackerel at age 1 and year-class size (number x 10^9) at age 1 calculated by virtual population analysis (VPA) showing 95% confidence limits for predicted values of year-class size. Calendar years refer to year-classes; 1968 is not included in the analysis.

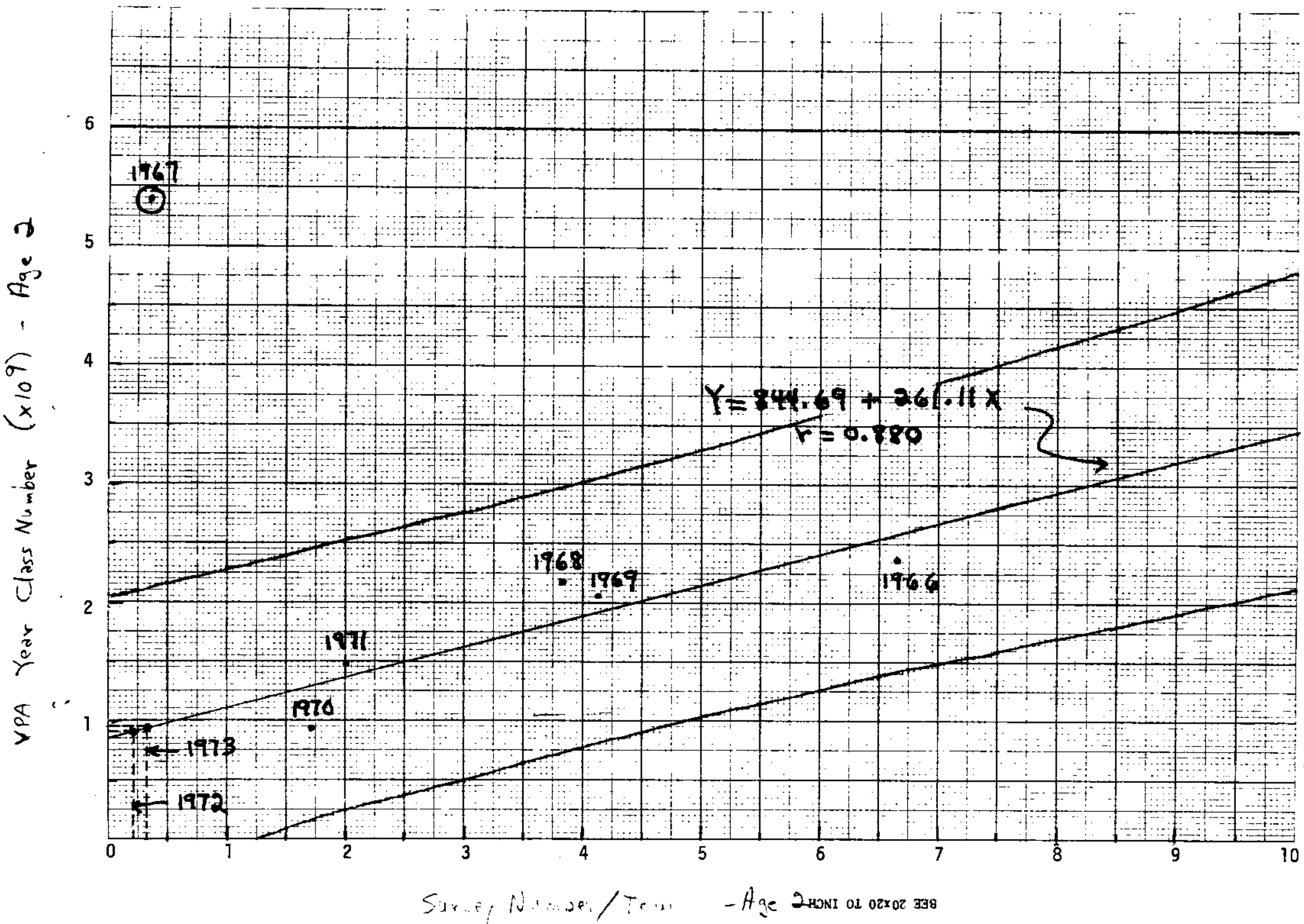

Figure 5a. Relationship between the spring survey number per tow index for mackerel at age 2 and year-class size (number x 10^9) at age 2 calculated by virtual population analysis (VPA) showing 95% confidence limits for predicted values of year-class size. Calendar years refer to year-classes; 1967 is not included in the analysis.

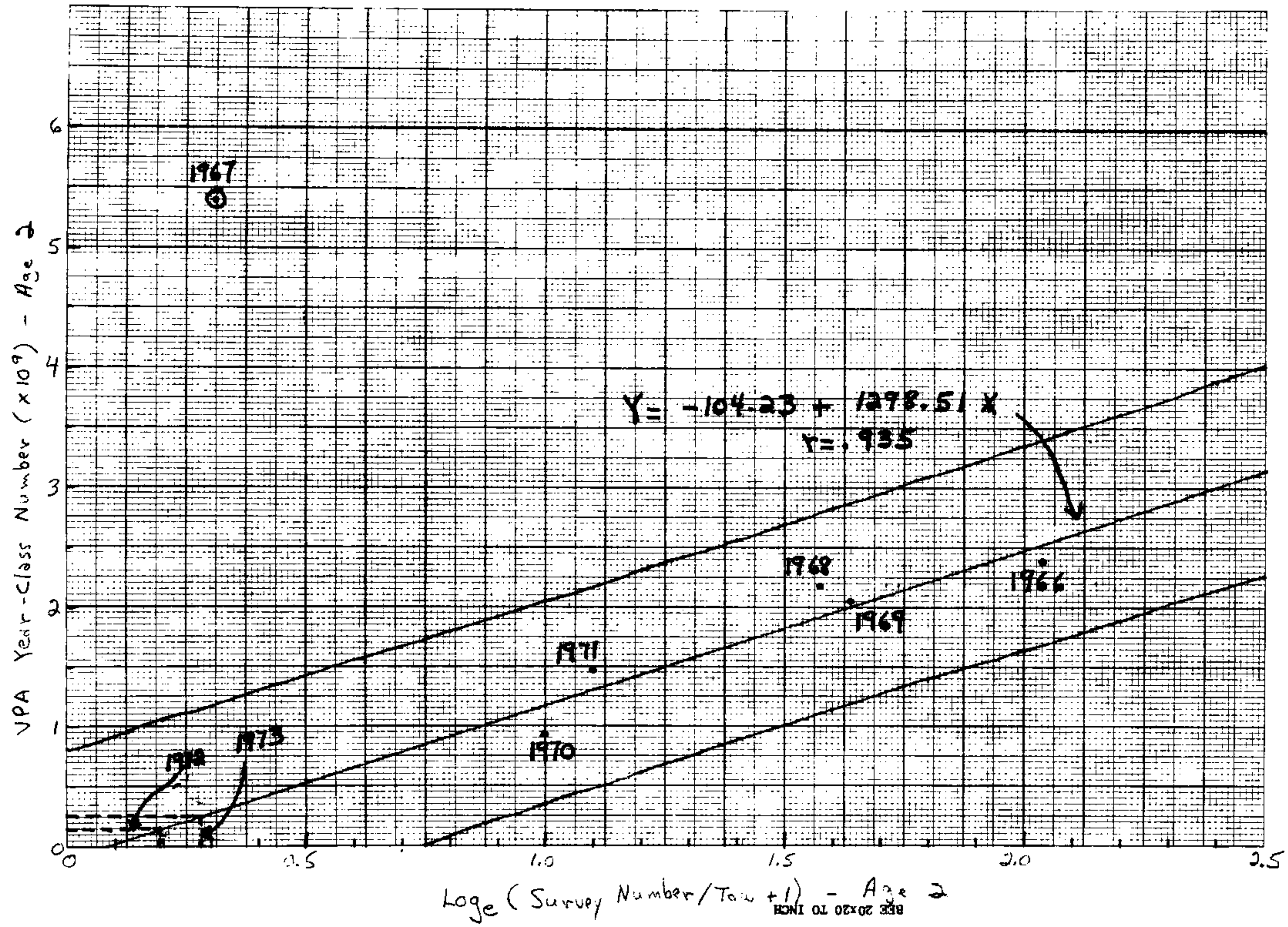

Figure 6a. Relationship between the spring survey $\log_e$ (number per tow +1) index for mackerel at age 2 and year-class size (number x 10^9) at age 2 calculated by virtual population analysis (VPA) showing 95% confidence limits for predicted values of year-class size. Calendar years refer to year-classes; 1967 is not included in the analysis.

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Introduction

One of the major problems associated with the assessment and management of the mackerel (*Scomber scombrus*) stock in the ICNAF area is the estimation of recruitment. Recruitment estimates used in past assessments have been determined in a variety of ways. Sizes of recruiting year-classes were determined primarily by applying assumed levels of fishing mortality to commercial catches (numbers at age) through the use of partial recruitment rates at age, supported to some extent by percentage age compositions of survey and commercial catch samples (ICNAF, 1974a, 1974b). In April 1975, the Mackerel Working Group predicted strong 1973 and 1974 year-classes based on stock-recruitment curves (ICNAF, 1975). The practice of estimating incoming year-class strength from one or two years of commercial fishery data can result in highly erroneous predictions. It is highly desirable, therefore, that estimates be based on data independent of commercial statistics such as that from research vessel surveys.

Research vessel surveys have been conducted by the United States (US) each spring since 1968 from Nova Scotia to Cape Hatteras. The area sampled has encompassed the mackerel overwintering grounds in ICNAF Subarea 5 and Statistical Area 6 (SA 5-6) extending from Georges Bank to Cape Hatteras (Anderson and Almeida, 1976). Catch per tow indices obtained from these surveys for mackerel (Anderson, 1976) agree with other estimates of mackerel abundance determined from commercial statistics. In this paper, survey catch (number) per tow of age 1 and 2 mackerel are presented and used to estimate year-class size. The validity of the survey indices as predictors is based on their demonstrated relationships to the year-class size (number) calculated by virtual population analysis (VPA).

Materials and Methods

US spring bottom trawl surveys (1968-present) have been based on a stratified random sampling design according to depth and area (Figure 1). Details concerning survey methods are described by Grosslein (1974).

Stratified mean number caught per tow per length interval was calculated for each year (1968-1975) for strata 1-25, 61-76. Age-length keys constructed from samples taken during the 1973-1975 surveys were used to determine the stratified mean number caught per tow of mackerel at age 1 and 2 in those years. For 1968-1972, when age samples were not taken, age 1 fish were defined as those measuring 22 cm and less (fork length) and age 2 fish were defined as those measuring 23-29 cm. These length intervals for ages 1 and 2 were determined from the 1973-1975 age-length keys.

Least squares linear regressions were calculated to describe the relationship at ages 1 and 2 between year-class size (number) computed by VPA (ICNAF, 1975) and number caught per tow in the survey. In addition to using number caught per tow, a $\log_e$ (number per tow + 1) transformation was utilized to reduce the wide variability of the number per tow indices, particularly the age 1 indices, the objective being to achieve the best relationship between the VPA year-class sizes and the survey indices.

Results

The survey indices of mackerel year-class abundance at ages 1 and 2 are given in Table 1. Indices were available for the 1967-1974 year-classes at age 1 and for the 1966-1973 year-classes at age 2. The 1969 survey catch per tow of mackerel was extremely anomalous (Anderson, 1976), and, therefore, the unrealistically low indices for the 1968 year-class at age 1 and the 1967 year-class at age 2 were not included in the analyses.

The age 1 index was greatest, by a considerable margin, for the 1967 year-class. This agrees with results of the VPA which indicate that this year-class was over twice as strong as any other during 1968-1971 (Table 1). The age 2 index was greatest for the 1966 year-class which also agrees with the VPA results (excluding the 1967 year-class which lacked an adequate survey index). The age 1 and 2 indices both suggest that the 1972 and 1973 year-classes were poor.

Comparison of $\log_e$ transformed survey numbers per tow at ages 1 and 2 for the 1969-1973 year-classes is shown in Figure 2. The results suggest that the survey data were fairly consistent in measuring the approximate size of those year-classes at both ages.

Linear regressions of VPA year-class size on survey number per tow and on $\log_e$ transformed survey number per tow were calculated for age 1 using data for the 1967, 1969-1971 year-classes (Figures 3 and 4). Coefficients of correlation for both regressions were significant at the 0.05 probability level ($r = 0.974$ and 0.966). From the relationship illustrated in Figure 3, which used the linear survey indices, the predicted sizes of the 1972-1974 year-classes at age 1 were 1971, 1976, and 2064 x 10^6 fish, respectively (Table 2). Using the $\log_e$ transformed survey indices (Figure 4), the predicted sizes of the 1972-1974 year-classes at age 1 were 1120, 1170, and 1958 x 10^6 fish, respectively (Table 2). The sizes of these year-classes used in the April 1975 assessment by the Mackerel Working Group were 1922, 3700, and 2500 x 10^6 fish, respectively.

Data for the 1966, 1968-1971 year-classes at age 2 (Table 1) were used to calculate linear regressions of VPA year-class size on survey number per tow and $\log_e$ transformed survey number per tow (Figures 5 and 6). The coefficients of correlation were both significant at the 0.05 probability level ($r = 0.880$ using linear survey indices; $r = 0.935$ using $\log_e$ transformed survey indices). The predicted sizes of the 1972 and 1973 year-classes at age 2 were 900 and 930 x 10^6 fish, respectively (Table 2), using the linear survey indices (Figure 5), and 146 and 262 x 10^6 fish, respectively (Table 2), using the $\log_e$ transformed survey indices (Figure 6). These year-classes were estimated as 1342 and 2644 x 10^6 fish, respectively, at age 2 in the April 1975 assessment.

Given the estimated sizes of the 1972-1973 year-classes at age 1 as predicted from the survey indices (Table 2) and given the catches at age 1 from these year-classes (ICNAF, 1975), the resulting sizes of these year-classes at age 2 were calculated for comparison with those predicted from the survey indices at age 2 and those used in the April 1975 assessment. These estimates were computed using the basic equations

$$C_i = N_i \frac{F_i}{Z_i}(1-e^{-Z_i}) \quad \text{and} \quad N_{i+1} = N_i e^{-Z_i}.$$

The sizes of the 1972-1973 year-classes at age 1 were also calculated given the estimated sizes of those year-classes at age 2 (Table 2), as predicted from survey indices, and given the catches at age 1. (<u>Note</u>: The 1974 catch data (numbers at age) from ICNAF (1975) were corrected taking into account the revised catch total for 1974.) Results are given in Table 3.

The 1972-1973 year-classes at age 1 were calculated to contain 1326 and 1373 x 10^6 fish, respectively, given catches at age 1 in 1973 and 1974 of 95.3 and 102.9 x 10^6 fish, respectively, and assuming sizes of 900 and 930 x 10^6 fish, respectively, at age 2 as predicted using the linear survey indices. If instead these year-classes were assumed to include only 146 and 262 x 10^6 fish, respectively, at age 2, as predicted from the $\log_e$ transformed survey indices, then the 1973 year-class at age 1 would have included 472 x 10^6 fish. No estimate could be obtained for the 1972 year-class because the catch of 260.7 x 10^6 fish at age 2 was greater than the predicted number of fish in the year-class at the beginning of age 2. Assuming sizes of 1971 and 1976 x 10^6 for the 1972 and 1973 year-classes, respectively, at age 1, as predicted using linear indices and given the catches at age 1 (see above), calculations indicated 1378 and 1455 x 10^6 fish, respectively, at age 2. Assuming sizes of 1120 and 1170 x 10^6 fish for those year-classes at age 1, as predicted using $\log_e$ transformed survey indices, they would contain 748 and 779 x 10^6 fish for those year-classes at age 2.

Discussion

Predictions of the size of mackerel year-classes at ages 1 and 2 from spring survey catches using linear regressions between VPA year-class sizes and survey number per tow indices (Figures 3-6) produced several estimates of the size of the 1972-1974 year-classes (Tables 2 and 3). The use of either linear or $\log_e$ transformed survey indices resulted in linear regressions with correlations of coefficient significant at the 0.05 probability level, with little apparent advantage from the standpoint of achieving a better statistical fit of the data to the line, in using linear or $\log_e$ transformed indices. The objective in transforming the indices was to reduce the wide variability of the linear indices for age 1(Table 1) in order to achieve the best relationship between VPA year-class sizes and survey indices. The relationship for age 1 fish described in Figure 3 using linear survey indices had a Y-intercept at 1917 x 10^6 fish, implying that as a minimum year-class size. This value was much higher than the size of the 1970 year-class (1370 x 10^6 fish) estimated by VPA, suggesting that 1917 x $10^6$is not realistic minimum size. Furthermore, from this relationship, the predicted sizes of the 1972-1974 year-classes at age 1 varied only from 1971 to 2064 x 10^6 fish (5% difference) whereas the survey year-class indices suggested that the 1974 year-class was twice as large as the 1972-1973 year-classes. The relationship for age 1 fish using $\log_e$ transformed survey indices (Figure 4) showed a minimum year-class size of 330 x 10^6 fish and resulted in predicted sizes of the 1972-1974 year-classes of 1120, 1170, and 1958 x 10^6 fish, respectively, which agreed proportionately to the survey indices.

For age 2 fish, the relationship between VPA year-class sizes and survey indices appeared to be more realistic using linear survey indices (Figure 5) instead of $\log_e$ transformed indices (Figure 6). The former indicated a Y-intercept at 845 x 10^6 fish, whereas the latter showed an unrealistic negative Y-intercept at -104 x 10^6, which can probably be assumed to be zero considering the variability of the data. The predicted size of the 1972 year-class at age 2 using the $\log_e$ transformed indices was less than the reported catch at that age indicating a meaningless relationship for predictive purposes. However, the sizes of the 1972-1973 year-classes at age 2 as predicted from the linear survey indices (900 and 930 x 10^6 fish, respectively) were only 16-17% higher than those calculated (748 and 779 x 10^6 fish, respectively) from the year-class sizes predicted at age 1 using $\log_e$ transformed indices (1120 and 1170 x 10^6 fish, respectively) given the reported catches at age 1.

The predictions of the size of the 1972-1974 year-classes at age 1 presented in this paper were less than the estimates used in the 1975 assessment on which the 1976 TAC was based. The values predicted for those year-classes using $\log_e$ transformed survey indices were 1120, 1170, and 1958 x 10^6 fish, respectively, as compared to 1922, 3700 and 2500 x 10^6 fish, respectively, used in the 1975 assessment. The greatest difference was with the 1973 year-class where the current estimate was only one-third of the estimate used in the 1975 assessment. The consequence of assuming the smaller year-class sizes is that the overall mackerel stock size is much less than previously assumed. The 1975 assessment assumed a stock biomass (age 1+ fish) at the beginning of 1975 of 1084.6 x 10^3 tons. Using the lower estimates of year-class size as given above results in a stock biomass at the beginning of 1975 about 40% lower. The implications from this are substantially higher rates of fishing mortality in 1975 and 1976 than previously assumed resulting in a further and possible substantial reduction in stock size. Such a condition would necessitate a signficant reduction in the TAC for 1977 in order to reduce fishing mortality to a level such as $F_{0.1}$ (0.3-0.4) and to prevent the further reduction of stock size to levels possibly detrimental to the production of future recruitment.

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Table 1. Indices of mackerel year-class size at ages 1 and 2 in ICNAF SA 3-6 determined from US spring survey catch per tow [number/tow and $\log_e$ (number/tow + 1)] compared to year-class sizes calculated from virtual population analysis (VPA).

Year-class	Age 1 Survey No./tow	Age 1 Survey $\log_e$(no./tow+1)	Age 1 VPA No.(10^6)	Age 2 Survey No./tow	Age 2 Survey $\log_e$(no./tow+1)	Age 2 VPA No.(10^6)
1966	-	-	-	6.665	2.037	2373.1
1967	60.921	4.126	7398.1	*0.366	*0.312	5397.8
1968	*0.092	*0.088	3097.1	3.826	1.574	2175.1
1969	1.910	1.068	2934.6	4.120	1.633	2051.6
1970	0.909	0.647	1370.0	1.706	0.995	929.1
1971	3.721	1.552	2039.9	1.994	1.097	1475.8
1972	0.600	0.470	-	0.213	0.193	-
1973	0.648	0.500	-	0.326	0.282	-
1974	1.636	0.969	-	-		-

* not used - see text.

Table 2. Sizes of 1972-1974 mackerel year-classes at ages 1 and 2 (10^6 fish) in ICNAF SA 3-6 predicted from the relationship between year-class sizes determined from virtual population analysis and (1) survey number/tow and (2) survey $\log_e$ (number/tow+1) indices in comparison to year-class sizes assumed in the 1975 assessment.

Year-class	Age 1 1975 assessment	Age 1 Survey no./tow	Age 1 Survey $\log_e$(no./tow+1)	Age 2 1975 assessment	Age 2 Survey no./tow	Age 2 Survey $\log_e$(no./tow+1)
1972	1922	1971	1120	1342	900	146
1973	3700	1976	1170	2644	930	262
1974	2500	2064	1958	1633	-	-

Table 3. Sizes of 1972-1973 mackerel year-classes at ages 1 and 2(10^6 fish) in ICNAF SA 3-6 (1) assumed in the 1975 assessment, (2) predicted from survey no./tow indices, (3) predicted from survey $\log_e$ (no./tow+1) indices, (4) assuming the predicted size at the other age from survey no./tow indices, and (5) assuming the predicted size at the other age from survey $\log_e$ (no./tow+1) indices.

Year-class	1975 assessment	Predicted from survey no./tow	Predicted from survey $\log_e$(no./tow+1)	Assuming survey no./tow prediction at the other age	Assuming survey $\log_e$ (no./tow+1) prediction at the other age
			Age 1		
1972	1922	1971	1120	1326	*
1973	3700	1976	1170	1373	472
			Age 2		
1972	1342	900	146	1378	748
1973	2644	930	262	1455	779

* Catch at age 2 greater than assumed year-class size so no estimate is possible.

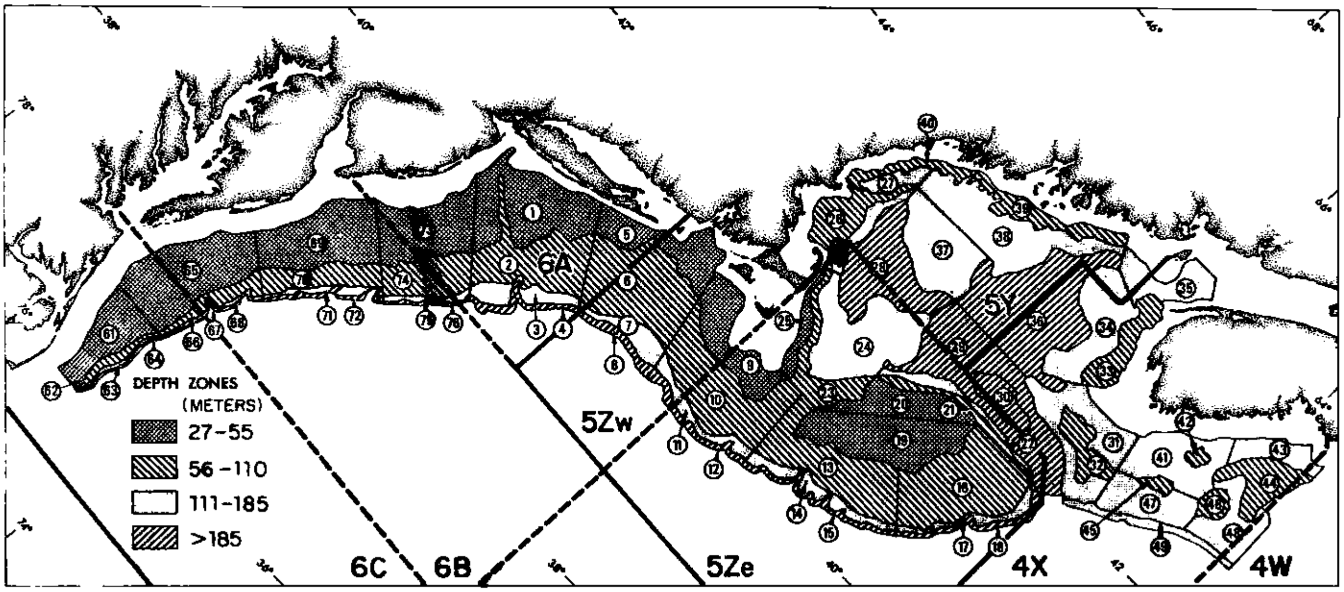

Fig. 1. US bottom trawl survey sampling strata in ICNAF SA 5-6.

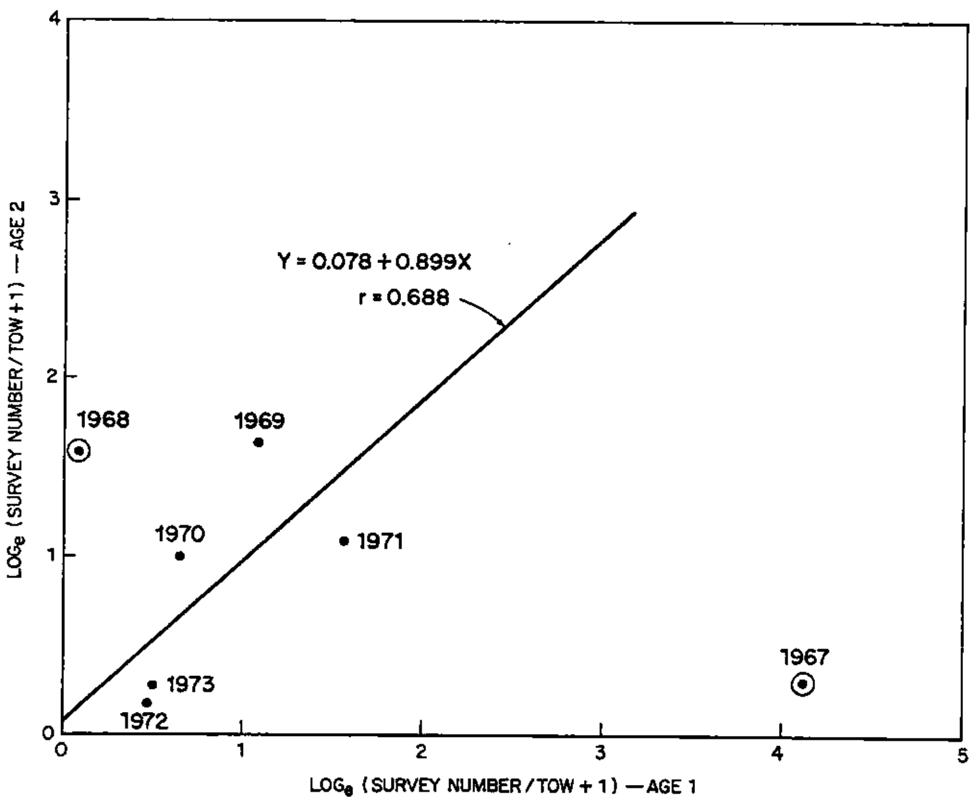

Fig. 2. Relationship between the spring survey log$_e$ transformed number per tow at age 1 and age 2. Calendar years refer to year-classes; 1967 and 1968 are not included in the analysis.

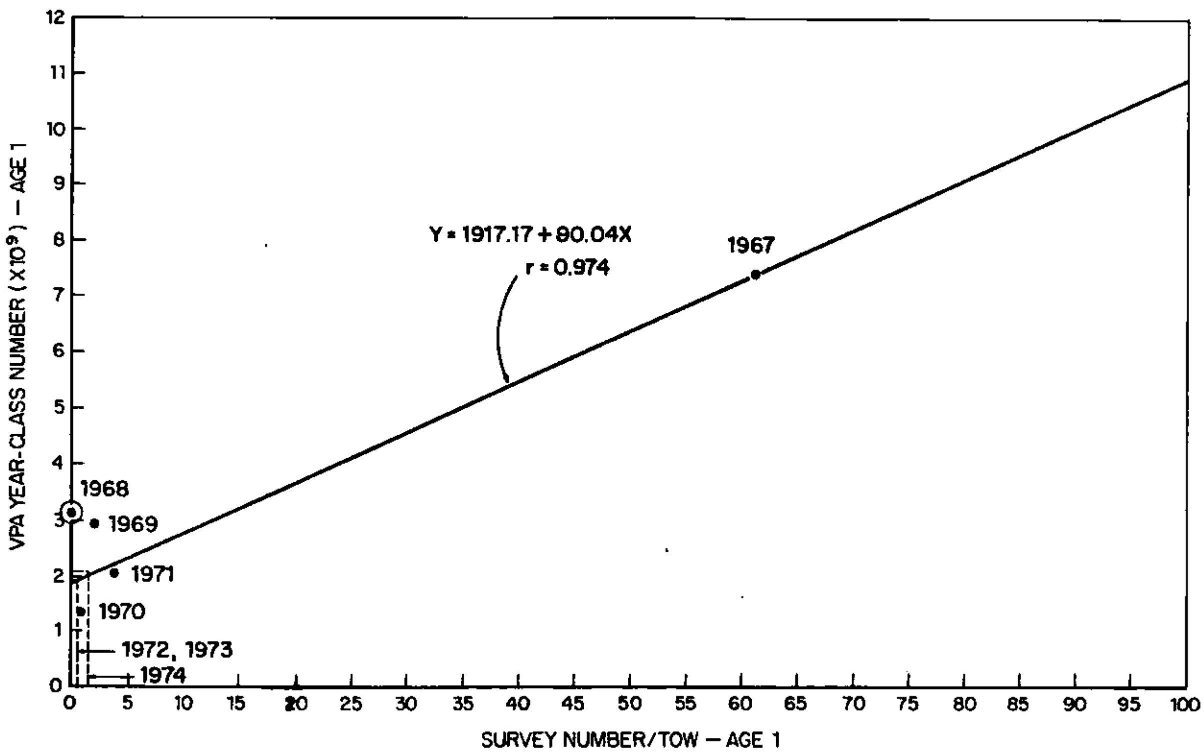

Fig. 3. Relationship between the spring survey number per tow index for mackerel at age 1 and year-class size (number x 10^9) at age 1 calculated by virtual population analysis (VPA). Calendar years refers to year-classes; 1968 is not included in the analysis.

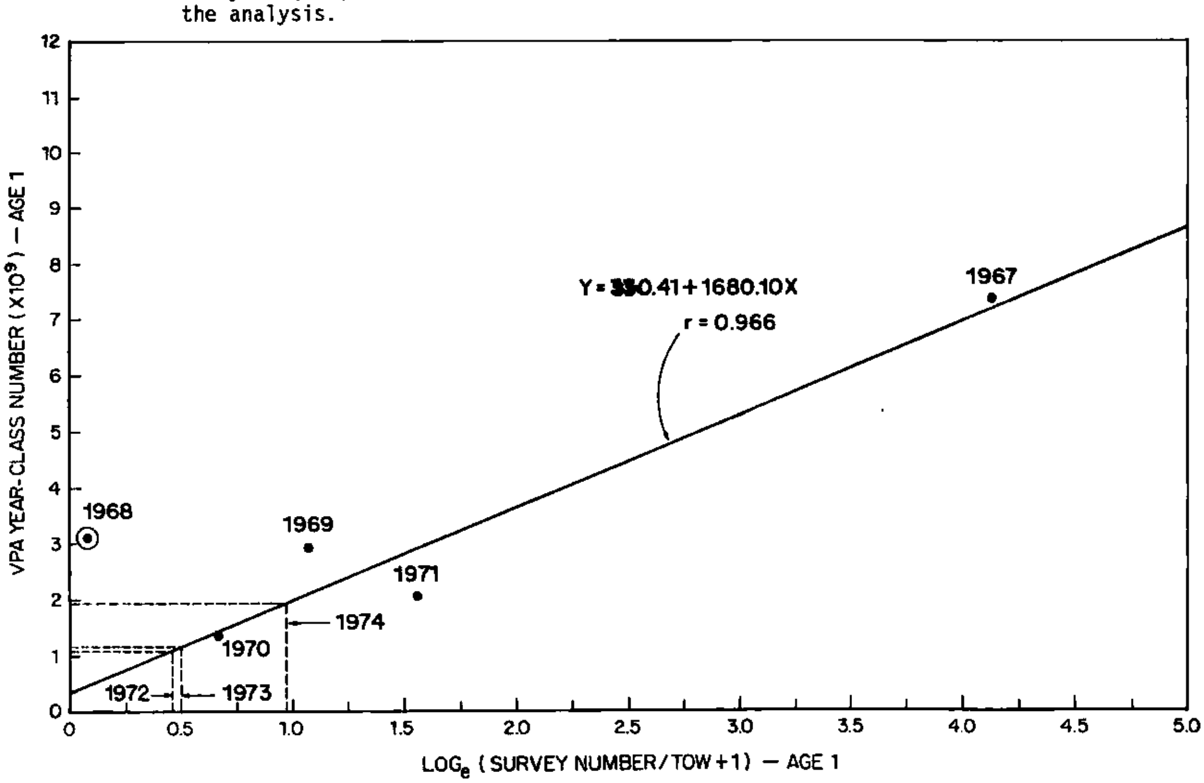

Fig. 4. Relationship between the spring survey $\log_e$ (number per tow +1) index for mackerel at age 1 and year-class size (number x 10^9) at age 1 calculated by virtual population analysis (VPA). Calendar years refer to year-classes; 1968 is not included in the analysis.

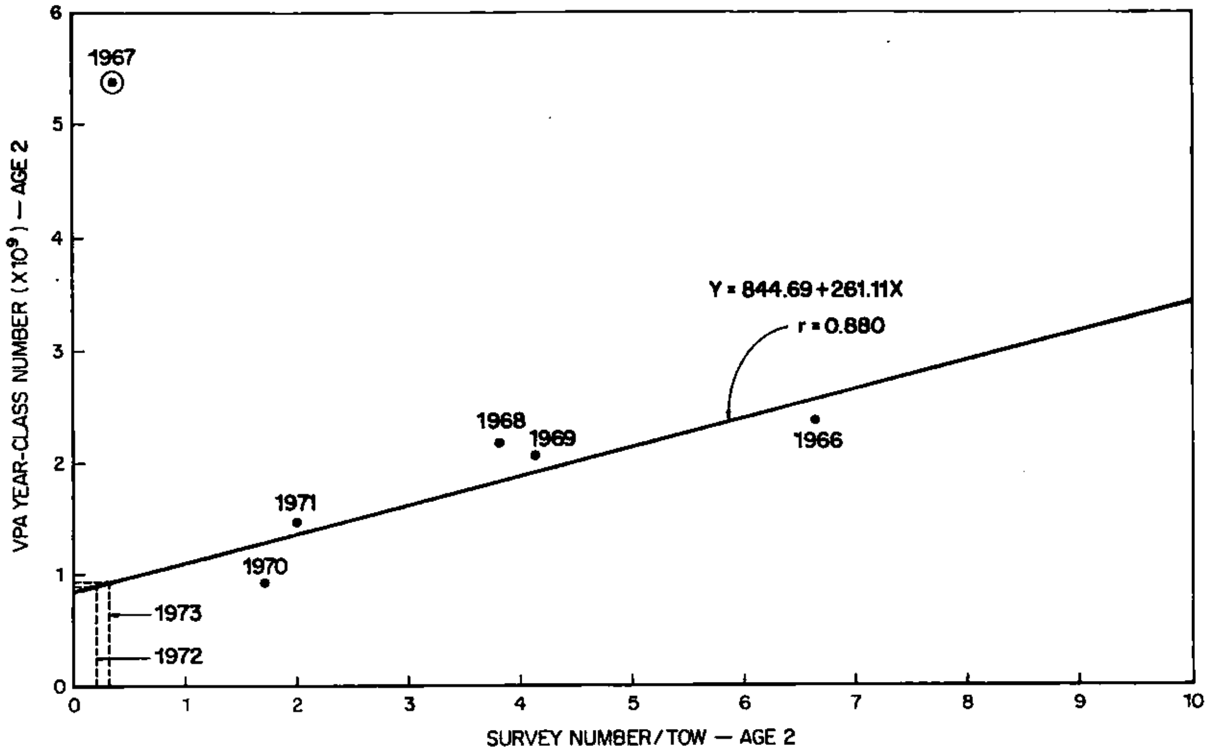

Fig. 5. Relationship between the spring survey number per tow index for mackerel at age 2 and year-class size (number x 10^9) at age 2 calculated by virtual population analysis (VPA). Calendar years refer to year-classes; 1967 is not included in the analysis.

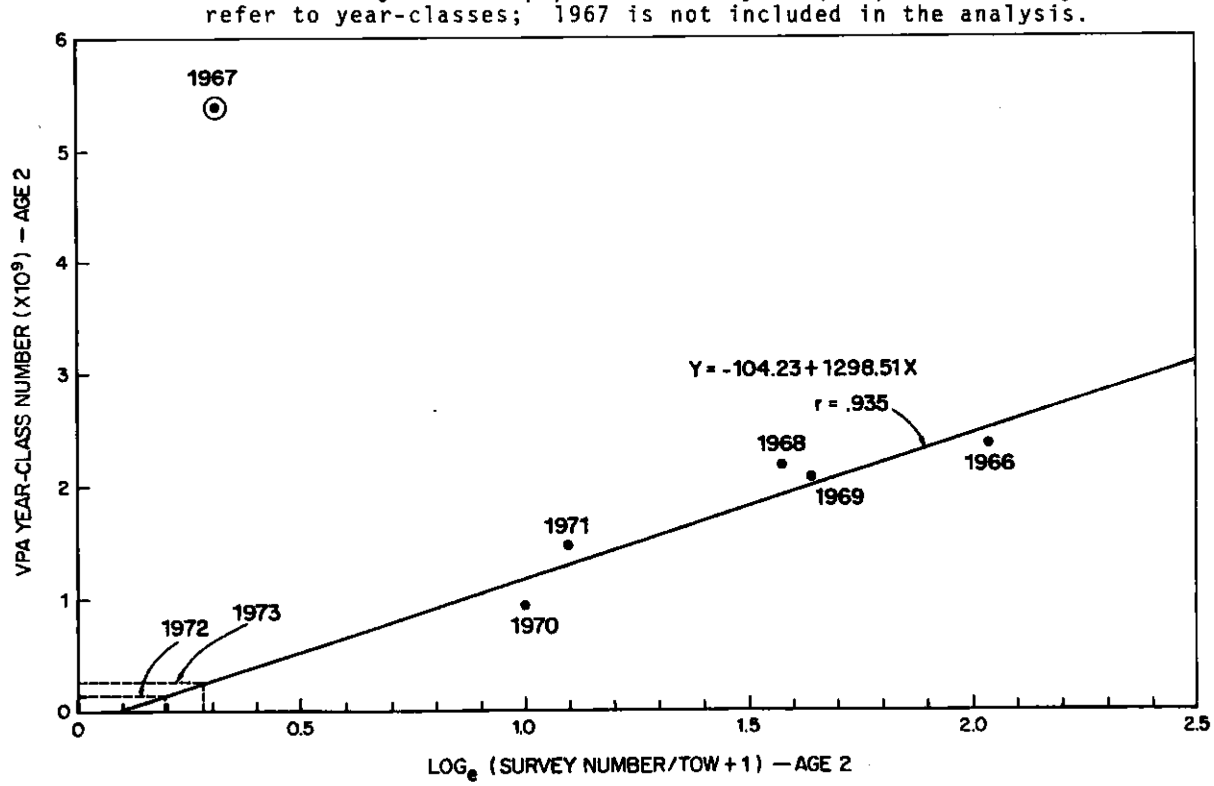

Fig. 6. Relationship between the spring survey $\log_e$ (number per tow +1) index for mackerel at age 2 and year-class size (number x 10^9) at age 2 calculated by virtual population analysis (VPA). Calendar years refer to year-classes; 1967 is not included in the analysis.