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Application of a Multiplicative Model to Research Survey Data from Two Cod Stocks

Alan Sinclair and Ghislain Chouinard

Department of Fisheries and Oceans, Gulf Fisheries Center, P.O. Box 5030, Moncton, New Brunswick, E1C 9B6. Canada

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Abstract

A multiplicative model was developed to analyze 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. Examples are presented for cod in 4TVn (J-A) and cod in 4VsW. The model accounted for variation among ages, year-classes, areas and time periods. The age effects indicated a substantial changes in the mortality schedule of the cod and this corresponded with changes in the fishery. The analysis indicated spatial segregation of age groups, with the younger fish being concentrated in shallow strata. The year-class terms were highly correlated with SPA estimates of year-class strength and provide a good recruitment index for catch projections. Multiplicative models present a relatively simple method for obtaining stock assessment parameters and information on the spatial distribution of marine fish from research surveys catch-at-age data.

Sommaire

Un modèle multiplicatif a été développé pour l'analyse des prise à l'âge provenant des relevés de recherche effectués selon un plan d'échantillonnage aléatoire stratifié. Notre objectif était d'étudier la répartition spatiale des groupes d'âge et d'établir un indice de l'abondance des classes d'âges. Les stocks de morue de 4TVn (J-A) et de 4VsW sont utilisés à titre d'exemple. Le modèle tenait compte de la variation entre les âges, les classes d'âges, les strates, et les periodes de temps. Les paramètres pour les âges ont indiqué des changements importants dans le patron de mortalité pour la morue qui sont en accord avec les changements dans les pêches. L'analyse a démontré une segrégation des groupes d'âges, où les jeunes poissons occupent les strates peu profondes. Les paramètres des classes d'âges étaient fortement correlées avec les estimés provenant des analyses sequentielles des populations et donc, donnent un bon indice du recrutement pour faire des prédictions. L'analyse multiplicative représente une méthode relativement simple pour obtenir des paramètres pour les évaluations des stocks ainsi que de l'information sur la répartition spatiale des poissons marins à partir des données des relevés de recherche des priese selon l'âge

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). These surveys are used in stock assessments as a relative abundance index to calibrate sequential population analyses (SPA). RV data present 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.

SPA is based on commercial catch-at-age data which may be unsuitable for this purpose because of misreporting, incomplete information on catches, low fishing mortalities, or uncertain stock identification. Shepherd and Nicholson (1991) described the use of multiplicative models for analyzing catch-at-age data. They expressed catch at age as a multiplicative function of year-class strength, age, and year. The age effect was a combination of total mortality and recruitment to the sampling gear. They noted that the model was appropriate only if fishing mortality and the exploitation pattern were constant through time. However the authors were not concerned about minor violations of this assumption. Because the parameters age, year-class and year were linearly related, the problem was indeterminate. To overcome this, the authors suggested the application of reasonable constraints to one of the effects.

In this paper, we investigated the application of multiplicative models to data from RV surveys for cod in the southern Gulf of St. Lawrence, hereafter referred to as 4TVn (strata 15-39 in Figure 1), and the eastern Scotian Shelf, referred to as 4VsW (strata 42-66 in Figure 1). In addition to gaining information on year-class strength, we investigated the spatial distribution of the fish in relation to age. The structure imposed was that regional abundance at age changes proportionally with variation in year-class strength.

We also investigated the sensitivity of estimates to temporal variations in the age effects and to observation weighting (i.e. by stratum area). SPA has been used for the assessment of these stocks since the mid-1970's, thus we were able to compare our model estimates of year-class strength to those of SPA. This analysis updates that presented by Chouinard and Sinclair (1989).

Methods

The basic data were obtained from the Canadian Department of Fisheries and Oceans Gulf Fisheries Center, Moncton, New Brunswick, and the St. Andrews Biological Station, St. Andrews, New Brunswick. The years 1971 to 1991 were used. Catch at age of cod was 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 nautical miles and the mean catch per tow, at age, by stratum was calculated for input to the model. Using mean catch per tow reduced the proportion of null values in the data set. The data were transformed as ln (C+0.5) to take care of null values. Strata having large numbers of null sets (i.e. 15, 25, and 39 for 4TVn cod and 53, 60, 61, and 66 for 4VsW cod) and age groups 0, 1, and 8+ were not included in the analysis to reduce the number of null observations. The 4TVn surveys were conducted in late August-September while the 4VsW surveys were conducted in late June-early August.

Because the surveys have been conducted in a standard manner since 1971, we did not include year effects in our model. Abnormal survey years could be detected by residual analysis. However, preliminary analysis indicated significant changes in the age effects during the time series. The effect of this on year-class estimates was investigated by comparing the parameter estimates from analyses for the entire period, separate analyses for successive periods (1971-75, 1976-80, 1981-85, and 1986-91), and an analysis that included additional parameters for an age*time period interaction. We added parameters for stratum effects and age*stratum interactions to investigate the spatial distribution at age. The overall model was

$$\ln (C_{aknp} + 0.5) = \beta + A_a + R_k + S_n + P_p + A_a{*}S_n + A_a{*}P_p + \varepsilon$$

where C_{aknp} is the catch at age a of year-class k in stratum n and in period p, A, R, S and P are the overall age, year-class, stratum and period effects, and β is the model intercept and ε is the error term.

The surveys have followed a stratified random design since 1971. Thus, one may argue that the strata means should be weighted by strata areas in an analysis of this type. We investigated the effect of such a weighting on the year-class estimates.

Statistical analysis was performed using the general linear models procedure (GLM) of SAS (SAS Institute Inc. 1989). A sample program is given in Annex 1. Least squares means estimates, that is the parameter estimates adjusted to the average of other parameters, of various parameters are presented. When log estimates were retransformed to the linear scale, the bias adjustment described by Gavaris (1980) and Bradu and Mundlak (1970) was used. The log residuals distribution were examined visually for normality and heteroscedasticity.

Results

4TVn Cod

The results of the separate analyses for the four time periods (Table 1) indicated all terms were significantly different from 0 ($P<0.005$). The models explained between 56% - 72% of the variation in the data. The stratum effect was relatively strong and this indicates an important spatial component in the distribution of cod in the area. The stratum*age interaction terms were statistically significant ($P < 0.002$-0.0001) thus indicating spatial segregation of age groups. The distribution of the log residuals were near normal and there was no evidence of heteroscedasticity. There were less that 10% zero observations in the analyses.

These preliminary analyses indicated significant changes in the age effects during the time period of the survey. Least squares means estimates of the age effects from four separate analyses are given in Figure 2. The curves are scaled to the average RV catch per tow in the different periods. The trends in age effects reflect different fishing patterns in the periods. Fishing mortality (F) was generally higher in the early 1970's and this may explain the early age of full recruitment to the survey and sharp decline with age. F was lower in the late 1970's and this may explain the reduction of the slope of the descending part of the curve as well as the increase in the age of full recruitment. The trend in age effect for the early 1980's indicates another shift in the age of full recruitment to age 6. This may be due to the reduction in growth of cod. The last time period indicates age 5 as fully recruited and perhaps a higher fishing mortality.

The year-class parameter estimates from the four temporal analyses are compared in Figure 3. All estimates are standardized to age 3. In the first three periods, 10 year-class estimates were obtained while 11 were obtained from the last time period. The 1969-73 year-classes were estimated in both analyses 1 and 2, the 1974-78 year-classes were estimated in analyses 2 and 3, and the 1979-83 year-classes were estimated in analyses 3 and 4. There is close agreement among the independent estimates of the more recent year-classes. However, the estimates for the 1969-71 year-classes are quite different, with the estimates from period 1 being substantially higher than those from period 2. This is likely due to the higher mortality in the earlier period, which is not accounted for in the second analysis. By the time these year-classes were sampled in the second time period, their numbers had been greatly reduced. Given the apparent age effect, the year-class estimates were artificially low.

Based on these results, we decided to add additional parameters to account for the change in age effect with time. Thus, we added age*time period interaction terms to the model. The effect of including four (71-75, 76-80, 81-85, 86-91), three (71-75, 76-80, 81-91) or no time periods as well as strata area as a weighting variable on the year-class estimates is shown in Figure 4. The correlations between the different options were high, the lowest being 0.967. The largest differences were for the 1964-69 year-classes between the model with no periods and the other three models. Accounting for time period resulted in larger estimates. Whether three or four time periods or weighting was used had very little effect on the year-class estimates. We prefer to include time period in the model and exclude strata area since the statistics from weighted regressions are somewhat more difficult to interpret.

The analysis of variance of the preferred model indicates that the time period terms were strong (Table 2). The overall R^2 was 0.60. Least square means estimates of the year-class effects indicate substantial variation over the time period studied (Figure 5). Recruitment estimates for the late 1960's to early 1970's were substantially lower than in the later period. The largest year-class estimate was for 1980 followed by a decline. The 1988 and 1989 year-classes are estimated to be among the lowest in recent years.

The retransformed and bias adjusted year-class estimates, standardized to age 3, strata 422, and period 4 are given in Table 3. The bias adjustment was substantial, adding about 60% to the antilog of the estimate. However, the adjustment was proportional and thus had no effect on the trend of the estimates. Thus, if the model estimates are used as an index, there is no need to apply the bias adjustment.

A retrospective comparison of year-class estimates indicates that they are robust to new data. The model was used on data sets ending in 1986, 1987, 1988, and 1991. The trends show only minor variations in the most recent years (Figure 6). The difference in estimates of the earliest year-classes was because the age*period interaction terms were not included in the models for the shorter data sets.

This model was first presented in the assessment using data until 1988 (Chouinard and Sinclair 1989). At that time the SPA estimates included year-classes up to 1984 (at age 4) due to the lack of commercial catch of younger ages. The multiplicative model gave estimates for the 1985 and 1986 year-classes as well. Linear regression of the SPA and multiplicative model estimates of year-class size (in the arithmetic scale) was highly significant ($R^2 = 0.83$, $p < .0001$, Figure 7). However, the 1984 year-class had a high residual. The model estimates of the 1985 and 1986 year-classes are shown on the x-axis. The SPA recruitment estimates were updated according to the 1991 assessment of the stock (Hanson et al. 1991) and the comparison was repeated (Figure 8). The 1985 and 1986 year-class estimates from SPA compared well to the model estimates. The SPA estimate of the 1984 year-class was revised downward and it is now more in line with the model estimates. It now appears that the multiplicative model gave a more consistent estimate of the 1984 year-class than did the SPA conducted with data to 1988.

The relationship between the SPA and retransformed, bias adjusted model year-class estimates is highly significant ($r^2 = 0.89$, Figure 9) and it was used to predict the sizes of the 1987-89 year-classes. The predicted values are 120, 71, and 70 million at age 3 respectively (Table 3). The high correlation between the SPA and model estimates may be misleading since the stratified mean numbers per tow from the survey are used as one calibration index for the SPA. However, the model estimates appear to be quite consistent from year to year (Figure 6) and, because the 1987-89 year-classes were not estimated from SPA in 1991, the predictions would be valuable for catch projections.

We interpreted the stratum*age parameters as indicating the average age composition in each stratum. The least squares mean catch at age by stratum along with their standard errors from the combined analysis are presented for selected strata in Figure 10. 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. 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.

Least squares mean catch at age per stratum were calculated for the four separate temporal analyses. After retransforming to the arithmetic scale, these were used to calculate the mean age per stratum. While there was considerable variation in among time periods, the mean age was consistently lower for the earliest period in the eastern strata (26+) (Figure 11).

4VsW Cod

In this analysis, the number of zero observations was in the order of 15-20% of the observations, somewhat higher than for 4TVn cod. The residual distributions from most of the analyses were skewed. We were not able to determine the effect of this on the results of the analysis, and this should be studied further.

Preliminary analyses revealed that the year-class estimates were affected by the choice of model structure and the use of weighting by strata area (Figure 12). If four time periods were used in one analysis with no weighting, the year-class estimates showed an increasing trend from about 1970 (Figure 12, lower left). If strata area was used to weight the observations with the same time periods, the trend in year-class estimates increased from 1970-80 and leveled out (Figure 12, upper left). This may be due to relatively high catches in the small stratum 63 (Emerald Bank) in 1989. If the last two time periods were combined, the estimates from the latter 1970's to the most recent were scaled down. The 1983-85 and 1989 year-classes were estimated to be similar to the very low 1969-71. If no time periods were used, the estimates of the 1964-70 year-classes were scaled down. The correlations among these four series were weaker than for 4TVn cod.

A possible reason for the effect of the choice of time periods on the year-class estimates may be the estimated age effects. As was done for 4TVn cod, separate temporal analyses were performed on the 4VsW cod data. These analyses covered successive blocks of years as described in the methods section. The age effects from these analyses indicated important changes in the exploitation pattern of the resource (Figure 13, bottom left). The highest age effect was at age 3 for the 1971-75 analysis, after which the estimates declined sharply. This was the period of high fishing mortality by foreign fleets. The highest age effect was at age 4 in the other 3 analyses and the apparent exploitation rate was lower. The curves for the last 2 periods were very similar. It should be noted that these curves are scaled to the average year-class size in the analysis. When an age*period interaction was included in a single analysis, the shapes of the age effect curves were similar to those in the separate analyses (Figure 13, bottom right). However, the maximum age effect varied among the time periods. The curves are meant to represent the mortality schedule of a standard year-class, in a standard stratum, but in different time periods. The fact that the age effect curve for the latter time period peaked below the others suggests that the average catchability of cod may have varied among the time periods. However, it is also possible that some unaccounted for interaction, perhaps a change in spatial distribution, has caused this to occur. This was different than the results of the 4TVn analysis where the curves from the combined analysis peaked at similar absolute values (Figure 13).

The year-class estimates from the 4 separate analyses show considerable variation (Figure 14). The trends in overlapping year-classes in periods 1 and 2 (the 1969-73 year-classes) were quite different, the latter indicated a rapid increase where the former was stable. This likely due to the differences in age effects (Figure 13). For the year-classes 1974-78, the estimates from period 2 decreased while those from period 3 increased. However, the absolute differences were smaller in comparison to the other comparisons. Where the estimates for the 1979-83 year-classes from period 3 declined substantially, the estimates for these year-classes from period 4 showed a slight increase.

A comparison of mean age by stratum between time periods indicates that the cod were younger in all strata during the 1971-75 period (Figure 15). In subsequent years, there was little variation in mean age in individual strata. There was also a tendency for older cod to be found in the deeper strata.

SPA for 4VsW cod has not been accepted for assessment purposes in recent years due to a strong retrospective pattern. However, Fanning and MacEachern (1991) present the results of an illustrative SPA. We compared the antilogs of the four series of year-class estimates presented in Figure 12 with their age 3 SPA population estimates. The highest correlation was with the index calculated including 3 time periods (1971-75, 1976-80, 1981-91) and with the observations weighted by strata area.

Index	4 Periods Wtd.	3 Periods Wtd.	4 Periods Unwtd.	No Periods Wtd.
Correlation (r)	0.494	0.850	0.286	0.761

We favored the three period weighted analysis. The use of strata areas as weights was justified due to the strong influence of the catch in one small strata in 1989 on the year-class estimates. We also favored the use of three time periods instead of four due to the similarity of the trend in age effects from the separate analyses for periods three and four and the uncertainty in interpreting the different trends in age effects in the combined analysis when four periods were used. The fact that the year-class estimates from the three period analysis gave the highest correlation with SPA also supported this choice.

The analysis of variance from the multiplicative analysis using the above structure is given in Table 3. The model explained 72% of the variance. The regression between model estimates of year-class strength and those from SPA is shown in Figure 16 and the basic data are given in Table 5.

Model estimates of year-class strength for 4TVn and 4VsW are highly correlated (R^2=0.49, P<0.0001). The dynamic range (i.e. range in log scale) is higher for 4TVn cod (Figure 17). The peaks in strong year-classes correspond between stocks.

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. Normally we reserve age-structured analysis for commercial catch -at-age data. However, there is no reason not to apply this or other age-structured techniques to RV data given that the annual surveys give sequential estimates of the same year-classes. The addition of parameters for strata and strata-age interactions provided information on the spatial distribution of the fish. However, multiplicative models such as this one assume that main effects are proportional across the time series. These assumptions may be restrictive and require confirmation. We found that by breaking the time series into several shorter analyses and comparing the relevant parameter estimates provides useful diagnostics. It may also be possible to introduce year-class*stratum interaction terms to investigate possible density-dependent distribution hypotheses.

A significant shift in the mortality schedule of both cod stocks was noted in by analyzing separate temporal models. The age effects varied among the different time periods (Figure 2, 13). This change corresponded to changes in the exploitation of the resource, that is high F in the early 1970's, increased mesh size in the early 1980's, and reduced growth rates in the 1980's. These changes were accounted for in the model by the addition of age*time period interactions.

A shift in the relative age composition among strata was also noted for the 4TVn stock, with the eastern strata showing a lower mean age in the early 1970's than in the other three periods. Swain and Wade (in press) noted a shift in distribution of cod toward the eastern strata with the increase in abundance of the stock in the 1980's and suggested that this may be due to density-dependent habitat selection. For this to affect the age composition, it would require a greater expansion of distribution of older cod. Another possible explanation is differential spatial exploitation of the stock between the periods. Templeman (1962), in summarizing his and other authors' work on cod stock definition, noted that there may be as many as five stock components in the southern Gulf. As indicated in Figure 18, the proportion of the total stock catch taken from 4Vn in winter was the highest during the early 1970's. If indeed there are several stock components in the southern Gulf, and if the 4Vn winter fishery exerts relatively higher exploitation on the eastern components, this could lead to a lower than average mean age in the eastern strata in the early 1970's. Further investigation of this question is warranted. This suggests a departure from the proportional distribution assumption of the model for the earliest time period. No attempt was made to correct for this. However, it is not expected that this will have a significant impact on the year-class parameters estimated for the entire time period.

Overall, the year-class estimates from the 4TVn surveys were robust to the model formulation. The inclusion of age*time period interaction terms produced higher estimates of the 1960's year-classes. The use of strata area in a weighted regression had little effect on the year-class estimates. Model estimates of year-class strength compared favorably to those from SPA. In fact, it was found that in the case of the 1984 year-class, the model gave a more consistent estimate than the SPA. The relationship is suitable for year-class prediction for catch projections as well as for checking calibrated estimates from SPA. Using the multiplicative model, two additional year-class estimates are available for projections.

In the case of 4VsW cod, the year-class estimates were sensitive to the model formulation. Different options of time period and observation weighting were attempted. Unweighted regression produced an increasing trend in year-class size due mainly to recent high catches in a relatively small strata (i.e.. stratum 63). The year-class estimates from the unweighted model had the lowest correlation with SPA estimates of year-class strength. Thus, the use of strata areas as weights seems appropriate for this stock. The age parameters may not be well estimated. If four time periods are included in the model and the age effects are estimated for a standard year-class, the effects reach different maxima. This suggests that the year-classes included in the last analysis were not as available to the survey as those included in the earlier analyses. However, it may also be that the fits are relatively weak and the age effects may be confounded with other parameters, such as those describing the spatial distribution. The last two time periods were combined to overcome this problem. However, it is not clear what has caused this problem and further work is needed.

Overall, we find that such models provide a relatively simple method for obtaining stock assessment parameters and information on spatial distribution from research survey 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 four multiplicative model of year-class, stratum, age and stratum*age effects on the mean catch per tow of 4TVn cod.

Period 1971-75

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	134	556.7	4.15	4.79	0.0001
Error	495	429.0	0.87		
Total	629	985.7			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	9	47.6	5.29	6.10	0.0001
STRAT	20	301.5	15.07	17.39	0.0001
AGE	5	94.7	18.94	21.86	0.0001
STRAT*AGE	100	131.1	1.31	1.51	0.0024

Period 1976-80

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	134	1030.7	7.69	9.09	0.0001	.72
Error	483	408.5	0.85			
Total	617	1439.2				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	9	213.6	23.73	28.06	0.0001
STRAT	20	463.9	23.20	27.43	0.0001
AGE	5	112.5	22.49	26.60	0.0001
STRAT*AGE	100	157.9	1.58	1.87	0.0001

Period 1981-85

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	134	969.0	7.23	7.92	0.0001	.69
Error	477	435.8	0.91			
Total	611	1404.9				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	9	43.5	4.83	5.28	0.0001
STRAT	20	634.4	31.72	34.72	0.0001
AGE	5	80.4	16.09	17.61	0.0001
STRAT*AGE	100	202.4	2.02	2.22	0.0001

Period 1986-91

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	135	1086.6	8.05	11.37	0.0001	.72
Error	602	426.2	0.71			
Total	737	1512.8				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	10	84.4	8.44	11.92	0.0001
STRAT	20	564.7	28.23	39.88	0.0001
AGE	5	106.0	21.20	29.94	0.0001
STRAT*AGE	100	240.2	2.40	3.39	0.0001

Table 2: Analysis of variance results from a multiplicative model of the mean catch per tow of cod from the southern Gulf of St. Lawrence for the period 1971-1991.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	168	3694.3	21.99	21.93	0.0001	.60
Error	2429	2435.9	1.00			
Total	2597	6130.1				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	25	340.7	13.63	13.59	0.0001
STRAT	20	1431.9	71.59	71.39	0.0001
AGE	5	390.0	77.99	77.77	0.0001
STRAT*AGE	100	577.2	5.77	5.76	0.0001
AGE*PER	18	78.3	4.35	4.34	0.0001

Table 3: Year class parameter estimates from a multiplicative analysis of southern Gulf of St. Lawrence cod RV results. The ln parameter estimates are given in column 2, the standard deviation of the regression

Year class	Ln Predicted	Standard error of Mean	Standard error of predicted	Adjusted Index (N per Tow)	Age 3 from 1991 SPA $*10^{-6}$	Predicted year-class $*10^{-6}$
64	4.062	0.429	1.089	87.471		
65	3.938	0.389	1.074	78.549		
66	3.619	0.372	1.068	57.481		
67	3.334	0.362	1.065	43.363		
68	3.510	0.354	1.062	51.846	88.303	
69	2.802	0.344	1.059	25.646	34.345	
70	3.071	0.339	1.057	33.620	46.385	
71	3.224	0.334	1.056	39.228	52.872	
72	3.295	0.329	1.054	42.185	42.096	
73	4.204	0.323	1.052	104.898	118.469	
74	4.706	0.312	1.049	173.977	166.615	
75	4.868	0.307	1.048	204.799	161.455	
76	4.559	0.302	1.046	150.689	113.965	
77	4.658	0.296	1.044	166.554	113.741	
78	4.451	0.290	1.042	135.684	91.260	
79	5.033	0.277	1.039	243.650	190.457	
80	5.267	0.271	1.038	308.587	249.154	
81	4.827	0.266	1.036	198.839	136.091	
82	4.814	0.261	1.035	196.681	135.550	
83	4.467	0.252	1.033	139.374	116.211	
84	4.194	0.249	1.032	106.129	103.809	
85	4.001	0.250	1.032	87.421	108.245	
86	4.118	0.253	1.033	98.249	114.720	
87	4.475	0.259	1.034	140.171		120.192
88	3.680	0.272	1.038	63.094		70.575
89	3.683	0.334	1.056	62.066		69.914

Table 4: Analysis of variance results of a multiplicative analysis of mean numbers per strata at age 2-7 for 4VsW cod RV results. Model parameters included age, strata, strata*age, and time period*age. Time periods were 1971-75, 1976-80, 1981-91.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	156	3063089.9198	19635.1918	17.71	0.0001
Error	2363	2620320.2114	1108.8956		
Corrected Total	2519	5683410.1312			

	R-Square	C.V.	Root MSE	CATCH Mean
	0.538953	4898.327	33.300084	0.6798256

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YC	25	171551.4132	6862.0565	6.19	0.0001
STRAT	19	1651854.5074	86939.7109	78.40	0.0001
AGE	5	158967.8512	31793.5702	28.67	0.0001
STRAT*AGE	95	476760.2629	5018.5291	4.53	0.0001
AGE*PERIOD	12	78210.8064	6517.5672	5.88	0.0001

Table 5: Year class parameter estimates from a multiplicative model of 4VsW cod RV results. The model included three time periods and the observations were weighted by strata areas. These were regressed on SPA age 3 population estimates (from Fanning and MacEachern, Res. Doc. 91/44)

Year class	LS Mean	exp(LS Mean)	SPA age 3 ('000)	Prediction ('000)
64	0.931	2.538		
65	0.692	1.997		
66	0.729	2.072		
67	0.206	1.229		
68	0.495	1.640	57749	
69	0.035	1.035	44405	
70	0.078	1.082	41011	
71	0.062	1.064	34193	
72	0.237	1.267	33903	
73	0.483	1.622	41169	
74	0.769	2.157	53355	
75	0.549	1.732	47206	
76	0.338	1.401	44537	
77	0.592	1.807	68439	
78	0.618	1.856	60877	
79	0.745	2.107	70972	
80	0.915	2.498	76102	
81	0.581	1.788	43953	
82	0.588	1.801	43173	
83	0.123	1.130	18593	
84	0.167	1.181	21000	
85	0.156	1.169	27782	
86	0.353	1.423	43424	
87	0.683	1.980		58525
88	0.246	1.279		37106
89	0.127	1.136		32737

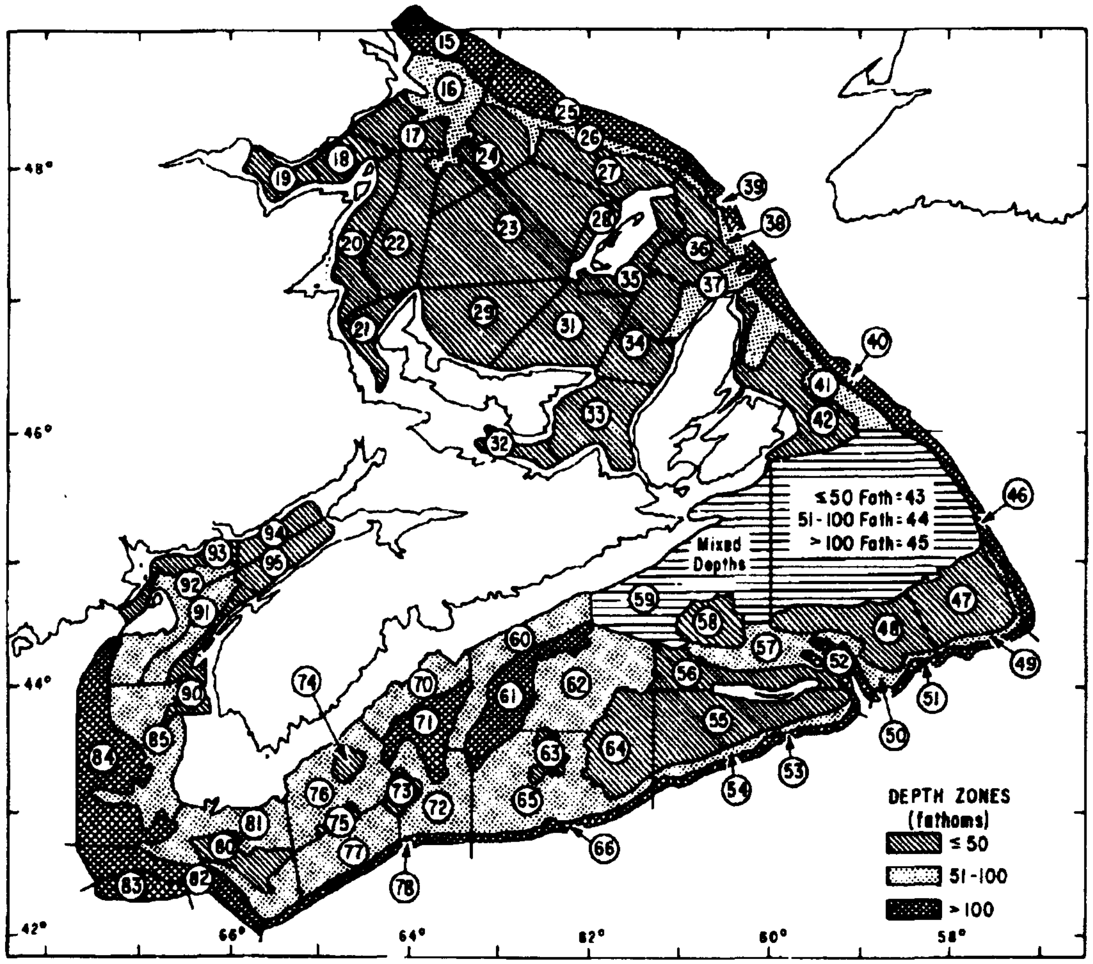


Figure 1: Stratification scheme of the southern Gulf of St. Lawrence and Scotian Shelf groundfish surveys.

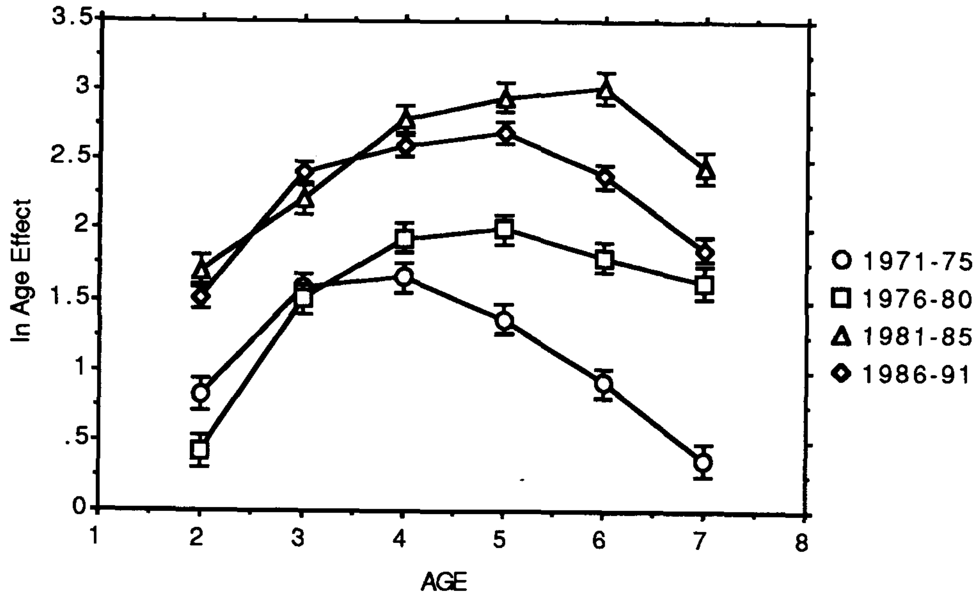


Figure 2: Least squares estimates of age effects from four separate time periods.

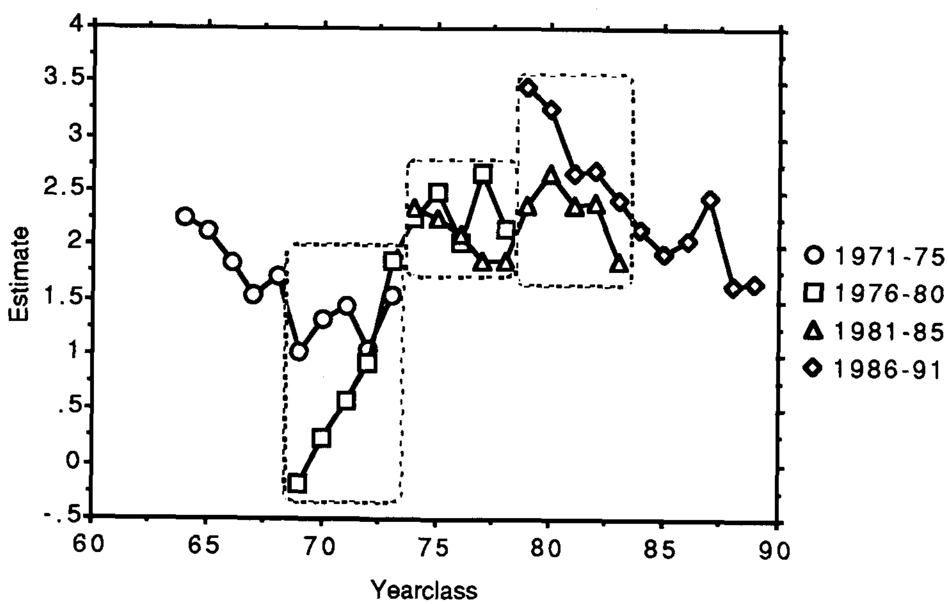
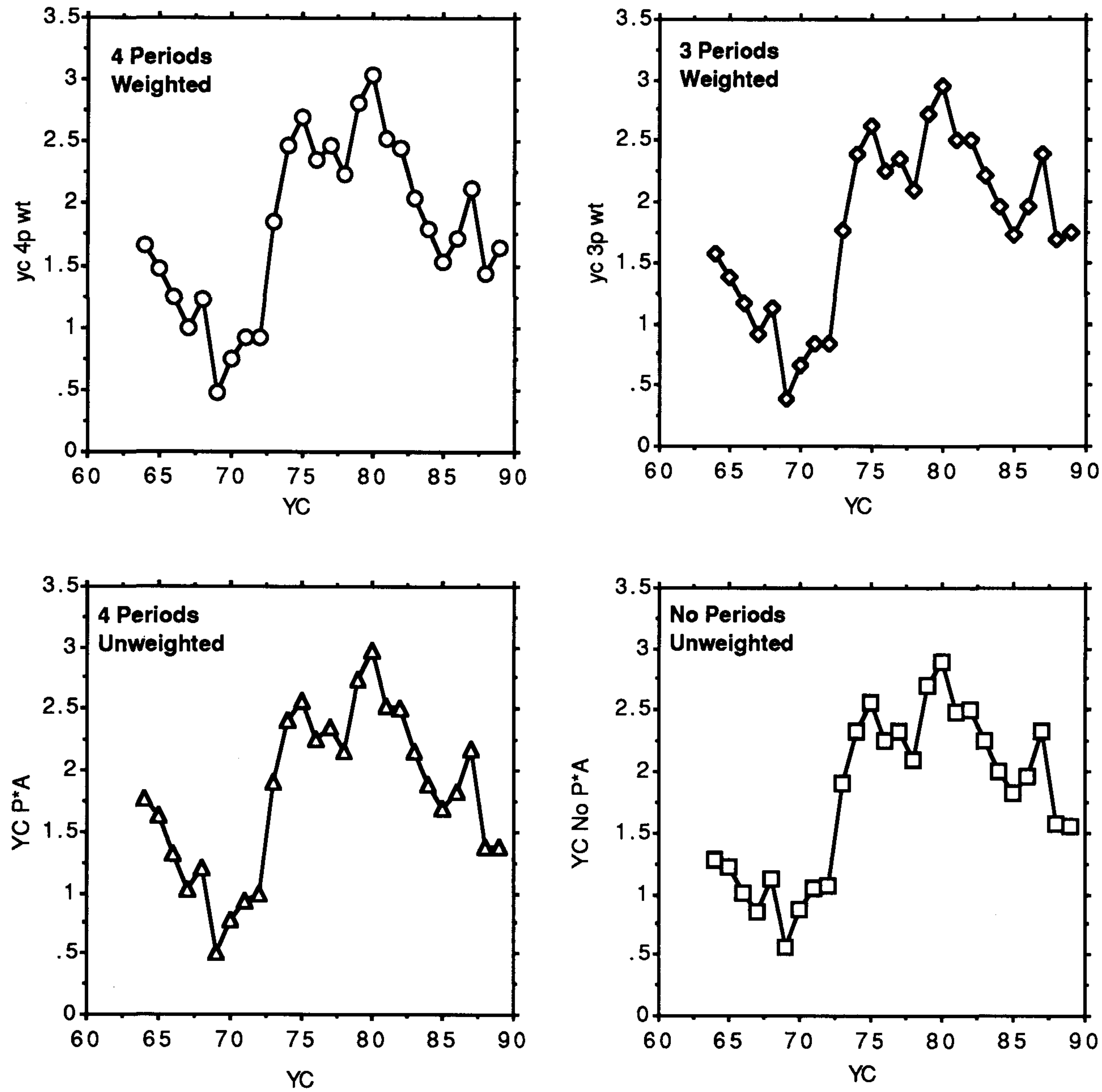


Figure 3: Ln year-class estimates from four separate analyses. The boxes indicate independent estimates of year-classes from different time periods.



Correlation Matrix for Variables: $X_1 \ldots X_4$

	yc 4p wt	yc 3p wt	YC P*A	YC No P...
yc 4p wt	1			
yc 3p wt	.982	1		
YC P*A	.990	.979	1	
YC No P*A	.967	.983	.967	1

Figure 4: Comparison of year-class estimates for 4TVn cod under different model assumptions regarding the time periods used and weighting by strata areas.

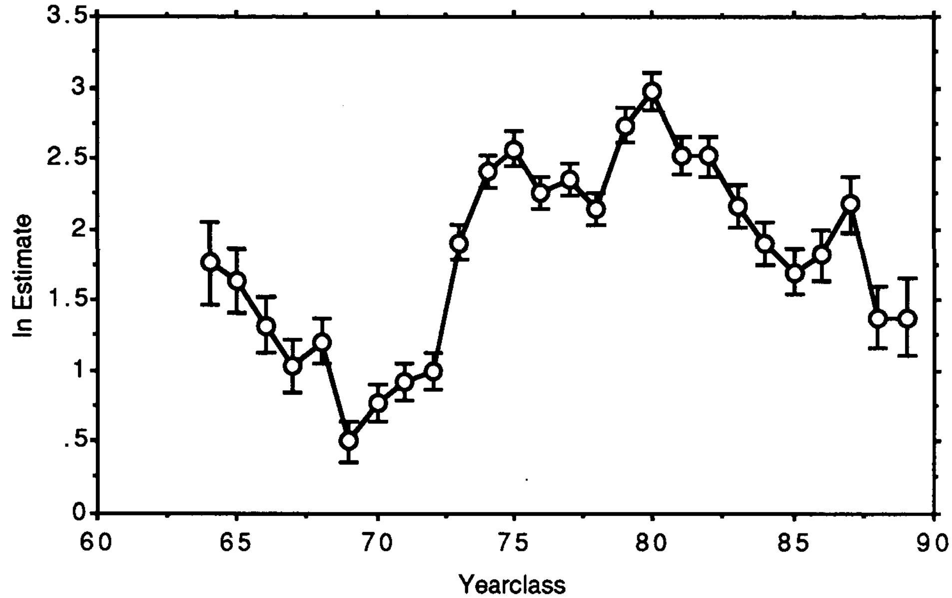


Figure 5: Least squares estimates of year-class effects from a multiplicative analysis of RV catch at age. Vertical bars give 1 standard error.

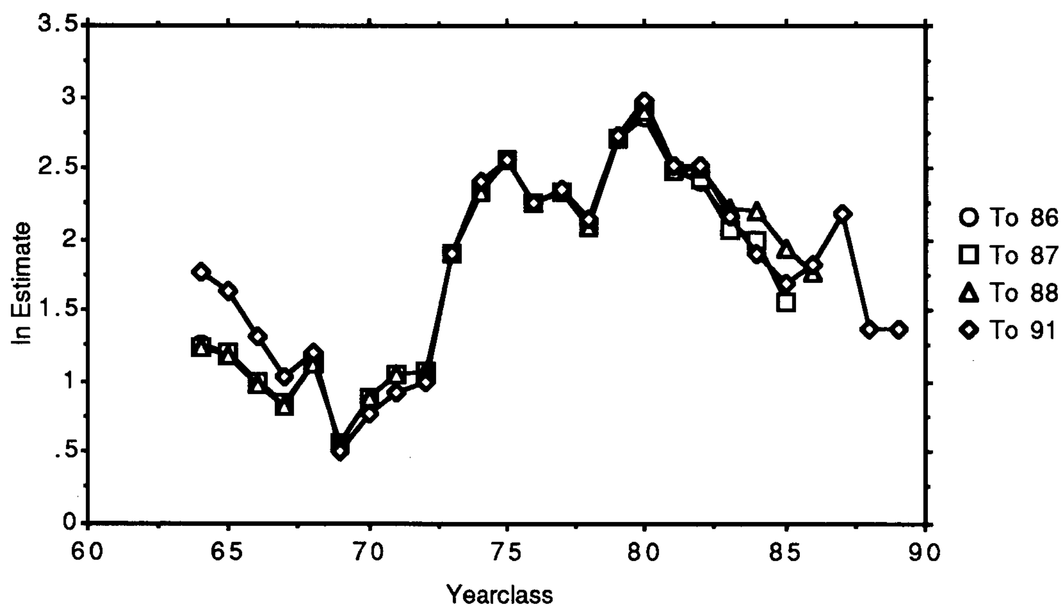


Figure 6: Comparison of year-class estimates from RV data sets of different lengths. The legend indicates the last year included in the analysis

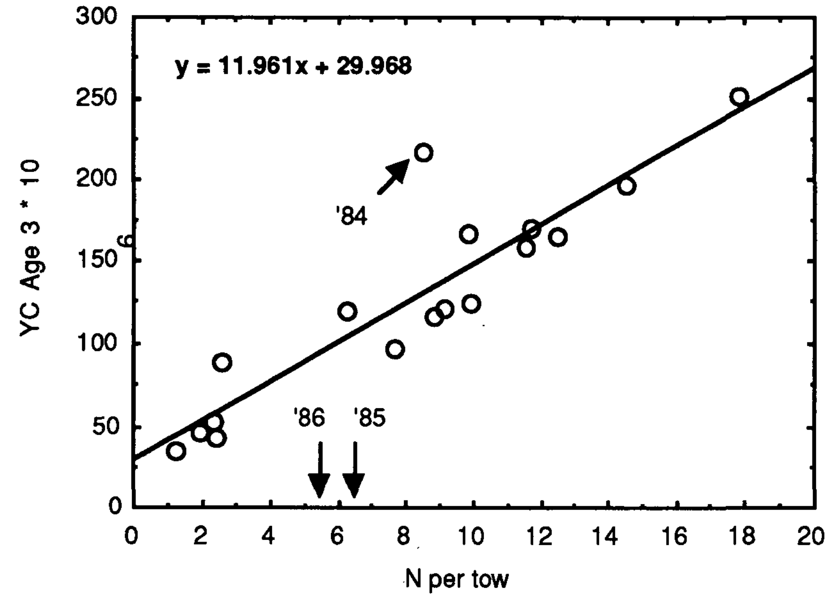


Figure 7: Comparison of SPA age 3 year-class estimates for 4TVn cod and those obtained from a multiplicative analysis of RV catch at age. The SPA contained estimates of the 1968 to 1984 year-classes. The model estimates of the 1985 and 1986 year-classes are shown on the x-axis.

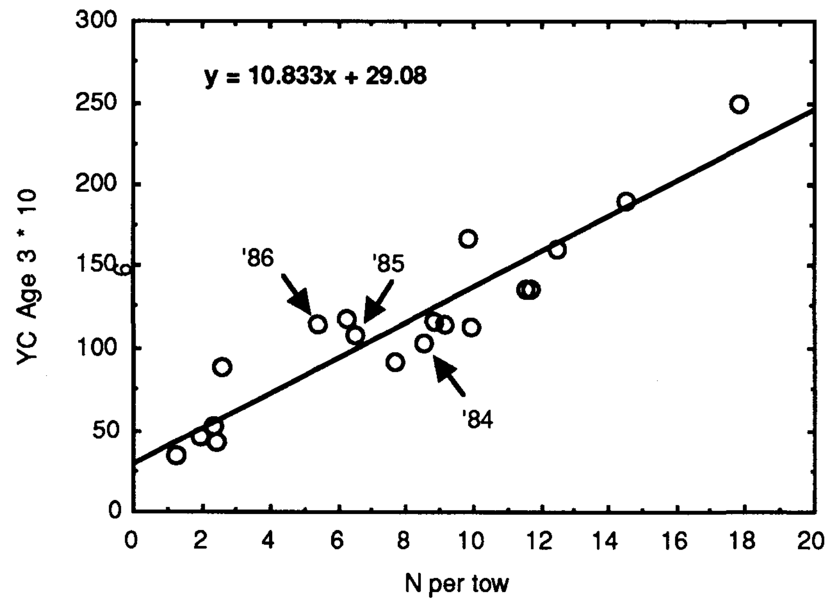


Figure 8: Comparison of SPA age 3 year-class estimates for 4TVn cod and those obtained from a multiplicative analysis of RV catch at age. The SPA contained estimates of the 1968 to 1986 year-classes. The points for the 1984-86 year-classes are labeled for comparison to Figure 7.

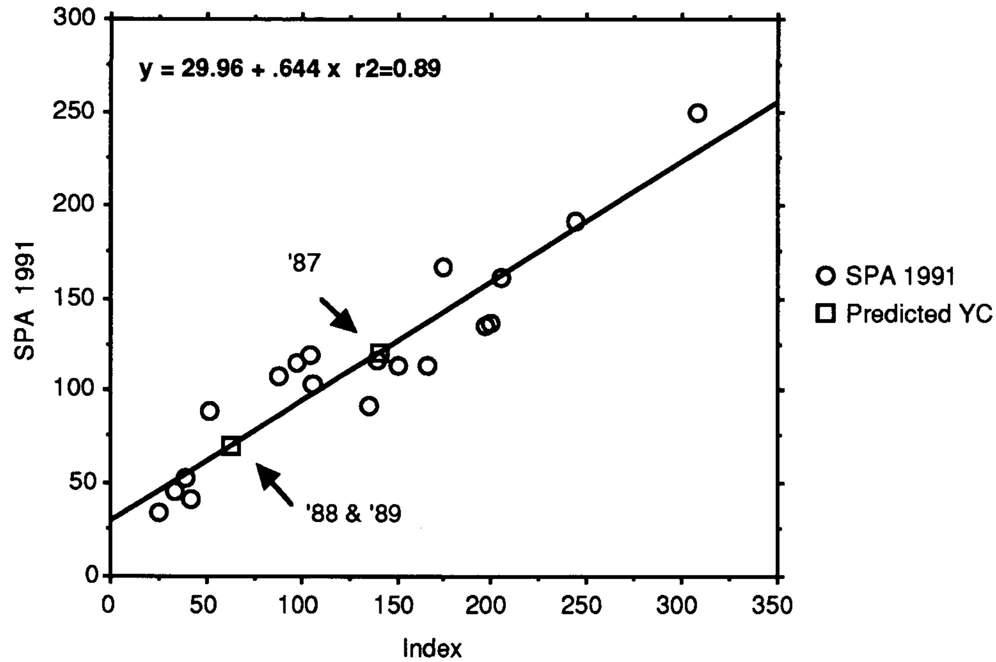


Figure 9: Regression of SPA age 3 year-class size on multiplicative model estimate of year-class size. The position of the predicted sizes of the 1987-89 year-classes is indicated.

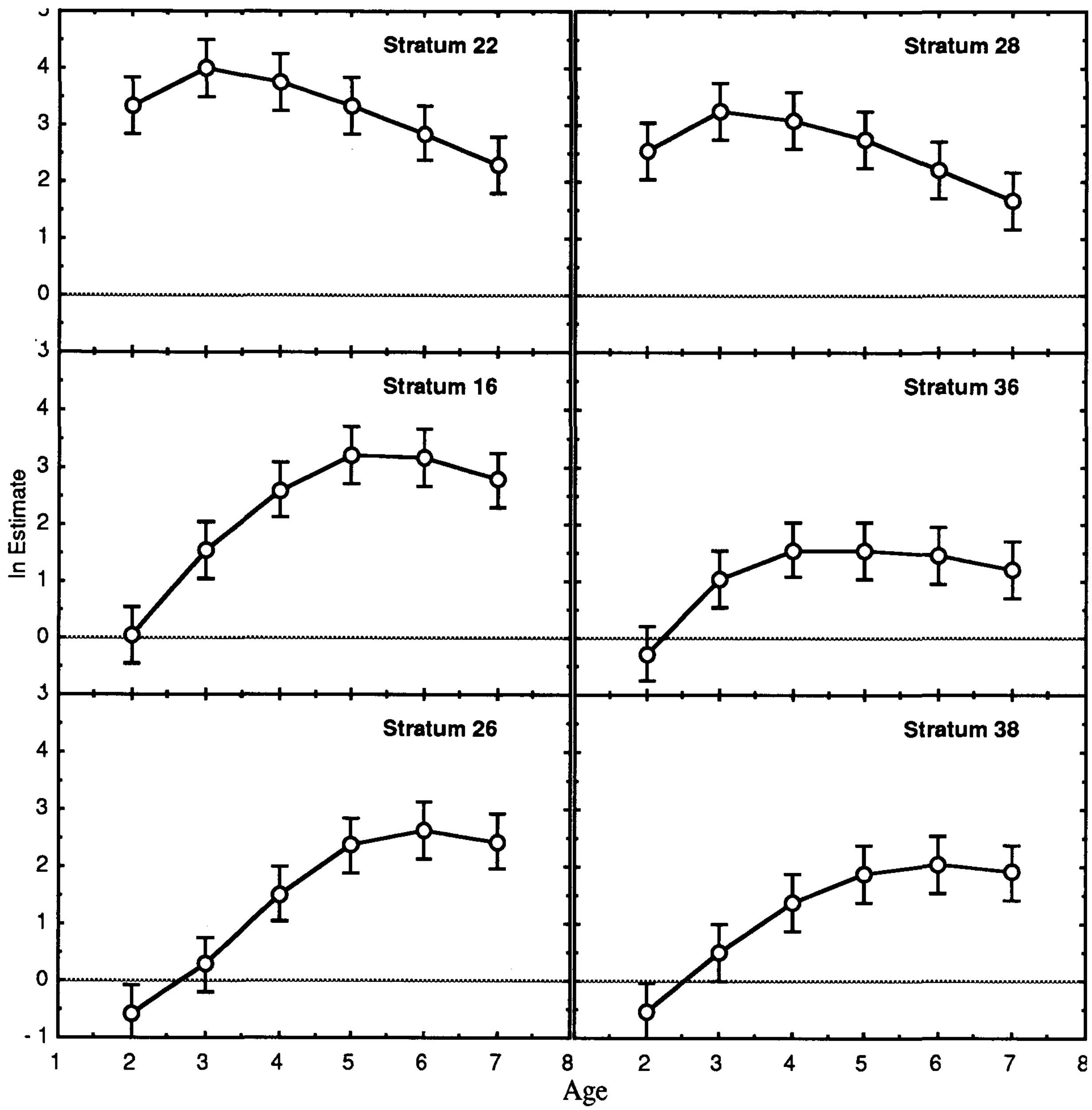


Figure 10: Least squares means estimates of the mean catch per tow at age and per stratum from a multiplicative analysis of RV data. Vertical bars give two standard errors of the estimates.

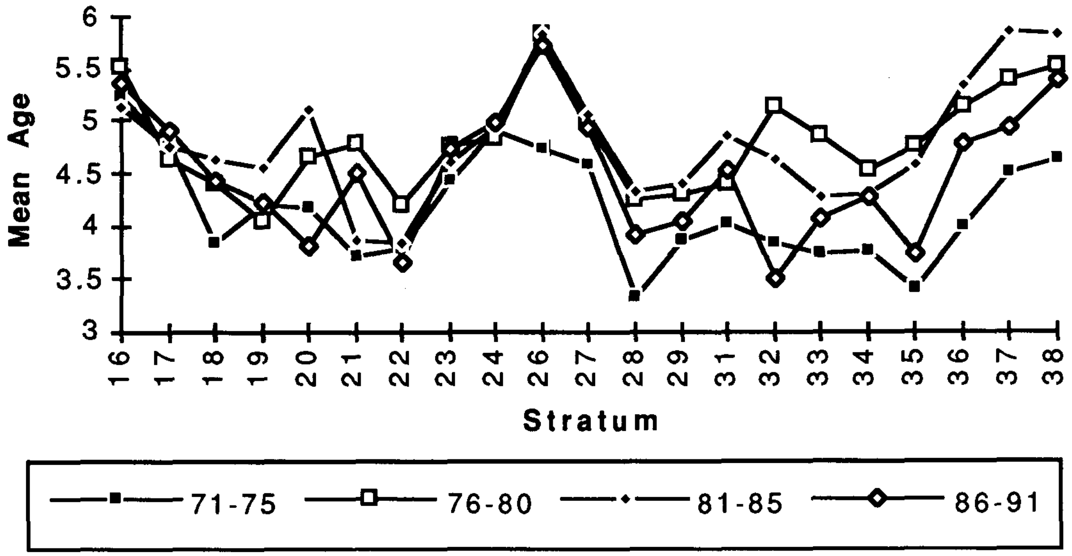
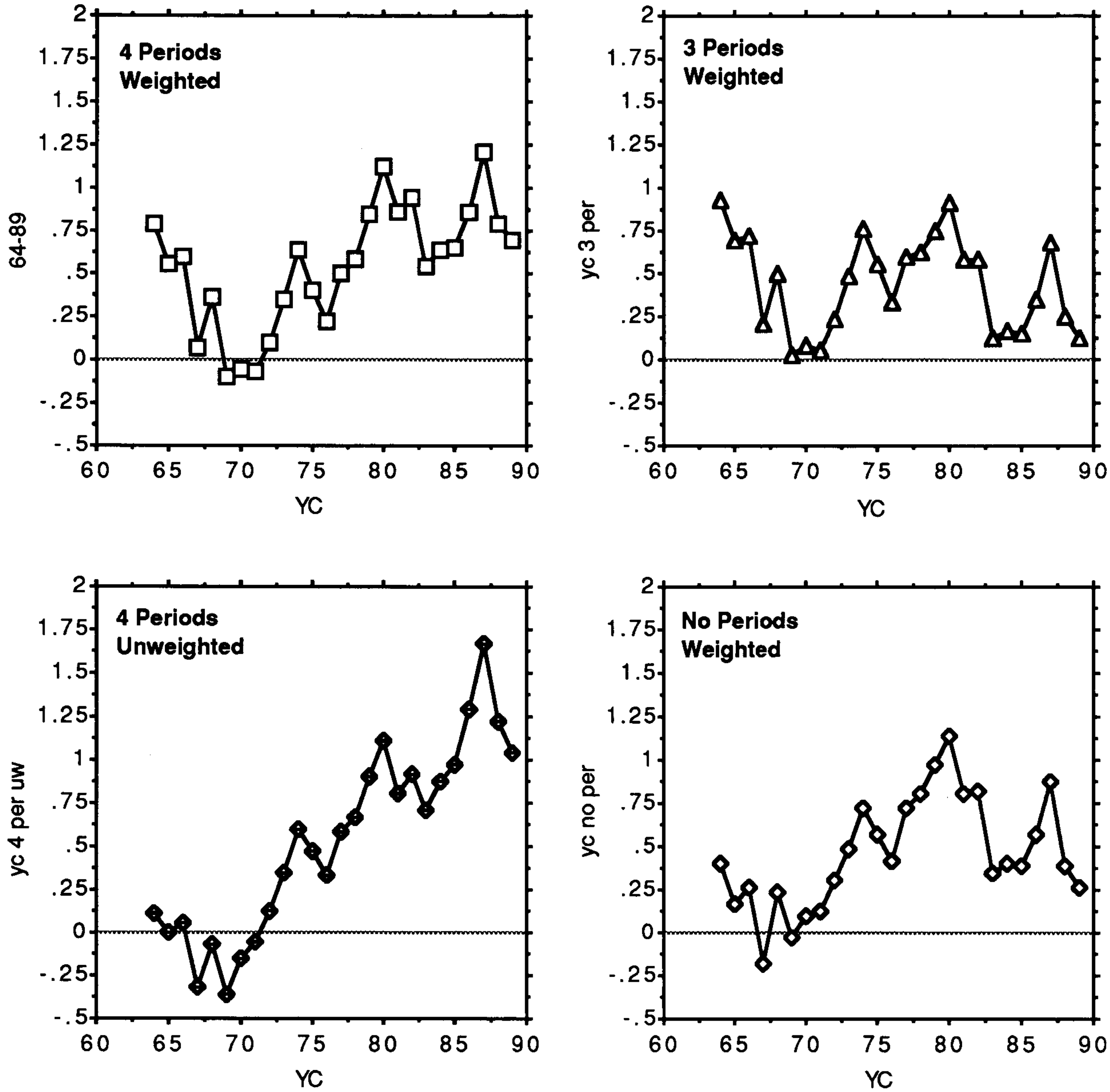


Figure 11: Comparison of mean age per stratum for four separate analyses of southern Gulf cod RV data. The time periods of the analyses are shown in the legend.



Correlation Matrix for Variables: X_1 ... X_4

	64-89	yc 3 per	yc 4 per...	yc no per
64-89	1			
yc 3 per	.621	1		
yc 4 per uw	.835	.209	1	
yc no per	.767	.670	.718	1

Figure 12: Comparison of year-class estimates for 4VsW cod under different model assumptions regarding the time periods used and weighting by strata areas.

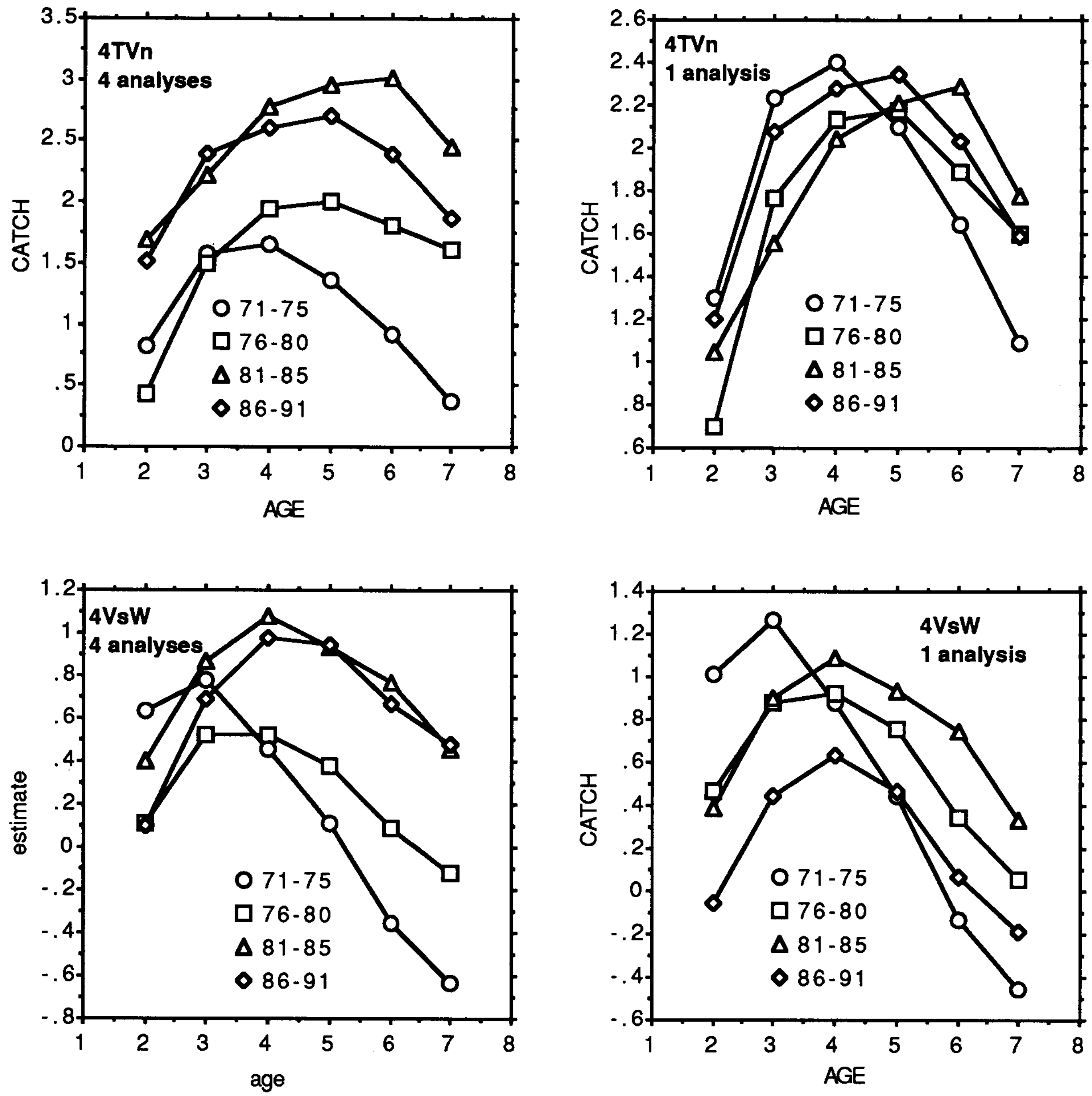


Figure 13: Estimated age effects from multiplicative analyses of 4TVn and 4VsW cod RV catch at age. The age effects were estimated either in four separate blocks (4 analyses) or in single analyses where period*age interaction terms were used in the model.

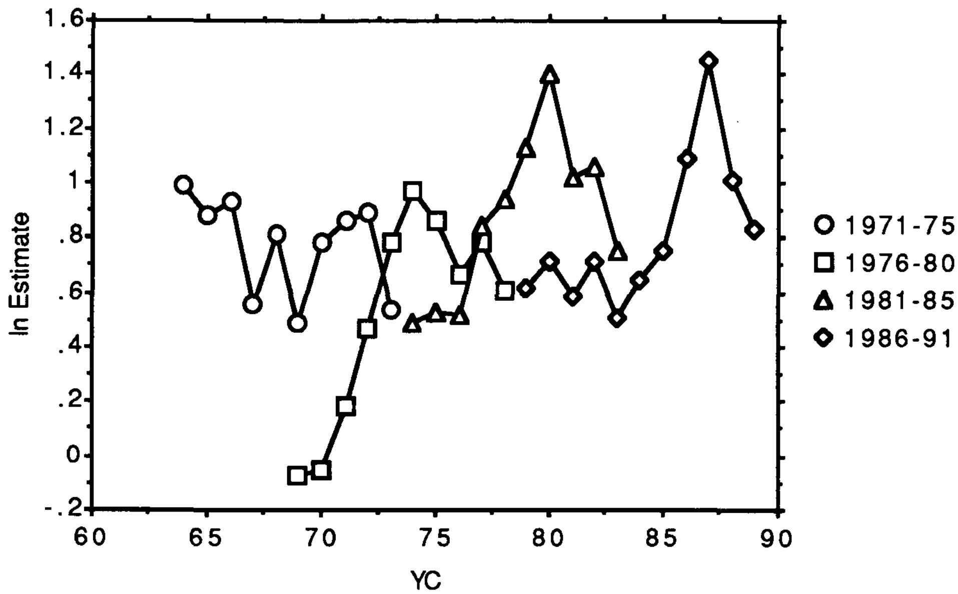


Figure 14: Ln year-class effects from four separate analyses of the 1971-1989 4VsW cod summer survey results.

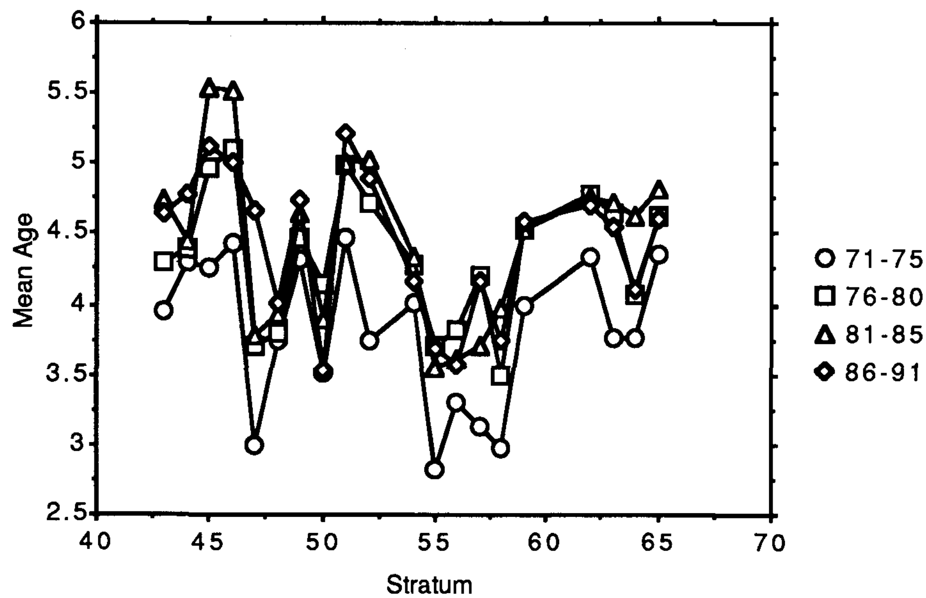


Figure 15: Comparison of estimated mean age per strata from four separate analyses of the 4VsW cod RV data.

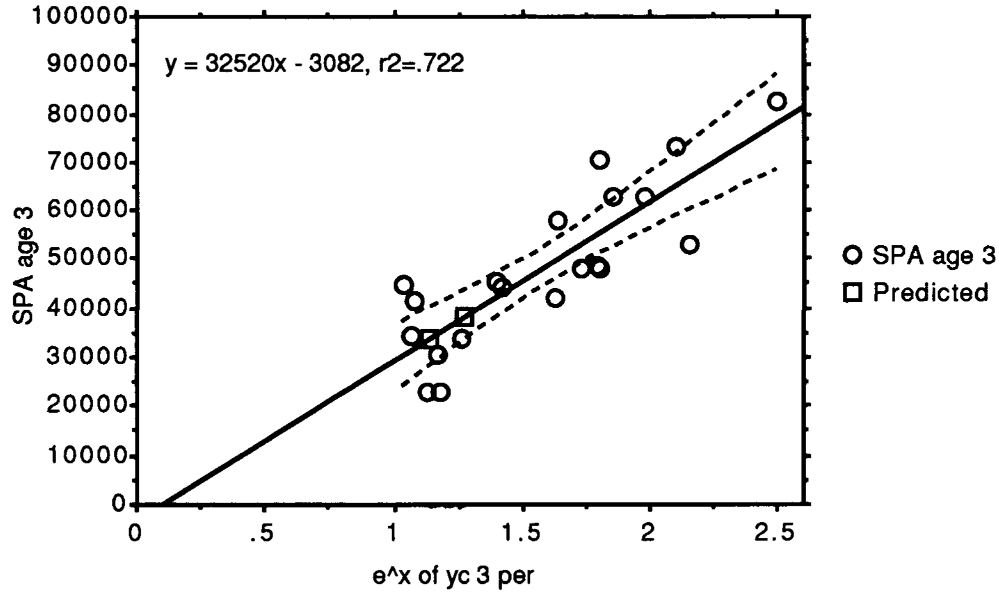


Figure 16: Regression of SPA age 3 numbers on the antilog of yearclass effects from a weighted model using 3 time periods.

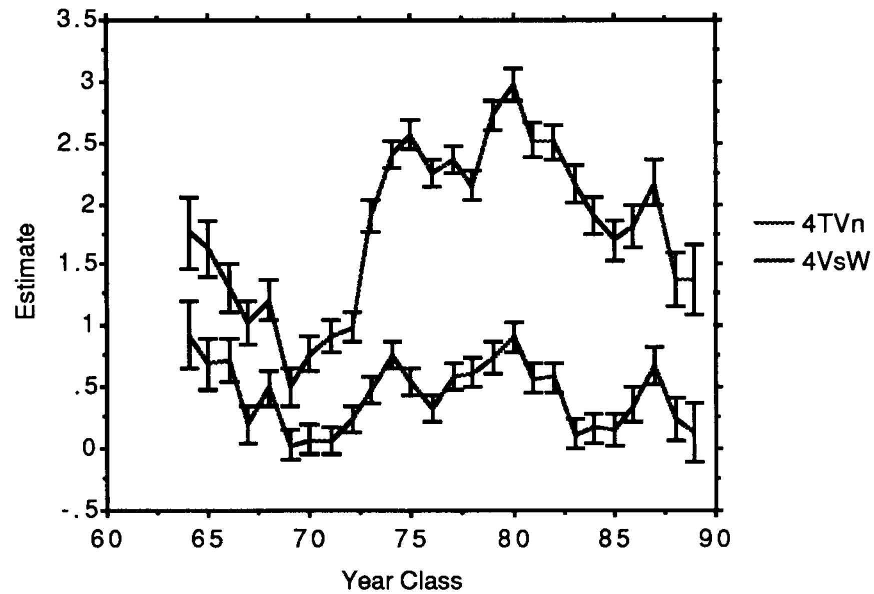


Figure 17: Comparison of yearclass estimates from the 4VsW and 4TVn cod surveys.

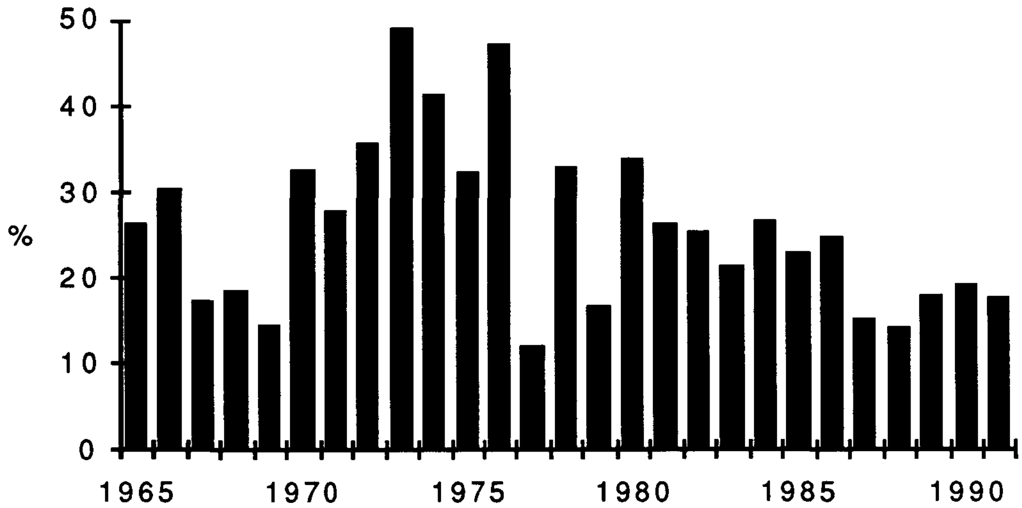


Figure 18: Percent of the total 4TVn (J-A) catch taken in Subdiv. 4Vn.

Annex 1: Sample SAS program used to calculate multiplicative model.

```
options linesize=80;
libname z v5 '[a_sinclair.rv.crv]';
data one;
 set z.rvmn7191;
 if strat gt 415 and strat ne 425 and strat ne 439;
 if 71 <= year <= 75 then period = 1;
 if 76 <= year <= 80 then period = 2;
 if 81 <= year <= 85 then period = 3;
 if 86 <= year <= 91 then period = 4;
 flag = '1';

/* Add dummy observations for standard yearclass estimates */
data add;
 do yc = 64 to 89;
  catch = .;
  flag = '0';
  period = 4;
  strat = 422;
  age = 3;
  output;
 end;

proc append base=one new=add force;

proc glm data=one;
 class yc strat age period;
 model catch=yc strat age period strat*age period*age/;
 lsmeans yc strat*age period*age/s;
 output out=res1 p=yhat r=res stdp=stdmean stdi=stdval;

proc plot data=res1;
 plot res*(yhat strat yc)=age;
 plot res*age;

proc univariate data=res1 plot normal;
 var res;

/* Retransform yearclass estimates for standard */
data out;
 set res1 (where=(flag = '0'));
 value=exp(yhat+0.5*stdval*stdval-stdmean*stdmean);
 stderror=value*sqrt(1-exp(-stdmean*stdmean));
 keep yc strat age period yhat value stdmean stdval;

proc print;
```