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Analysis of Research Survey Catch at Age Data Using a Multiplicative Model

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Abstract

A multiplicative model was developed for analyzing catch-at-age data from stratified random groundfish abundance surveys. Our objective was to investigate the spatial distribution of different age groups and to develop an index of year-class strength. An example is presented for cod in NAFO Div. 4T. The model tested included age, year-class, and stratum effects as well as an age*stratum interaction. The model explained 60% of the variation in the data. The estimated coefficients of the age*stratum interaction indicated spatial segregation of the age groups, with the younger fish being concentrated in shallow inshore strata. The coefficients for the year-class terms were highly correlated with VPA estimates of year-class strength (R^2=.87). The age effects of the model were interpreted as an average catch curve for the time period. The model presents a relatively simple method for obtaining stock assessment parameters and information on spatial distribution from research surveys catch-at-age data when other estimates (eg VPA) are not available.

Introduction

Stratified random bottom trawl surveys (RV) have been used to monitor groundfish abundance in the Northwest Atlantic for over 20 years (Doubleday 1981, Halliday and Koeller 1981). The results of these surveys are used in stock assessments to calibrate virtual population analysis or cohort analysis, hereafter referred to as sequential population analysis (SPA). The RV estimates are treated as indices of abundance while absolute abundance, stock biomass, and fishing mortality estimates are derived from SPA.

SPA is based on commercial catch-at-age data. These data are at times unsuitable for SPA due to misreporting of or incomplete information on catches, low fishing mortalities, or uncertain stock identification. Alternatively, the RV data present sequential estimates of year class strength at different ages, information on cumulative mortality, information on the spatial distribution of the fish, and the surveys are independent of the commercial fisheries.

Shepherd and Nicholson 1991 describe the use of multiplicative models for analyzing these types of data. In short, catch at age is expressed as a multiplicative function of yearclass strength, age, and cumulative total mortality to that age. The latter is a combination of fishing mortality and selection at age. It is pointed out several times in their paper that the model is true only if total fishing mortality and the exploitation pattern are constant through time. However the authors did not seem to worry about minor violations of this assumption. The authors fitted parameters for age, yearclass and year effects. Since these parameters are linearly related thus making the problem indeterminate, the authors suggested the application of reasonable constraints to one of the effects. In their cases they decided to constrain the trend in the year effect to some reasonable level. In the case of commercial catch at age this trend could be set at the observed trend in fishing effort.

In this paper we investigate the application of this approach to data from RV surveys for cod in the southern Gulf of St. Lawrence, Canada (Figure 1). SPA has been used for the assessment of this stock since the mid-1970's and thus we were able to compare our model results to those of SPA. Since the surveys have been conducted in a standard manner sine 1971 we elected not to include year effects in our model. Abnormal survey years could be detected by residual analysis. However, we were interested in the spatial distribution of the cod in the area, and in particular the differences with age. To investigate the distribution we added parameters for stratum effects and age*stratum interactions. Our overall model was

$$\ln C_{akn} = \upsilon + E_a + R_k + S_n + E_a{*}S_n$$

where C_{akn} is the catch at age a of yearclass k and in stratum n, E, R, and S are the overall age, yearclass and stratum effects, and υ is the model intercept.

Methods

The basic data were obtained from the Canadian Department of Fisheries and Oceans Gulf Fisheries Center, Moncton, New Brunswick. The years 1971 to 1988 were used. Catch at age of cod were calculated on a tow by tow basis according to a two stage sampling scheme described by Halliday and Koeller 1981. Catch per tow was adjusted to a standard tow length of 1.75 nm and the mean catch per tow at age by stratum was calculated for input to the model. The data were transformed as ln (C+.5) to take care of null values. Strata with large numbers of null sets (ie 15,25, and 39) and age groups 0, 1, and 8+ were not included in the analysis to reduce the number of null observations to less than 10%.

Statistical analysis was performed using the general linear models procedure (PROC GLM) of SAS (Annon 1985).

Results

The analysis of variance of the overall model (Table 1) indicated all terms were significant and the model explained 60% of total variance. The stratum effect was relatively strong and this indicates an important spatial component in the distribution of cod in the area. While the stratum*age interaction term was weak, it was statistically significant ($p < .0001$) thus indicating spatial segregation of age groups. Standard residual analysis indicated normality and no autocorrelation with the main effects.

Least square means estimates of the yearclass effects indicate substantial variation over the time period studied (Figure 2). Recruitment estimates for the late 1960's to early 1970's were substantially lower than in the later period. The largest yearclass estimate was for 1980.

Yearclass estimates are also available from SPA. For this stock the SPA is calibrated with RV stratified mean catch per tow at age and commercial CPUE (Chouinard and Sinclair 1989). We present two comparisons of SPA and model estimates of yearclass size. Our RV time series covers the period 1971 to 1988. SPA estimates for commercial and research data for the same period are given in (Chouinard and Sinclair 1989). SPA estimates included yearclasses up to 1984 due to the lack of commercial catch of younger ages. Our model gives estimates for the 1985 and 1986 yearclasses as well. The two series are compared in Figure 3. The model estimates were converted to the arithmetic scale, no bias correction was applied. Linear regression of the two series was highly significant ($R^2 = .826$, $p < .0001$). The 1984 yearclass had a high residual. The position of the model estimates of the 1985 and 1986 yearclasses is shown on the x-axis.

The SPA recruitment estimates were updated according to the most recent assessment of the stock (Hansen et al. 1991) and the comparison was repeated (Figure 4). The 1985 and 1986 yearclasses were estimated in SPA and compared well to the model estimates. The SPA estimates of the 1984 yearclass was revised downward and it is now more in line with the model estimates.

We interpreted the stratum*age parameters as indicating the average age composition in each stratum. Least squares means were calculated along with their standard errors and these are presented for selected strata in Figure 5. The modal age in strata 22 and 28 was age 3, while in strata 16 and 36 it was 5, and in strata 26 and 38 the modal age was 6. It was also noted that strata 36 had relatively fewer cod than the other strata. Numbers weighted mean ages per stratum are presented in Figure 6. With reference to Figure 1, the general pattern is that the shallow strata close to land had a younger mean age than the deeper strata.

The model parameters for the age effects are presented in Figure 7. These were obtained from two separate analyses, one for the years 1971-79, the second for 1980-88. The results indicate a change in the total mortality pattern for cod between the two periods. The two series are scaled differently, which represents a lower abundance of cod in the area in the 1970's. However, the pattern is also different. The age effects peak at age 4 in the 1970's while the modal age is age 5 in the 1980's. This is likely to be the result of reduced fishing mortality, increased mesh size, and slower cod growth in the latter period.

Discussion

We have found the multiplicative analysis described by Shepherd and Nicholson 1991 to be useful in analyzing abundance-at-age data from stratified random groundfish surveys. The addition of parameters on strata and strata-age interactions provided information on the spatial distribution of the fish.

Estimates of yearclass strength from the model compared favorably to those from SPA. In fact, it was found that in the case of the 1984 yearclass, the model gave a more consistent estimate than the SPA.

The change in the age specific mortality pattern between the 1970's and 1980's is consistent with changes in the fishery associated with different management measures. The analysis assumes that this pattern was fixed throughout the period and while we have not attempted to investigate the effect of such a violation of the assumption on the results such additional work is warranted.

Overall, we find that such models provide a relatively simple method for obtaining stock assessment parameters and information on spatial distribution from research surveys catch-at-age data. We recommend their use along with SPA, and certainly when commercial data are insufficient to perform SPA.

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Table 1: Analysis of variance results from a multiplicative model of yearclass, stratum, age and stratum*age effects on the mean catch per tow of cod.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	147	3291.36	22.39	20.96	0.0001	.598
Error	2072	2213.00	1.06			
Total	2219	5504.36				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	22	1152.81	52.40	49.06	0.0001
STRAT	20	1268.20	63.41	59.37	0.0001
AGE	5	371.23	74.24	69.52	0.0001
STRAT*AGE	100	510.06	5.10	4.78	0.0001

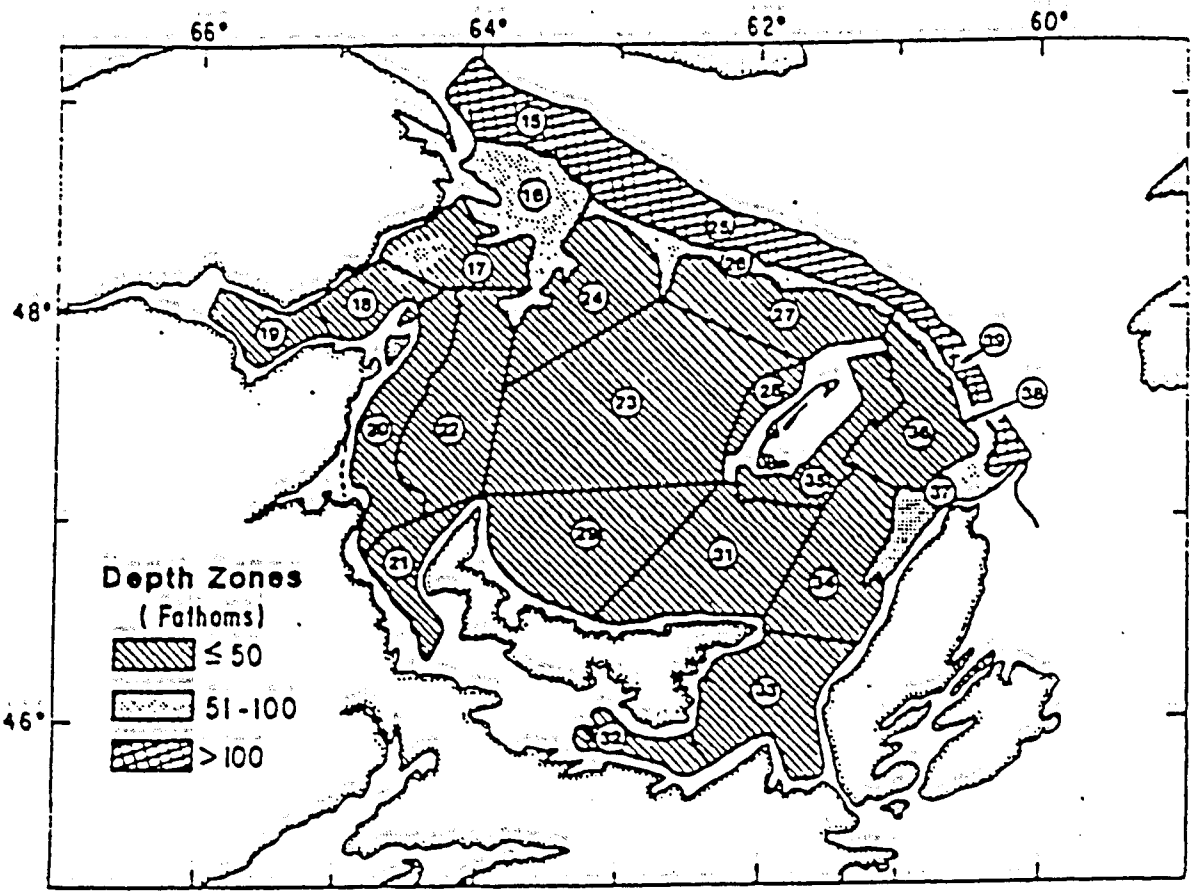

Figure 1: Stratification scheme of the southern Gulf of St. Lawrence groundfish survey.

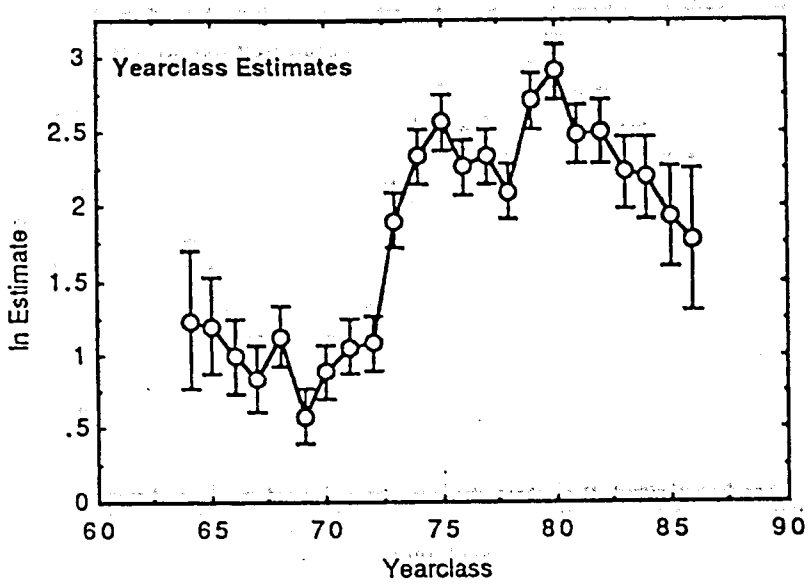

Figure 2: Least squares estimates of yearclass effects from a multiplicative analysis of RV catch at age. Vertical bars give 2 standard errors.

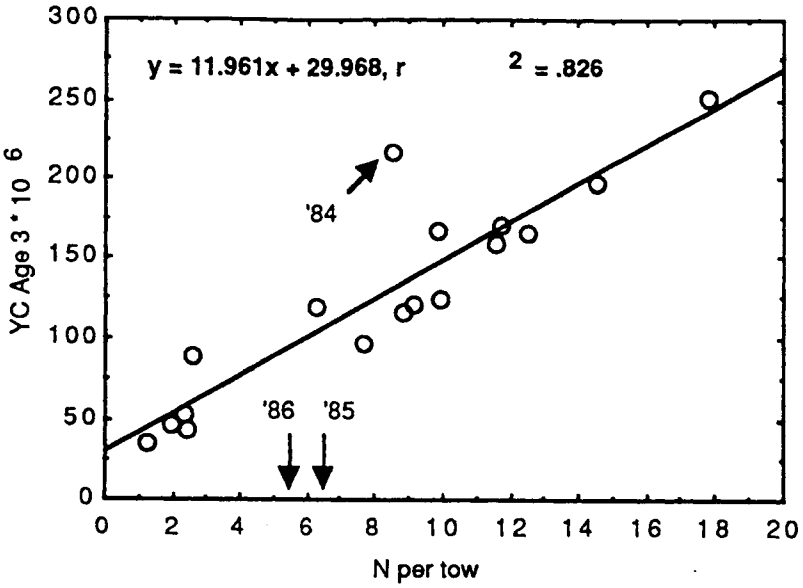

Figure 3: Comparison of SPA age 3 yearclass estimates and those obtained from a multiplicative analysis of RV catch at age. The SPA contained estimates of the 1968 to 1984 yearclasses. The model estimates of the 1985 and 1986 yearclasses are shown on the x-axis.

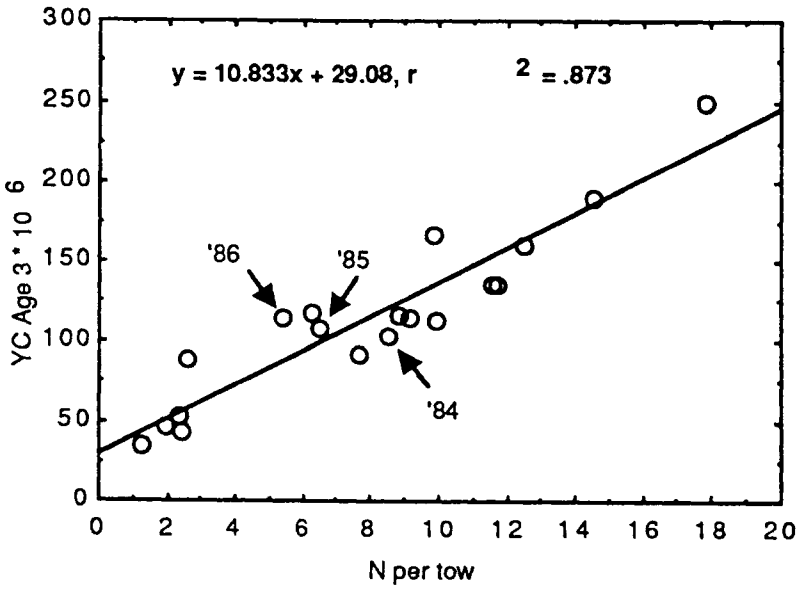

Figure 4: Comparison of SPA age 3 yearclass estimates and those obtained from a multiplicative analysis of RV catch at age. The SPA contained estimates of the 1968 to 1986 yearclasses. The points for the 1984-86 yearclasses are labeled for comparison to Figure 3.

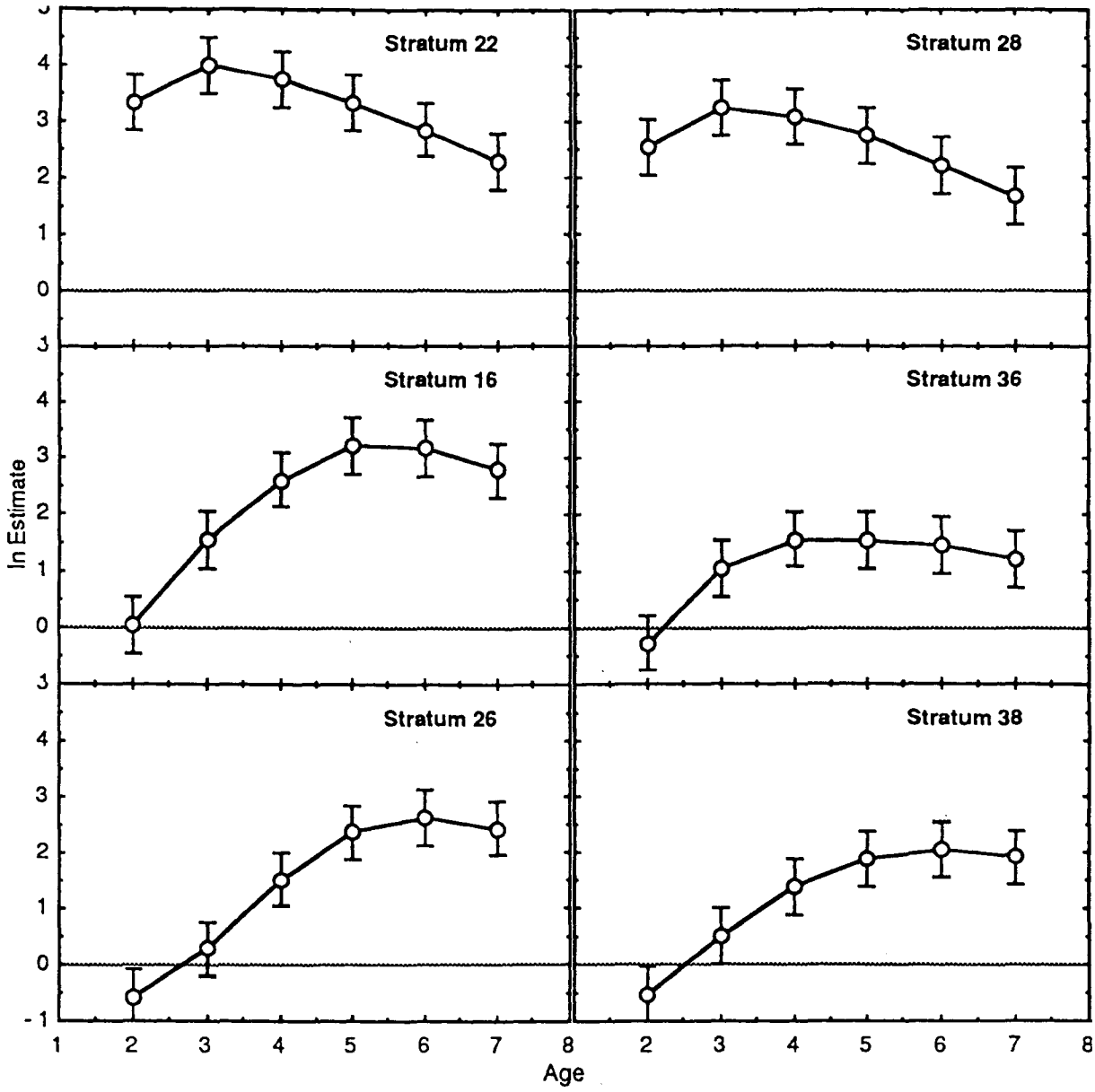

Figure 5: Least squares means estimates of the mean catch per tow at age and per stratum from a multiplicative analysis of RV data. Vertical bars give two standard errors of the estimates.

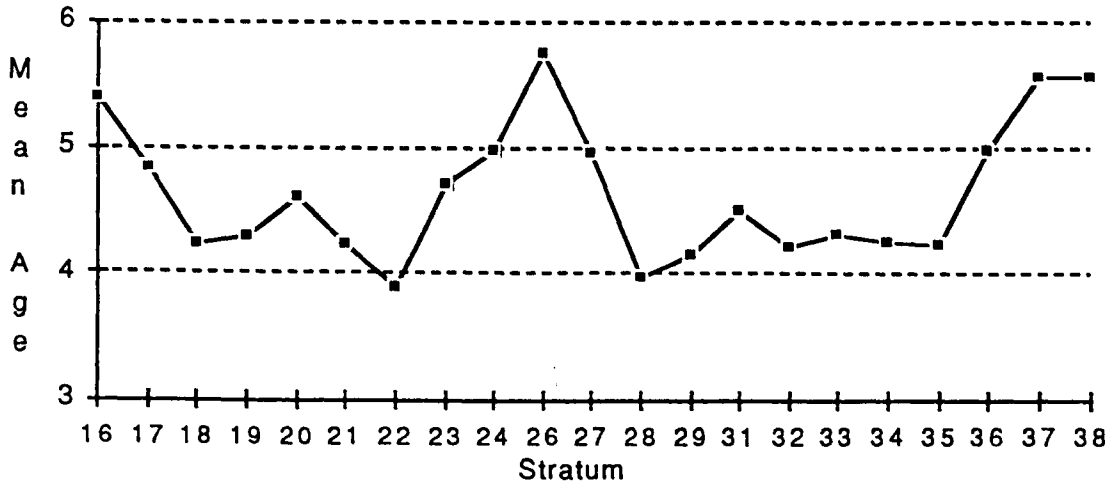

Figure 6: Numbers weighted mean age per stratum from calculated from the stratum*age parameters.

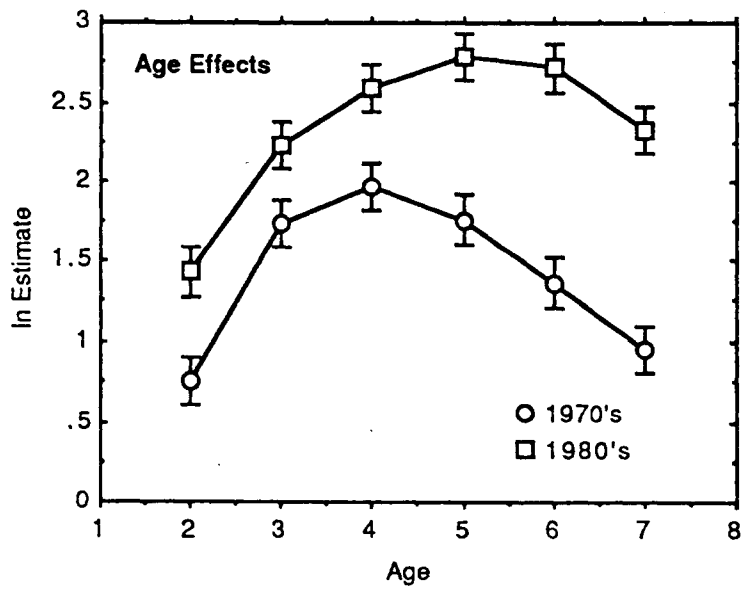

Figure 7: Least squares means of the age effects estimated from RV catch at age data using a multiplicative model.