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Year-class effects in 3Ps cod catch and index data

Effets de classes d'âge dans les données sur l'indice d'abondance et les prises de morue de 3Ps

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ABSTRACT

Age-disaggregated catch and population index data contain information on recruitment (number of young at an initial age) and the cumulative effects of mortality. In this research document these two effects in combination are considered to comprise the year-class effect. Methods exist for disentangling these two effects from survey and catch data e.g. Adaptive Framework for Sequential Population Analysis (ADAPT), but where such methods have not been applied for some reason, there is still value in looking at the combined effect within a data series and between data series. If recruitment is low and/or mortality is high, the year-class effect will be diminished. Significant year-class effects were found in all indices and the commercial catch data available for assessing the 3Ps cod stock. In addition, year-class effects are coherent across most data sets. Most of the data support a conclusion of a diminished year-class effect in the recent period, likely through some combination of poor recruitment and/or heavy fishing. Simulation results indicate that significant year-class effects are unlikely to be generated or obscured by random error, unless the effect is small and the error is large. Failure to achieve a quantitative assessment of 3Ps cod in 2006 led to provision of qualitative advice. This advice is likely to have less impact on decision-making than an accepted quantitative assessment. Although Virtual Population Analysis (VPA) based methods such as ADAPT may provide unsatisfactory fits to 3Ps cod data, significant and coherent year-class effects suggest that this is a relatively information-rich stock and if ADAPT fits are not satisfactory, alternative quantitative assessment approaches should be urgently considered.

RÉSUMÉ

Les données sur l'indice d'abondance et les prises désagrégées à l'âge contiennent de l'information sur le recrutement (nombre de jeunes à un âge initial) et sur les effets cumulatifs de la mortalité. Dans le présent document de recherche ces deux effets sont étudiés en association pour mesurer l'effet de classes d'âge. Il existe des méthodes permettant de dissocier ces deux effets dans les données des relevés et des prises, p. ex. le cadre adaptatif pour l'analyse séquentielle de population (ADAPT), mais là où ces méthodes n'ont pas été appliquées pour quelque raison, il demeure intéressant d'examiner l'effet combiné dans une série chronologique et entre les séries chronologiques. Si le recrutement est faible et que la mortalité est élevée, l'effet de classes d'âge est amoindri. On trouve des effets de classes d'âge marqués dans tous les indices d'abondance et les données sur les prises commerciales disponibles pour l'évaluation du stock de 3Ps. De plus, ces effets sont cohérents pour presque tous les ensembles de données. La plupart des données appuient la conclusion relative à une baisse de l'effet de classes d'âge au cours de la récente période, vraisemblablement due à une combinaison de faible recrutement et(ou) de forte exploitation. Les résultats des simulations montrent qu'il est peu probable que des effets de classes d'âge soient produits ou masqués par une erreur aléatoire, à moins que l'effet ne soit faible et l'erreur, importante. L'incapacité de réaliser une évaluation quantitative de la morue de 3Ps en 2006 a mené à la formulation d'une évaluation qualitative. Cet avis a généralement moins d'incidence sur la prise de décision qu'une évaluation quantitative approuvée. Bien que les méthodes basées sur l'analyse des populations virtuelles (APV) comme ADAPT puissent fournir des résultats peu satisfaisants pour les données sur la morue de 3Ps, d'importants effets de classes d'âge cohérents semblent indiquer qu'il s'agit là d'un stock relativement riche en information et que si l'application d'ADAPT n'est pas satisfaisante, d'autres méthodes d'évaluation quantitative devraient être envisagées de façon pressante.

INTRODUCTION

Age-disaggregated catch and population index data may contain information on recruitment (number of young at an initial age) and the cumulative effects of both fishing and natural mortality, but will also contain variability arising from a number of non-informative sources. The combination of initial recruitment and subsequent mortality is referred to in this paper as the "year-class effect". Analysis of variance assuming lognormal multiplicative errors provides one approach for investigating the components of variation in age-disaggregated data, including the year-class effect (Gavaris 1980; Shepherd and Nicholson 1991). One model that may be fit has two categorical (class) variables, age and year-class. The age effect comprises a combination of selectivity at age by the sampling gear or fishery and cumulative survival to age resulting from natural mortality and fishing mortality. The year-class effect is expected to relate to the average contribution of the year-class or cohort in the population over the period of its lifespan for which data are available – a combination of initial recruitment and subsequent mortality not captured by the average age effect.

Fishing mortality may vary considerably as a consequence of management actions and changes in stock size under constant quotas or lagged reductions in quotas during stock declines. Cumulative mortality that is greater than or less than that predicted by an average age effect will alter the estimate of the relative year-class effect in the model. This is illustrated with a simple simulation. Generally only the younger ages (before recruitment to the fishery) are used if estimation of relative recruitment strength is the objective, because the recruitment signal gets increasingly confounded by cumulative mortality effects as a cohort ages. However, these cumulative mortality effects are of potential interest too in terms of the overall presence of the year-class in the population over its lifespan, particularly in the absence of a quantitative assessment model that teases apart the effects of recruitment and mortality. In this study the entire age range of the cohort for which data are available is therefore examined to determine the year-class effect.

Errors associated with estimates of year-class effects are considered to arise from variability in both year effects and age effects. Strong year effects commonly exist in indices for 3Ps cod. The usefulness of year-class effects models is that they average out this source of variability to some extent. Despite variability in year and age effects, significant year-class effects are commonly found in indices and catch data for groundfish stocks. We show that this is also the case for five abundance index series and catch data for 3Ps cod off the southern coast of Newfoundland (St. Pierre Bank and surrounding area). Cross-correlation is used to show that several of the indices are coherent in terms of their information regarding relative year-class effects. We examine whether year-class effects could be generated spuriously from variability not associated with changes in year-class strength or cumulative mortality. Our null model is that there is no variability in initial recruitment or subsequent mortality. We introduce random error in a simulation model and analyse the resulting data for significant spurious year-class effects to determine the probability of incorrectly rejecting the null hypothesis (Type I error). We also examined the statistical power of the model to correctly detect year-class effects when they do exist, or alternatively, failing to reject the null hypothesis when it ought to be rejected (Type II error).

METHODS

Four different analyses, three using simulation and one empirical, were undertaken in the following order: (i) effects of changes in recruitment and subsequent mortality on perceived magnitude of the year-class effect estimated using general linear models (GLM; simulation); (ii) year-class effect in survey index and catch data for 3Ps cod (GLM, empirical); (iii) probability of spurious year-class effects leading to incorrectly rejecting the null hypothesis (Type I error, simulation); and (iv) probability of failing to detect year-class effects when they do exist (Type II error, simulation).

EFFECTS OF CHANGES IN RECRUITMENT AND SUBSEQUENT MORTALITY ON PERCEIVED MAGNITUDE OF THE YEAR-CLASS EFFECT

A simple underlying population model was subject to constant recruitment and constant mortality, as well as change in recruitment and a change in mortality within the time period. The simulated data were analysed using PROC GLM in SAS (procedure for general linear models; SAS Institute Inc. Cary, NC, USA). Index data were generated from an underlying population model

$$N_{a+1,y+1} = N_{a,y}e^{-(M+F_yS_a)},$$

where $N_{a,y}$ is the number alive at age a (a=1 to 14) in year y (y=1 to 100), M is the instantaneous rate of natural mortality, F_y is the year specific instantaneous rate of fishing mortality and S_a is age dependent partial recruitment to the fishery (selectivity). Annual recruitment ($N_{a,y}$ when a=1) was set equal to R. A constant vector for S_a was assumed (0 0 0.01 0.04 0.13 0.34 0.68 1 0.92 1.00 0.96 0.84 0.63 0.81) based on the estimates from the “flat-topped” (referring to the F constraint on the oldest age) ADAPT obtained in the 2005 assessment of 3Ps cod and as used in projections to evaluate TAC options (Brattey et al. 2005). An index at age for each year, $I_{a,y}$, was generated as follows

$$I_{a,y} = N_{a,y}q_a$$

where q_a is the survey catchability, assumed to be a constant vector for ages 1-14 (0.000 0.051 0.065 0.061 0.075 0.123 0.119 0.111 0.179 0.012 0.021 0.023 0.023 0.023) based on q_a estimates from the flat-topped ADAPT fit to the RV index in the 2005 assessment (Brattey et al. 2005).

A GLM model model was fit to the simulated index time-series for selected periods from the 100 year simulation

$\text{Log}(I_{a,y})$ = intercept + age + year-class +error, where age and year-class are categorical effects.

Error was assumed to be additive normal on the log scale (i.e. multiplicative lognormal error before log transformation).

Four runs were carried out:

(i) constant recruitment (*R*=10) and constant mortality (*M*=0.2 and *F*=0), year-classes 1972-98 estimated;

(ii) increase in recruitment (*R*=20) for years >1990 with constant mortality, year-classes 1972-98 estimated;

(iii) constant recruitment with increase in mortality (*F*=0.2) for year>1955, else *F*=0, year-classes 1930-70 estimated;

(iv) constant recruitment with increase in mortality (*F*=0.4) for years 1956-60, else *F*=0, year-classes 1930-70 estimated.

YEAR-CLASS EFFECT IN SURVEY INDEX AND CATCH DATA FOR 3PS COD

The same form of GLM model used above was fit to each of the survey indices and the catch data sets one at a time and the year-class effects plotted. An altered version of the model was then fit to the combined data

$$\text{Log}(I_{s,a,y}) = \text{intercept} + \text{survey*age} + \text{year-class} + \text{error},$$

where subscript s = survey (or catch type) and survey*age is a survey age interaction term to account for different catchabilities at age in each survey. The following years and ages were applied: RV index 1983-2005; 1-12; AT Cameron index 1972-1982; 1-11; Sentinel linetrawl index 1995-2005; 3-10; Sentinel gillnet index 1995-2005; 3-10; GEAC index 1997-2005, 2-12; Catch 1959-2006, 1-14. Zero values were set equal to half of the minimum observed value for the individual survey or catch series. Year-classes with less than two data points were eliminated from the analysis. The number of datapoints for each remaining year-class in the combined dataset is given in Table 1. Year-classes from 1946 to 2003 have two or more data points. Year-classes in the early 1990s have maximum data, for example 37 data points for the 1992 and 1993 year-classes. Cross-correlation comparing each index/catch series with each other was carried using Pearson correlation and examining significance at $\alpha = 0.05$.

SPURIOUS YEAR-CLASS EFFECTS IN A NULL MODEL

Assuming a significance level $\alpha = 0.05$, the probability that the null hypothesis will be rejected in error when it is true, or Type I error, was determined by generating simulated data from the population model described above with *R*=0.1, *M*=0.2 and *F*=0 (i.e. no year effect) and computing the number of runs out of 1000 which had a *p*-value equal to or lower than the α-level,

Variability was introduced in the observation model in the form of two random error terms ε_y and $\varepsilon_{a,y}$ representing random multiplicative lognormal year and year*age effects respectively in the relationship between the observed index at age in year y, $I_{a,y}$, to the true population size at age in year y, $N_{a,y}$

$$I_{a,y} = e^{Log(N_{a,y} q_a) + \varepsilon_y + \varepsilon_{a,y}},$$

where ε_y ~N[μ, σ_1] and $\varepsilon_{a,y}$ ~ N[μ, σ_2], normal distributions with μ=0 and σ_1 and σ_2 set at 0.2, 0.4, 0.6 or 0.8 in separate simulations. In these analyses, q_a was set equal to the following vector (0.01 0.2 0.4 0.6 0.8 1 1 1 1 1 1 1 1 1).

The following sets of runs were carried out:

(i) random year effect: σ_1 set at 0.2, 0.4, 0.6 and 0.8, while keeping *R* fixed at 0.1, *M*=0.2 and *F*=0.

(ii) Random year*age effect: σ_2 set at 0.2, 0.4, 0.6 and 0.8, while keeping *R* fixed at 0.1, *M*=0.2 and *F*=0.

(iii) Random year effect and year*age effect: σ_1 set at 0.6 and σ_2 set at 0.6, σ_1 set at 0.8 and σ_2 set at 0.8, while keeping *R* fixed at 0.1, *M*=0.2 and *F*=0.

The probability of incorrectly rejecting the null hypothesis of no year-class effect (Type I error) was computed directly from the cumulative probability distribution for 1000 runs (i.e. the proportion of runs with *p*-value $\leq$0.05)

Power test – failing to detect a year-class effect when one is present

The power of a statistical test is the probability that the test will correctly reject a false null hypothesis. Failing to reject a false null hypothesis is Type II error. The statistical power of the GLM model applied to simulated data was tested for a range of recruitment, fishing mortality and error on year and year*age conditions. A three fold variation in which *R*~U[0.1,0.3] and an order of magnitude variation in which *R*~U[0.1,1] were considered. Variable fishing mortality was taken into account in conjunction with variation in *R* in one trial, where *F*~U[0,0.6]. Only σ_1 = 0.8 and/or σ_2 = 0.8 were considered as initial results indicated that power was high for smaller errors.

RESULTS

EFFECTS OF CHANGES IN RECRUITMENT AND SUBSEQUENT MORTALITY ON PERCEIVED YEAR-CLASS EFFECT

Figure 1 shows that the GLM model correctly detects a constant year-class effect when recruitment and subsequent mortality are constant. The model also correctly detects the increase in recruitment that occurred after the 1990 year-class. There is no estimation error in these two cases. When fishing mortality increases part way through the series, the model interprets this as a decreasing trend in the magnitude of the year-class effect (Fig. 2). If mortality decreases again this is interpreted as an increase in the estimated year-class effect.

YEAR-CLASS EFFECT IN SURVEY INDEX AND CATCH DATA FOR 3PS COD

All model fits had significant age and year-class effects ($p<0.01$) (Table 2). Age and year-class explained between 64% and 96% of the total variance. The model explained the least amount of variation with respect to the RV index which is unfortunate given that this index has the most extensive temporal and spatial coverage. The year-class effects for each index and catch are plotted in Fig. 3a-d. Year-classes reflected in the RV index were highest in the early 1970s and lowest in the 1990s (Fig. 3a). The 1989 and 1997-98 year-class effects are greatest with regard to the recent period and there is a general increasing trend in year-class effect over the period 1991-98 overlapping the moratorium, after which the year-class effect has fluctuated. Standard errors for the year-class effects (SEs) are greatest in the first four years The AT Cameron index shows an increase in year-class effect over the early 1970s. High estimates in 1974 and 1978 have large SEs. The sentinel linetrawl and gillnet indices have similar trends in year-class effects (Fig. 3b) – high in the late 1980s and decreasing through the 1990s into 2000. The decline is more pronounced with regard to the gillnet index. The GEAC index also shows a somewhat similar trend (Fig. 3c). Year-class effect estimated from the commercial catch data (Fig. 3c, expanded scale for recent period in Fig. 3d) suggests a nearly continuous decline since the late 1970s. Focusing on the more recent period, the magnitude of the year-class effect has declined to very low levels since the 1989 year-class.

The standardized year-class effect estimates are plotted together in Fig. 4 to demonstrate the fairly high degree of coherency in the data. In the recent period the RV and GEAC estimates, both of which include the St. Pierre Bank area, are higher than the inshore sentinel indices indicating some degree of spatial heterogeneity in effects. The coherency in the indices and catch data is shown more clearly by cross-correlation plots (Fig. 5). Pearson correlation coefficients are significant for all comparisons except for that between RV and ATC.

The year-class effect estimates from the combined indices plus the catch series are shown in Fig. 6. The model explains 95% of the variation in the data and the year-class effect is highly significant (Table 2). There has been an overall declining trend in magnitude of the year-class effect with the recent period being the lowest.

SPURIOUS YEAR-CLASS EFFECTS IN A NULL MODEL

Results for the stochastic simulation trials for the null model are given in Table 3. The probability of incorrectly rejecting the null hypothesis (i.e. of making a Type I error) is generally quite low. Spurious year-class effects will not commonly be generated by random year effects or random year* age effects.

There is a somewhat higher probability of Type I error in the case of random year effects (about 10%) compared with random year*age effects (about 4-6%). The probability of Type I error does not appear to increase with increasing σ in either case, or when both sources of error are present at the same time, which is somewhat counter-intuitive and should be investigated further.

POWER TEST – FAILING TO DETECT A YEAR-CLASS EFFECT WHEN ONE IS PRESENT

The results of the analysis of statistical power for the GLM model fits to the simulated data are given in Table 4. Power was highest (low probability of Type II error) for the case where there was a 10-fold variation in recruitment and error on the year*age effect only. Power was lowest for the case where there was a 3-fold variation in recruitment and error on both the year and year*age effect. The next lowest power was for the case where there was a 3-fold variation in recruitment and error on the year effect. When only error on the year*age effect was introduced, power tended to be higher. An additional year-class effect introduced through variation in fishing mortality resulted in higher power.

DISCUSSION

Multiplicative modeling of age-disaggregated data can provide insight into the year-class effects in a population. These year-class effects are a combination of recruitment to the initial age in the analysis and subsequent cumulative mortality from both fishing and natural causes. Because interest often focuses mainly on recruitment, it is common practice to examine only the younger ages in the estimation (e.g. Healey and Dwyer 2005). There is however also information of relevance to stock assessment on the subsequent presence of fish born in a particular year as they progress through the population. If they are heavily fished this will be reflected by a lower year-class effect than would otherwise be the case. While it is useful to distinguish between the effects of recruitment and mortality, it is also useful to monitor the combined effect particularly when there is no quantitative assessment model in place to separate out the year-class strength and fishing mortality effects. Low year-class effect values arise from a combination of both poor recruitment and high fishing mortality, both of which are cause for concern in the fisheries management context. In the present analysis we have not considered the impact on estimates of year-class effect of the degree of incompleteness of cohorts at the beginning and end of each index series. Year-class effect estimates are sensitive to this problem, but restricting the analysis to only complete cohorts (i.e. all ages represented in the data for a year-class) would not be informative due to the low number of complete cohorts in most of the data sets.

Cod in NAFO Subdiv. 3Ps constitutes a relatively data-rich and information-rich stock. There are lots of data and the data have coherent year-class effects.

Catch-at-age data go back to 1959, although some discrepancies in the early portion of the series still need to be rectified (Brattey *et al*. 2005), probably caused by lack of updating of the catch numbers at age once final catch estimates for the year have been obtained. There are fishery-independent survey data from five different sources. There are significant year-class effects in all the indices evaluated for 3Ps cod, as well as in the catch at age data. These year-class effects are largely coherent across the sources of information. Four sources of information suggest that year-class effects for the recent period have been low – sentinel linetrawl, sentinel gillnet, GEAC and commercial catch data. Of the other two sources of information, the AT Cameron index applies only to the early period, while the year-class effects from the RV index, while not particularly low for the recent period, are below that estimated for the early 1970s. In combination the indices and catch data indicate a strongly declining trend in year-class effect.

The simulation studies show that spurious year-class effects are unlikely to be generated by error in the data arising from variability in year effects and year*age effects. Also, an order of magnitude variation in recruitment is likely to be detected as a significant year-class effect with a high probability despite large amounts of error. A three-fold variation in recruitment will have a lower probability of being detected. Substantial variation in fishing mortality increased the probability of correctly detecting significant year-class effects.

The failure to arrive at a satisfactory quantitative assessment for 3Ps cod in 2006 based on separating out recruitment and mortality processes is of considerable concern. An ADAPT model fit was accepted in the 2005 assessment and used as a basis for providing scientific advice on TAC options for 2006-09 (Brattey et al. 2005). Re-examination of this model fit in the 2006 assessment retrospectively led to it being dismissed as a valid interpretation of the data on statistical grounds, precluding use of the results to carry out updated projections from 2005 in the absence of a complete 3Ps research vessel survey in 2006. In the absence of an accepted quantitative assessment in 2006, scientific advice for the 2007-08 fishing season is qualitative and general, and likely to have less impact on management decisions than would have been the case had a quantitative analysis been agreed on in the assessment. A tendency to down-weight scientific advice the more uncertain it becomes is risk-prone and in direct contradiction to the basic tenet of the Precautionary Approach (Shelton 2007).

VPA-based methods such as ADAPT may be too restrictive for cases where large amounts of error exist in some of the tuning indices, such as in 3Ps cod, and where the relationship between reported catch and actual deaths due to fishing is uncertain. Given the evidence of significant and coherent year-class effects in the available data, statistical catch-at-age methods, which give more flexibility with regard to how errors enter into the models and the data sources used for estimation (Hilborn and Walters 1992; e.g. Brodizak 2002), should be examined.

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Table 1. Number of data points for each year-class in the combined dataset. Year-classes with less than two data points were eliminated.

Yearclass	N	Yearclass	N
1946	2	1975	24
1947	3	1976	24
1948	4	1977	24
1949	5	1978	24
1950	6	1979	24
1951	7	1980	23
1952	8	1981	23
1953	9	1982	22
1954	10	1983	21
1955	11	1984	20
1956	12	1985	22
1957	12	1986	24
1958	12	1987	26
1959	12	1988	28
1960	12	1989	30
1961	13	1990	32
1962	14	1991	34
1963	15	1992	37
1964	16	1993	37
1965	17	1994	36
1966	18	1995	35
1967	19	1996	31
1968	20	1997	27
1969	21	1998	23
1970	22	1999	19
1971	24	2000	15
1972	24	2001	11
1973	24	2002	7
1974	24	2003	3

Table 2. Model fit and significance of the age effect and year-class effect (Type III SS) for the individual index time series and for the combined model. In the case of the combined model, the age effect is replaced by a survey*age effect.

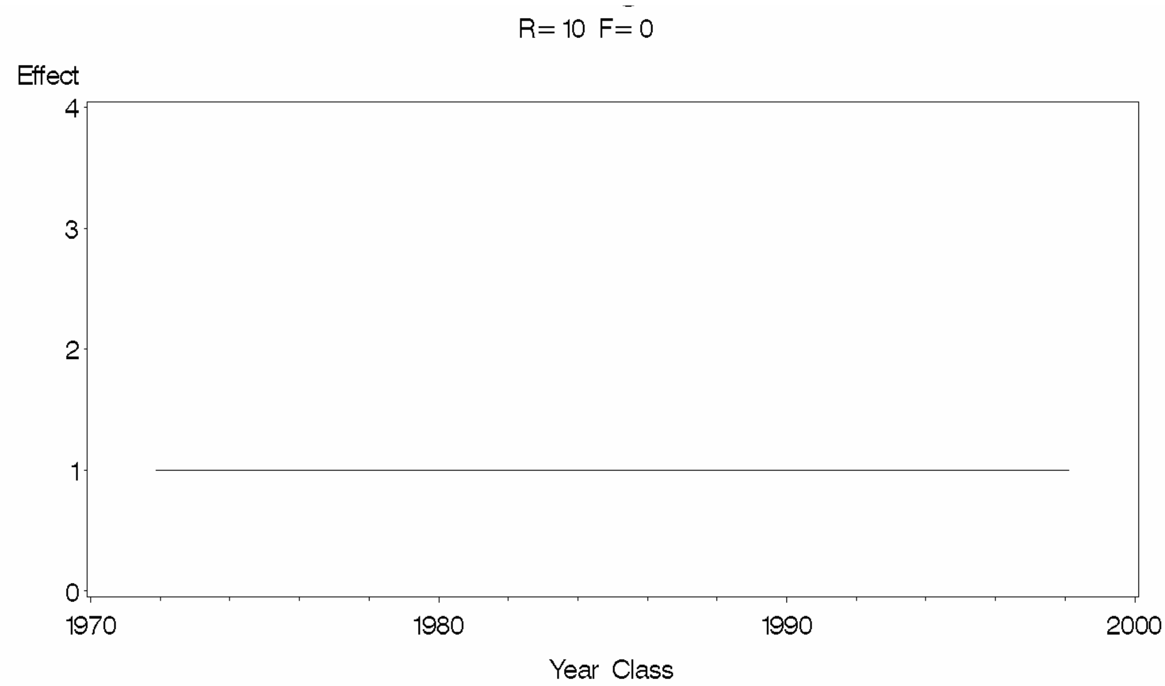
Index	R-Square	Age effect	Year-class effect
RV	0.643	<0.0001	0.0014
AT Cameron	0.764	<0.0001	0.0007
Sentinel linetrawl	0.959	<0.0001	<0.0001
Sentinel gillnet	0.943	<0.0001	<0.0001
GEAC	0.838	<0.0001	<0.0001
Catch	0.927	<0.0001	<0.0001
Combined	0.951	<0.0001	<0.0001

Table 3. Results from stochastic simulation trials for the null model. Proportion of runs (out of a 1000) in which the *p*-value was ≤ 0.05, i.e. the probability of incorrectly rejecting the null hypothesis when it is true (Type I error).

Simulation	***R***	***M***	***F***	σ_1	σ_2	**Proportion**
1	0.1	0.2	0	0.2	0	0.108
2	0.1	0.2	0	0.4	0	0.102
3	0.1	0.2	0	0.6	0	0.106
4	0.1	0.2	0	0.8	0	0.100
5	0.1	0.2	0	0	0.2	0.058
6	0.1	0.2	0	0	0.4	0.052
7	0.1	0.2	0	0	0.6	0.042
8	0.1	0.2	0	0	0.8	0.045
9	0.1	0.2	0	0.6	0.6	0.065
10	0.1	0.2	0	0.8	0.8	0.063

Table 4. Results from stochastic simulation trials to look at statistical power. Proportion of runs (out of a 1000) in which the *p*-value was ≤ 0.05, i.e. the probability of correctly rejecting the false null hypothesis. Type II error is given by 1-Proportion.

Simulation	***R***	***M***	***F***	σ_1	σ_2	**Proportion**
1	U[0.1,0.3]	0.2	0	0.8	0	0.664
2	U[0.1,1]	0.2	0	0.8	0	0.999
3	U[0.1,0.3]	0.2	0	0	0.8	0.891
4	U[0.1,1]	0.2	0	0	0.8	1.000
5	U[0.1,0.3]	0.2	0	0.8	0.8	0.377
6	U[0.1,1]	0.2	0	0.8	0.8	0.975
7	U0.1,0.3]	0.2	U[0,0.6]	0.8	0.8	0.491



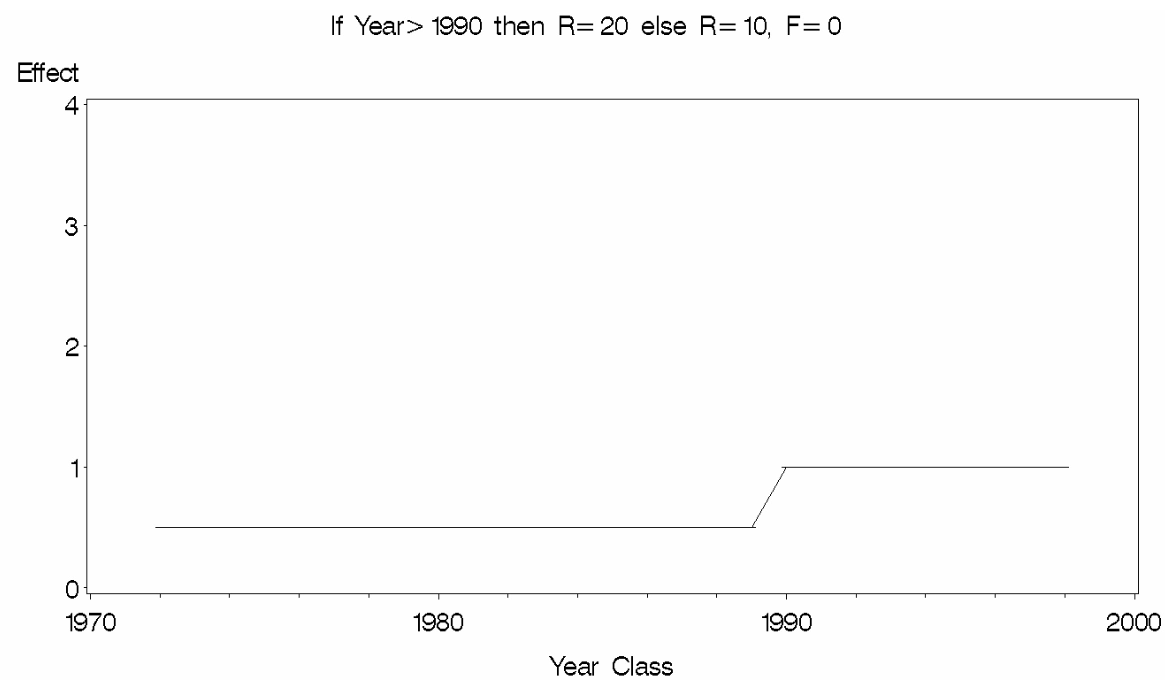
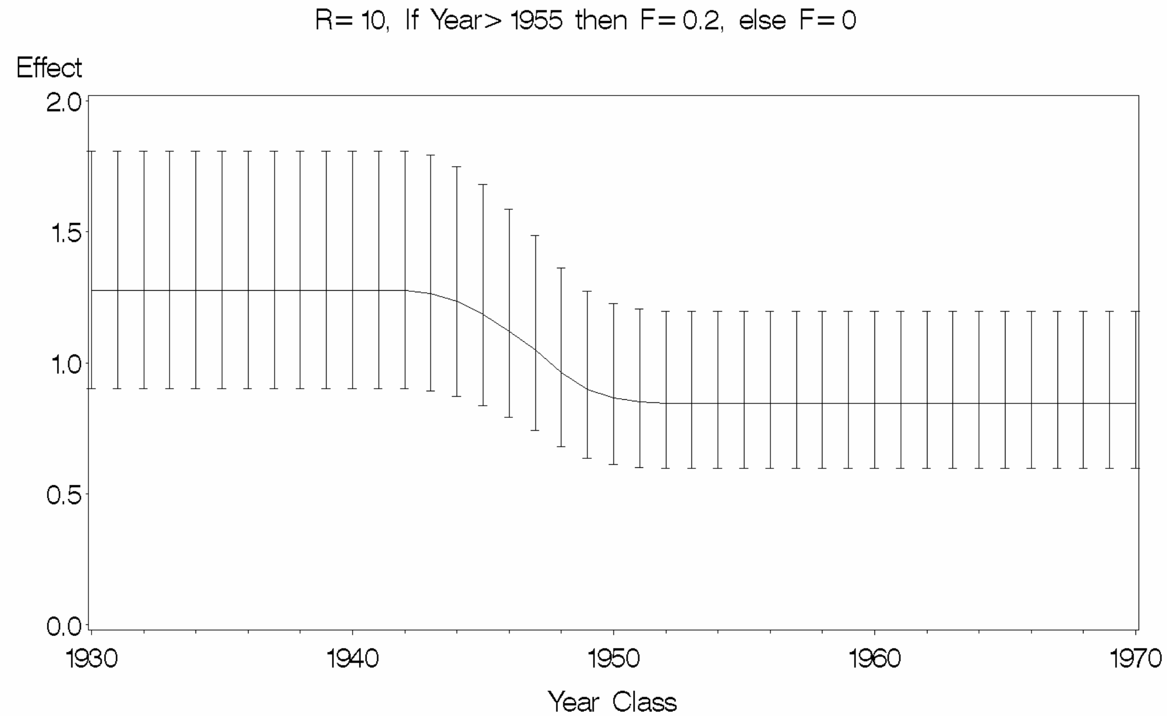


Figure 1. Year-class effect estimated from simulated data with constant recruitment and mortality (top) and an increase in recruitment from 1990 onwards (bottom).



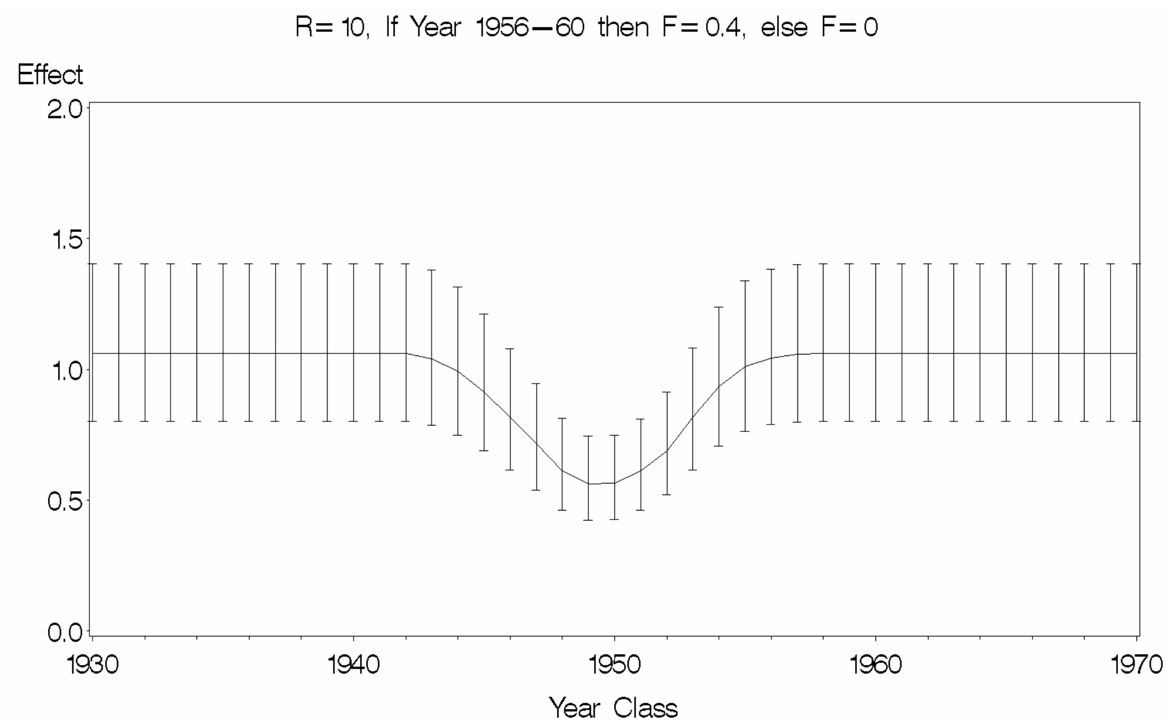
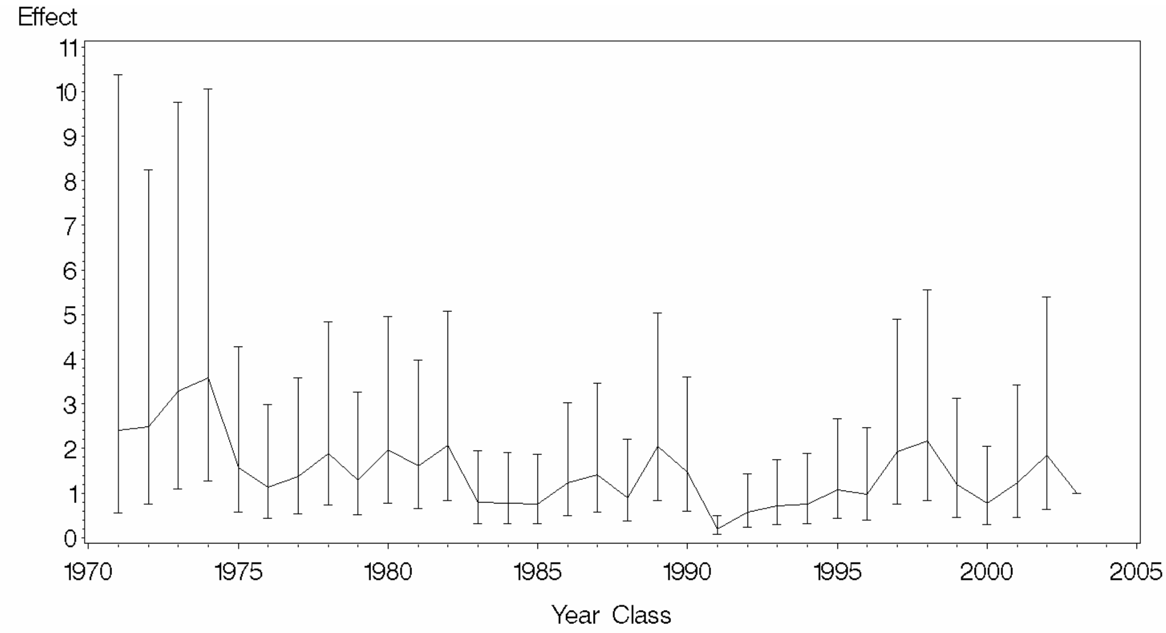


Figure 2. Year-class effects estimated from simulated data with constant recruitment and an increase in *F* 0 to 0.2 from 1956 onwards (top) and an increase from 0 to 0.4 in 1956 and then back to 0 from 1961 onwards (bottom). Error bars are plus and minus two standard errors of the estimate.



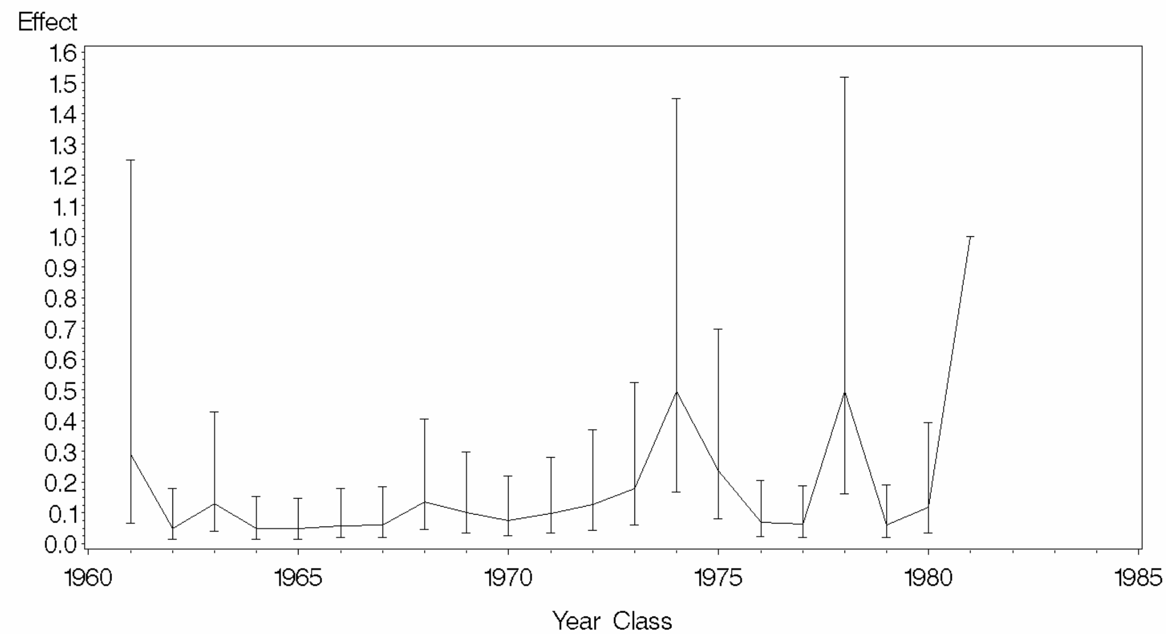
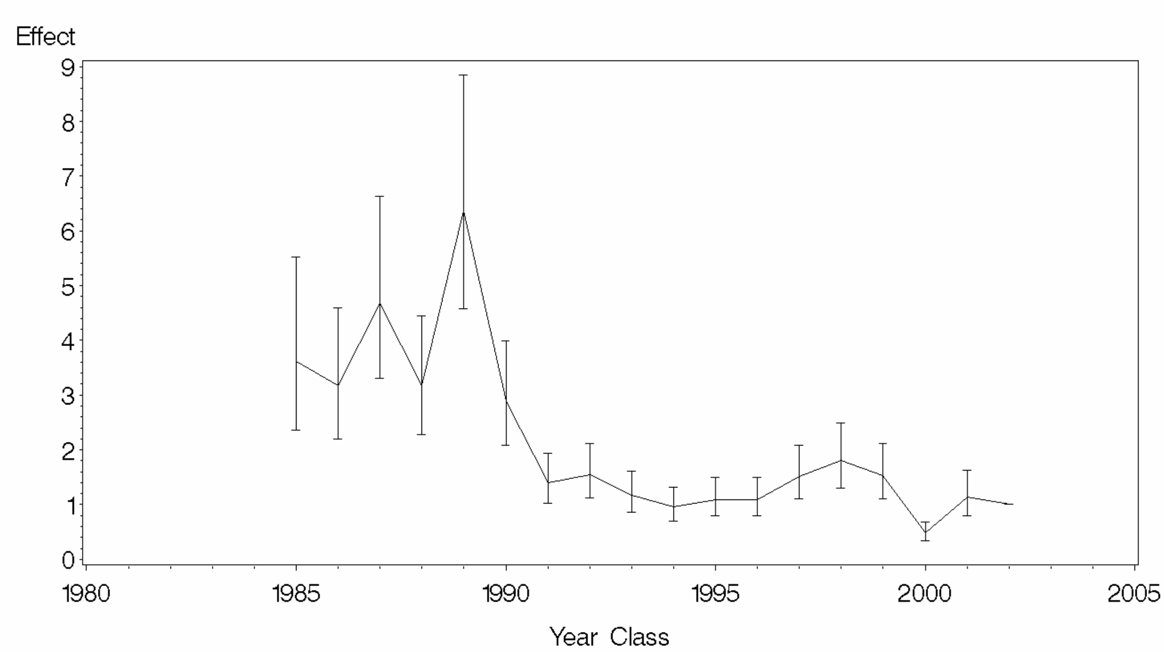


Figure 3a**.** Year-class effects from a GLM model applied to the RV index (top) and AT Cameron index (bottom) for 3Ps cod.



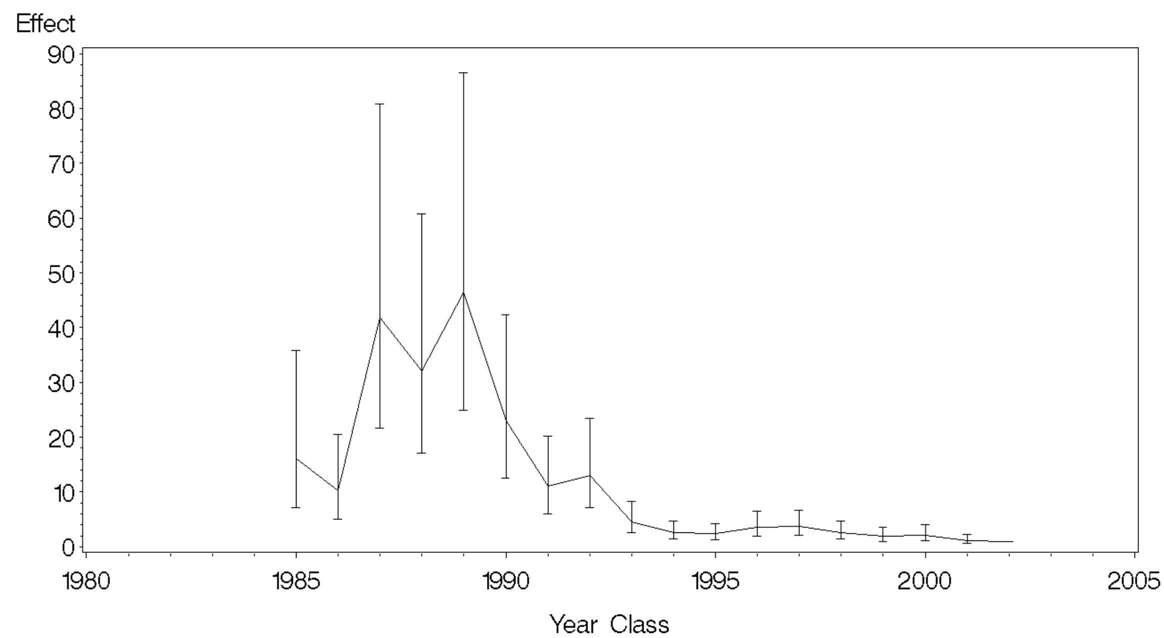


Figure 3b**.** Year-class effects from a GLM model applied to the Sentinel linetrawl index (top) and Sentinel gillnet index (bottom) for 3Ps cod.

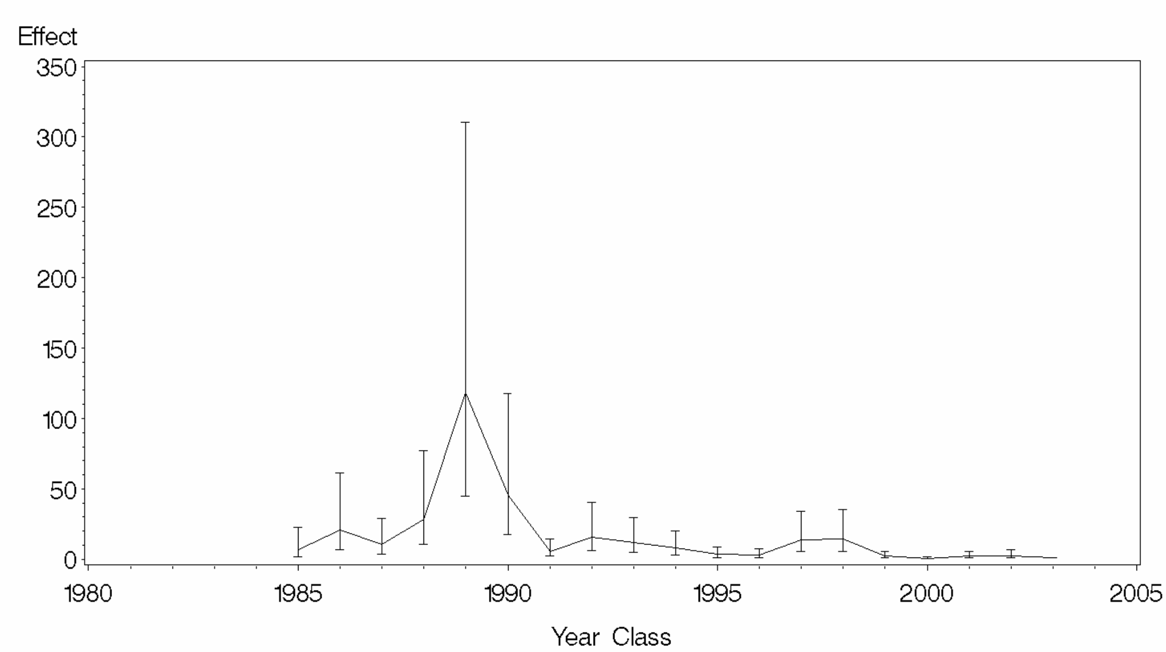


Figure 3c. Year-class effects from a GLM model applied to the GEAC index (top) and commercial catch data (bottom) for 3Ps cod.

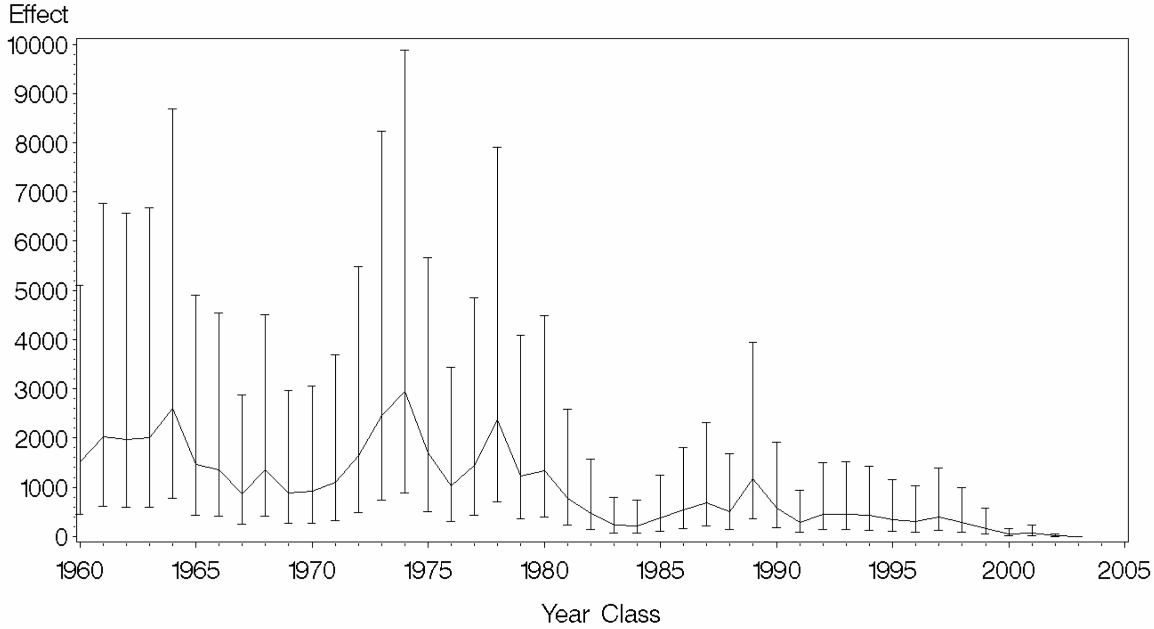


Figure 3d. Year-class effects from a GLM model applied to the commercial catch data for 3Ps cod expanded for the more recent period.

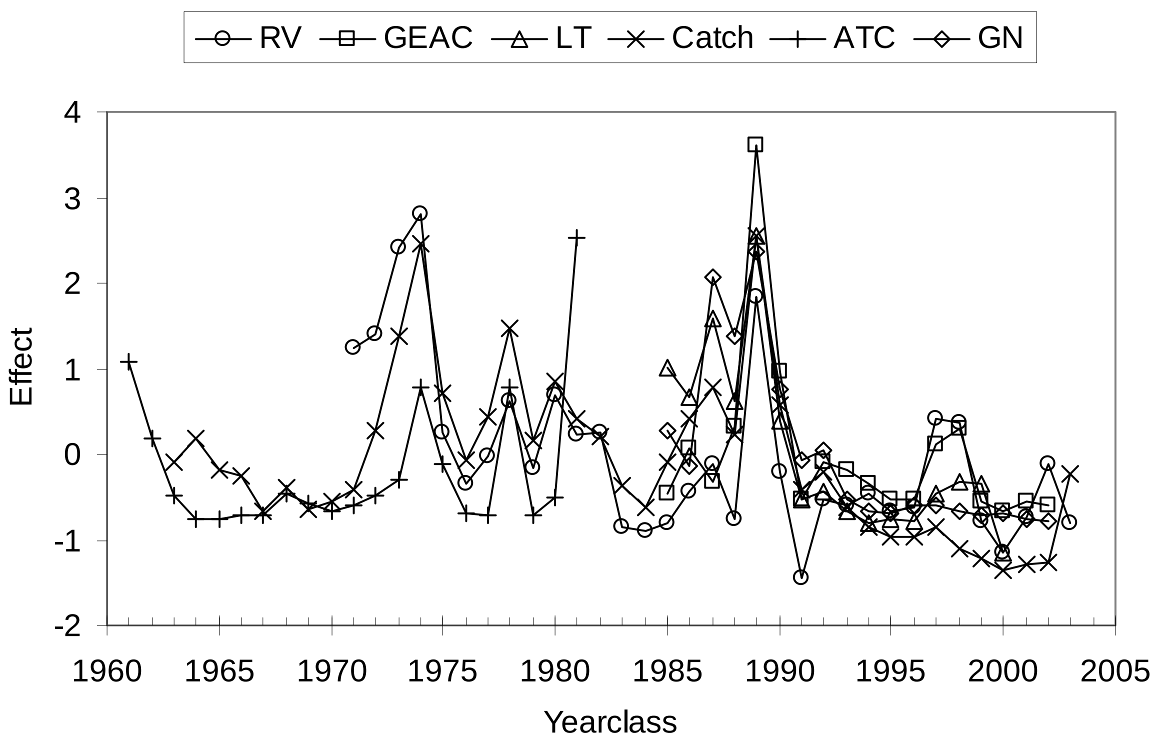


Figure 4. Standardized year-class effects for all indices and catch data superimposed to examine coherence. Standardized effect = (effect – mean effect)/standard deviation.

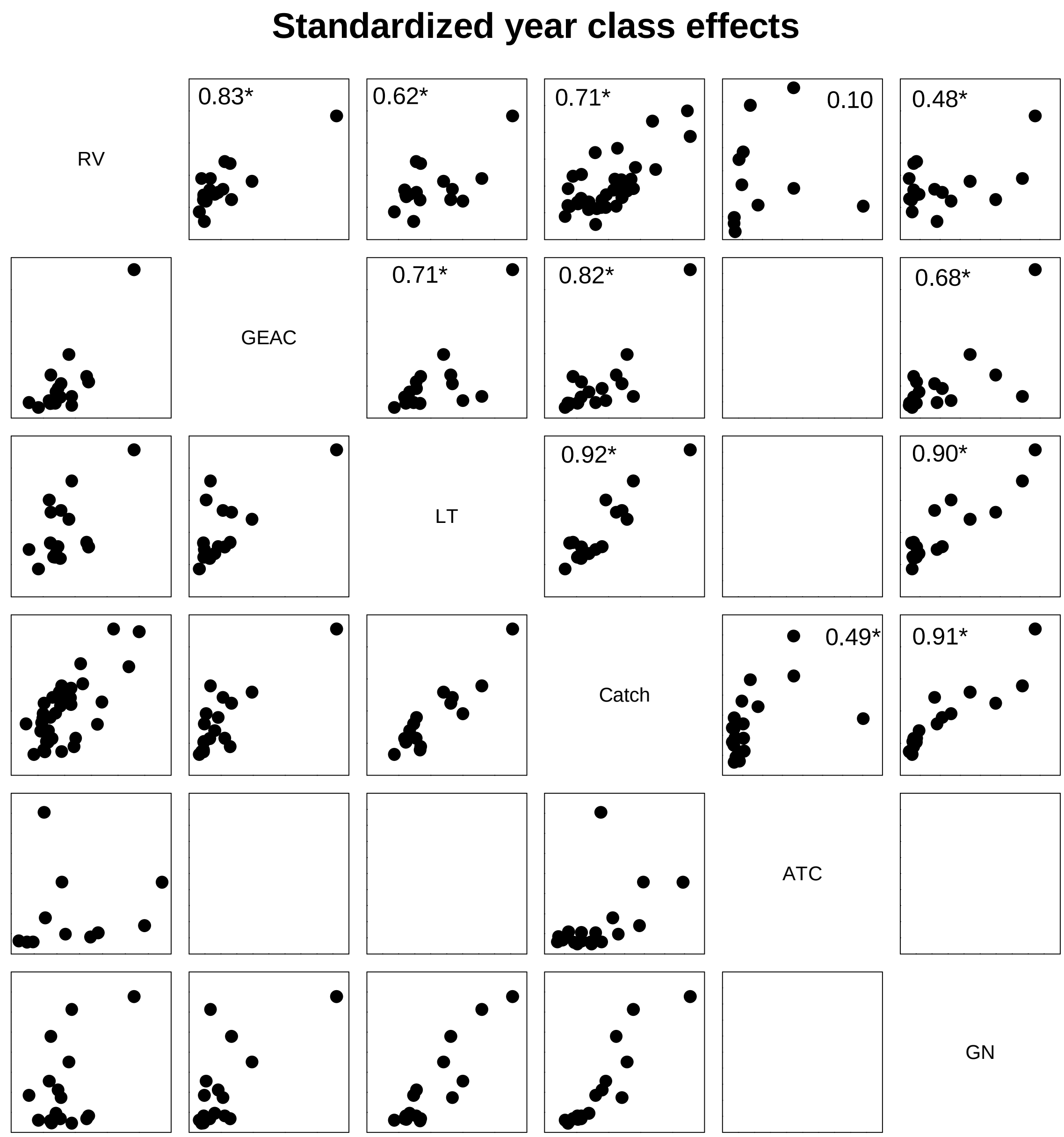


Figure 5. Cross-correlation of standardized year-class effects from survey indices and catch series. Pearson correlation coefficients are given for each comparison. Signficance at the $\alpha = 0.05$ is indicated by *. RV = research vessel survey index, GEAC = industry survey index, LT = sentinel linetrawl index, ATC = AR Cameron research vessel index and GN = sentinel gillnet index (see Brattey et al. 2005 for more information on data inputs).

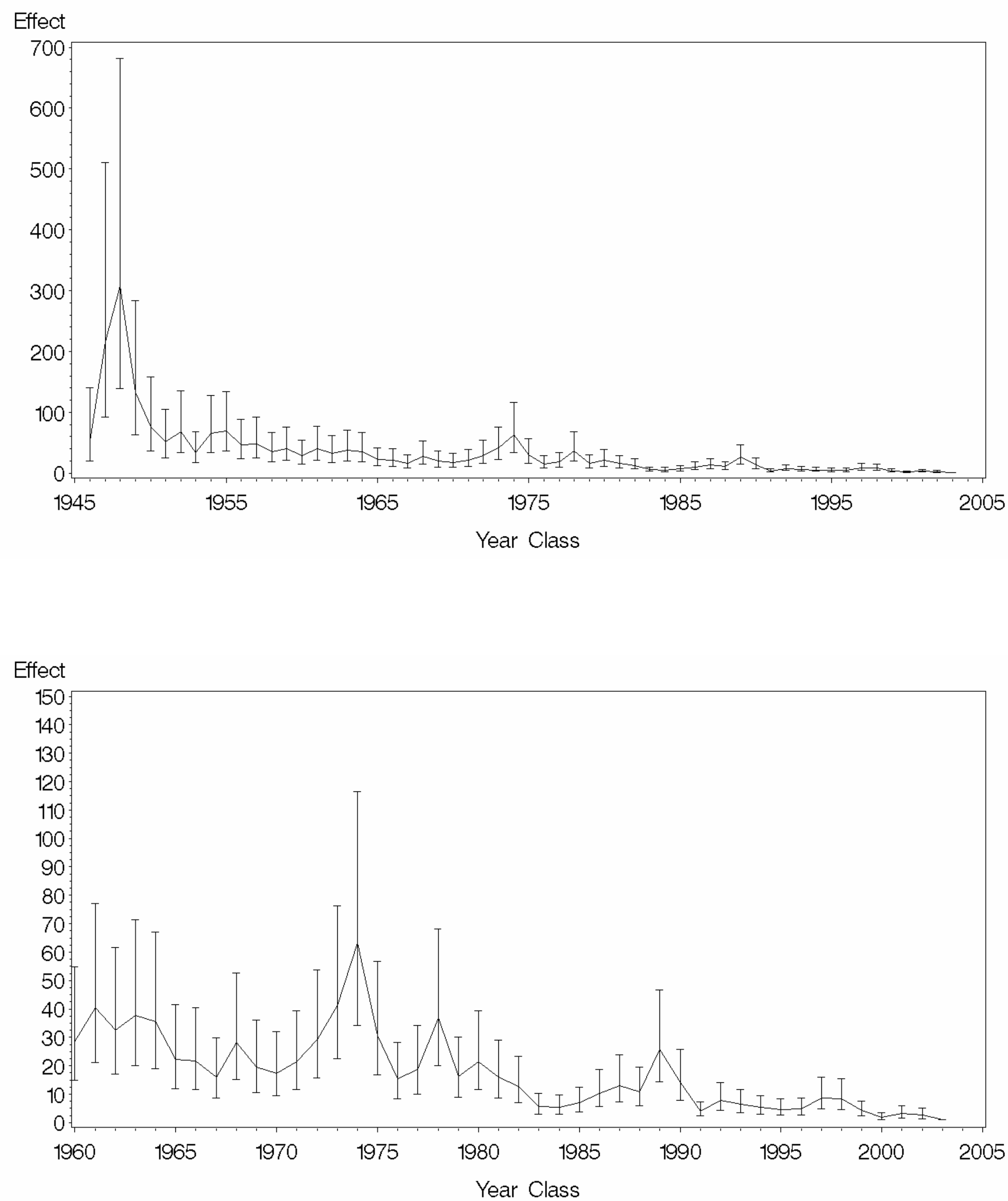


Figure 6. Year-class effects from a GLM model applied to all indices and the commercial catch data combined for 3Ps cod. Bottom panel expands the more recent period.