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Analysis of Pre-recruit Data from Surveys for Greenland Halibut in NAFO Subarea 2 and Divisions 3KLMNO

by

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Abstract

Research survey data are analyzed to predict relative year-class strength from 1975 to 2000. Log-additive models with fixed year-class strength and survey-age effects that have common variance among pre-specified *groups* (e.g. group = survey-age combinations) and zero covariance between groups are utilized to model the error structure of the data. Variance estimation of each group is iteratively re-weighted. Likelihood ratio tests reduce the number of variance parameters estimated. The most parsimonious model indicates that the 1993, 1994, and 1995 estimates of year-class strength are predominant over the time period, and the two most recent year class strength estimates, the 1999 and 2000 cohorts are also relatively strong.

Introduction

In the 2001 assessment of the Subarea 2 + Div. 3KLMNO Greenland halibut stock, year-class strength was estimated using a mixed linear model (Healey *et al*., 2001). These results indicated that the 1993, 1994, and 1995 cohorts were exceptionally strong relative to all others in the time series, and that the three subsequent year-classes were much weaker, with the final (1998) year-class estimated to be below both mean and median year-class strengths. Using the same model structure we analyze updated survey data and provide an update of year-class strength. Also in 2001, the Subarea 2 + Div. 3KLMNO Greenland halibut stock was assessed using the extended survivors analysis framework (Mahé and Bowering, 2001). Results showed that stock size has increased in recent years, and that the year classes from 1993-95 were primarily responsible for this increase. Data from Canadian fall research surveys in Div. 2J3K, and from EU surveys in Div. 3M were used as indices of abundance in the SPA calibrations. In this paper we examine these data, as well as additional survey data from other portions of the stock range or from surveys at other times (Div. 3L, Div. 2G, Div. 2H, Div 3LNO spring). Since the last assessment of this stock, additional survey data has been collected, and corrections have been made to some erroneous values in one of the indices used in the last assessment.

Methods and Materials

<u>Description of research vessel survey data</u>

From 1977-94 in Div. 2J and 1978-94 in Div. 3K, Canadian stratified random surveys were conducted during autumn by the research vessel ***Gadus Atlantica*** using an Engel 145' bottom trawl. In Div. 3L from 1981-83, surveys were conducted by the ***A.T. Cameron*** using a Yankee 41.5 bottom trawl and in 1984-94 by either the ***A. Needler*** or the ***W. Templeman*** (sister ships) using an Engel 145 bottom trawl, which differed somewhat from the trawl used on the ***Gadus Atlantica***. No conversion factors were developed for G.halibut for the change in vessel gear which occurred after 1983. In 1995-2001, the surveys in autumn in Subareas 2 and 3 were conducted by the research vessels ***Teleost***, ***W. Templeman*** and ***A.Needler*** using a Campelen 1800 shrimp trawl with rockhopper footgear. The fall 1995 survey is incomplete due to survey coverage and timing issues. For details on the trawls used in these surveys, see McCallum and Walsh (1996). Warren (1996) outlined the conversion factors used for Greenland halibut catches, required for comparison of results from 1995 and onward with those prior to 1995. The 1997 assessment of this stock contained several tables and figures outlining these comparisons for G. halibut (Brodie *et al*., 1997). In Div. 2GH, surveys were carried out in 1996-99, but only sporadically before then (see Brodie *et al*. (1999) for a detailed description of the various components of the fall surveys). Div. 2H was again surveyed in 2001; however no survey has been conducted in Div. 2G since 1999. Due to the intermittent nature of the survey coverage in Div. 2GH, we consider the data from Div. 2G and 2H as separate indices.

Canadian surveys were also conducted during spring in Div. 3LNO since 1971. In most years, the maximum depth surveyed was less than 731 m, and in many surveys the depth was less than 366 m. As with the fall surveys, there were 3 different vessel-gear combinations used in these surveys, covering the periods 1971-82, 1984-95, and 1996 onward. No conversions exist for the spring survey data. Data considered in this analysis are from Div. 3L from the periods 1977-95 and 1996-2001, and Div. 3N and 3O from 1996-2001.

EU surveys in Div. 3M have been conducted since 1988. These research vessel surveys have been conducted during July, to a maximum depth of 731 m. For a description of the methodology and results, see Vazquez (2000). Abundance-at-age data were used from 1992-2001, due to some questions with age interpretations in the earlier surveys.

Thus, there are seven independent data series (Table 1) available for analysis: (i) the Canadian fall Div. 2G series (Campelen trawl; 1996-1999), (ii) the Canadian fall Div. 2H series (Campelen trawl; 1996-1999, 2001), (iii) the Canadian fall Div. 2J3KLMNO series (Campelen trawl; 1996-2001), (iv) the Canadian fall Div. 2J3KL series (Engel trawl; 1981-1994), (v) the Canadian spring Div. 3L series (Yankee 41.5 trawl 1977-82; Engel trawl; 1984-95), (vi) the Canadian spring Div. 3LNO series (Campelen trawl; 1996-2001), and (vii) the EU July Div. 3M series (1992-2001). Abundance estimates (in thousands) were based on the standard swept-area calculations for all series. For all survey series, abundance estimates at ages 1-4 were selected for the modelling exercise, as these are ages at which fishing mortality would be minimal. Only those year-classes observed at least three times were included in the analysis.

As noted in the introduction, some erroneous index values were used in the previous modelling exercise. Inaccurate Canadian fall Div. 2J3KLMNO Campelen data (Table 1-IV in Healey *et al*., 2001) were used – the index values for 1998-2000 are incorrect. Estimates using the final model formulation from last years assessment were reproduced using the corrected data (Fig. 1). The estimates of relative strength change slightly, but the trends are unchanged – there are moderate recuitment pulses around 1984 and 1990, and a strong recruitment pulse from 1993-1995 centered about the 1994 cohort. Also, the 1996-1998 cohorts are estimated to be weaker than the previous cohorts.

Model Description

A multiplicative model was used to estimate the relative year class strength produced by the spawning stock.

On a log-scale the model can be written as follows:

$$\log(I_{s,a,y}) = \mu + Y_y + (SA)_{s,a} + \varepsilon_{s,a,y} ,$$

where: μ = overall mean
s = survey subscript
a = age subscript
y = year class subscript
I = Index (Abundance in 000’s)
Y = year class effect
SA = Survey × Age effect, and
ε = error term.

We assume that $\varepsilon_{s,a,y}$~N(0,σ^2_{group}) for pre-specified *group*s. Each *group* has a common variance, and there is no covariance between observations (for example, if group = survey, then indices within a survey are assumed to have a common variance). For a full description of the model used, see Healey *et al*. (2001).

In the Canadian spring Div. 3L series (1977-95), there are six instances in which the index values observed at age 1 are zero. These must be adjusted for inclusion in the log-additive model; we have replaced the zeroes with 1% of the minimum (non-zero) observed index from this survey, following the sensitivity examination in Healey *et al*. (2001).

Results and Discussion

Relative Year Class Strength

The initial model used 28 covariance parameters – one for each survey × age combination (7 surveys × 4 ages). The estimated year-class strength (measured by the least-squares means for year-class effects) indicates moderate recruitment pulses around 1984 and 1990 (Fig. 2). In addition, there is a stronger recruitment pulse from 1993 to 1995 that peaks in 1994. The relative strength of the estimates of the 1999 and 2000 year-classes is among the highest in the series. The 2000 estimate has a higher associated variance since there are fewer observations of this cohort.

A scatter plot of standardized (by the appropriate variance parameter) residuals versus year (Fig. 3) shows no systematic trends; just a few of the standardized residuals lie outside of the +/- 2 reference lines. However, year effects are evident in 1977, 1980, and 1983. Furthermore, the final Canadian Div. 3L Spring survey with the Engel trawl (1995) stands out – all residuals are negative; there appears to be a year effect. More detailed residual examination, omitted for brevity, indicates the model performs well.

Results show that four of the twenty-eight estimated weight parameters (Fig. 4) receive over 50% of the total weights (inverse of the variance parameter); these indices dominate the estimate of cohort strength.

A series of likelihood ratio tests (LRT) were conducted to see if the number of estimated variance parameters could be reduced (Table 2a). Fixed effects were still estimated for each year-class and survey-age combination. A series of 7 sub-models were sequentially fit to the data. In each sub-model one survey had the four survey-age variance parameters collapsed into a single survey variance parameter, leaving 25-variance parameters (the other 6 surveys still had a variance parameter fit to all four ages) to be estimated. The sub-models were used to test the hypothesis that the variance parameters within a survey are equal. Minus twice the difference in the sub and full model (restricted) loglikelihoods is asymptotically χ^2 distributed, with degrees of freedom equal to the difference in the degrees of freedom in the full and sub-models. These tests indicate that the only significant differences in survey × age variance parameters are for the Canadian spring Div. 3L series (1977-95). Note also that the test for the Canadian fall Div. 2J3KL Engels series is "marginally significant" with a p-value of 0.0478. It was decided that this level of significance was not sufficient to warrant estimating multiple variance parameters for the Canadian fall Div. 2J3KL Engels index and that a single variance parameter for this survey would be used. The remaining five surveys also have their survey × age variance parameters collapsed to a single parameter for each survey, but the Div. 3L spring series cannot. Thus, a 10-variance parameter model was constructed, which has 4-variance parameters for the Div. 3L spring series, and 1-variance parameter for each of the six other survey series. LRT's indicated that this model was not significantly different than the full 28-variance parameter model (Table 2b). As a result of the variance estimates from the 10-variance parameter model, we next considered an 8-variance parameter model, following Healey *et al*. (2001). This model contains 6-variance parameters for the six surveys which had no significant differences in survey × age variance, and for the Div. 3L spring series, a variance parameter for age 1, and a combined parameter for ages 2-4. Our analyses suggest that the model used in Healey *et al*. (2001) is still appropriate for the updated data. All estimates of year-class strength for this model (8-variance parameters; Table 3, Fig. 5) are significant. Note that the 1999 and 2000 cohorts are estimated to be above average.

Notable differences between the full and final model are 1) pre-1990 year-classes are stronger in the final model, 2) the 1994 estimate of year-class strength is also slightly higher in the final model, but 3) the 1996-2000 year-classes are relatively weaker in the final model. The final model is not significantly different from the full 28-variance parameter model, or from a model with 10-variance parameters (LRT; Table 2b). The estimated weights (Table 4, Fig. 6) indicate the variance estimate for age 1 of the Canadian spring Div. 3L series is relatively large (and hence its estimation weight is quite small). Down weighting the survey × age index with many zeros is intuitively reasonable because the values we replace the zeros with are rather arbitrary. The weightings of the other surveys is variable, ranging from a low of 4.4% in the Div. 2G Canadian fall index, to a high of 36% Div. 2J3KLMNO Canadian fall series. We suggest the 8-variance parameters as the most parsimonious representation of these data.

A scatter plot of standardized residuals (Fig. 7) does not indicate the model assumptions have been seriously violated. Again, year effects are evident in 1977, 1980, and 1983. Time Series plots of standardized residuals against year-class by age and survey (Fig. 8) indicate no serious problems, with one exception. The spring indices measured over the period coinciding with the gear change from the Engels trawl to a Campelen trawl in Canadian surveys seems to have altered perceptions of year-class strength. The model over-predicts the year-class strength for the Engels data (for 1994-95) (Fig. 8e) whereas the year-class strength at the beginning of the subsequent Campelen series is under-predicted (1996-97; Fig. 8d). Fortunately, the EU July Div. 3M index has been consistent over the Canadian gear changeover period. The residuals from the EU survey (Fig. 8f) do not follow the same pattern as the Canadian Engels/Campelen data. Further, in the time series plots of standardized residuals, some trends in the residuals can be seen, however these patterns are not severe, and are not of concern. It is not surprising that survey indices collected over a broad geographic change (ranging from NAFO Div. 2G to the southern extent of Subarea 3) would indicate some differences in measuring year-class strength.

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Table 1. Index data. (Abundance in 000's).

I.Canadian fall Div. 2G series (Campelen trawl; 1996-1999).

YC	Age			
	1	2	3	4
1992				9240
1993			11254	15335
1994		18467	12125	1770
1995	38280	9751	1600	7580
1996	8348	2830	3520	
1997	13820	8150		
1998	15380			

II. Canadian fall Div. 2H series (Campelen trawl; 1996-1999, 2001).*

YC	Age			
	1	2	3	4
1992				12639
1993			25096	45591
1994		69304	60661	35480
1995	92106	59277	56780	23040
1996	34687	30720	15860	
1997	13890	35050		31410
1998	25380		32270	
1999		43900		
2000	52010			

* No survey in 2000.

III. Canadian fall Div. 2J3KLMNO series (Campelen trawl; 1996-2001).

YC	Age			
	1	2	3	4
1992				119538
1993			311981	230685
1994		503788	445849	230590
1995	847177	524914	289300	239180
1996	236128	237300	222370	107936
1997	205690	295400	144106	142986
1998	94350	196288	159380	
1999	340774	199670		
2000	377653			

IV. Canadian fall Div. 2J3KL series (Engel trawl; 1981-1994).

YC	Age			
	1	2	3	4
1977				19859
1978			28470	29507
1979		21363	22908	29672
1980	6934	5561	17128	36013
1981	1944	4533	21190	21841
1982	758	7076	15442	46828
1983	1444	12491	28704	35158
1984	7253	19808	46895	50002
1985	11747	8531	28180	62784
1986	1404	12348	33498	66120
1987	3992	9546	15021	37794
1988	2977	4989	11359	34313
1989	534	6720	26664	47991
1990	5808	14858	100945	43669
1991	1684	64350	42221	
1992	7691	30412		
1993	14541			

V.Canadian spring Div. 3L series (Yankee 41.5 trawl 1977-82; Engel trawl; 1984-95).

YC	Age			
	1	2	3	4
1973				3769
1974			1444	1675
1975		61	1531	2261
1976	0	355	997	2171
1977	110	175	1980	767
1978	0	994	1507	1285
1979	963	262	1580	
1980	0	587		
1981	0			1433
1982			632	914
1983		315	712	4385
1984	293	559	4755	3933
1985	267	2857	2142	1701
1986	115	641	789	1403
1987	127	735	556	1657
1988	480	307	144	1423
1989	66	94	835	3785
1990	330	218	3222	5661
1991	232	269	746	690
1992	29	75	561	
1993	0	111		
1994	0			

VI. Canadian spring Div. 3LNO series (Campelen trawl; 1996-2001).

YC	Age			
	1	2	3	4
1992				22530
1993			47960	33290
1994		43860	53480	65270
1995	15760	39720	40300	22070
1996	11910	8670	12000	15501
1997	2280	6190	10989	7094
1998	3140	10999	7753	
1999	8162	7490		
2000	5928			

VII.EU July Div. 3M series (1992-2001).

YC	Age			
	1	2	3	4
1988				861
1989			286	566
1990		800	599	1224
1991	922	933	1082	1249
1992	937	706	1369	2066
1993	832	1394	1527	5157
1994	6165	4613	4396	7835
1995	2874	2113	5149	7178
1996	1597	1268	1904	1405
1997	1434	426	312	687
1998	525	147	1154	
1999	1602	839		
2000	4157			

VIII. Canadian fall Div. 2J3K Campelen Equivalents (1978-1995).*

YC	Age			
	1	2	3	4
1974				146864
1975			243378	50861
1976		315362	95883	39304
1977	67133	128771	43767	41433
1978	76275	46187	109462	75651
1979	47941	158149	88918	75711
1980	141166	39589	71282	74837
1981	33748	34727	70143	54235
1982	12131	50917	65428	104606
1983	31845	113558	112555	99109
1984	192902	106161	212676	114836
1985	125257	81046	109246	174689
1986	36234	71555	174201	177413
1987	74055	95755	70539	103158
1988	52954	39744	44644	95263
1989	9858	59211	148380	182333
1990	84583	188121	497522	112859
1991	52907	281182	171493	39605
1992	62241	189873	122856	
1993	359982	397121		
1994†	342056			

* 1978 – 1994: Converted data - not used in final model.

† 1995: Campelen data – unconverted. See text.

Table 2a. Likelihood Ratio Test to evaluate effect of reducing the number of variance parameters. The "full" model has 28-variance parameters (df), with –2 Restricted Loglikelihood= 470.1096.

Null Model*	Test Statistic	df	p-value
2G Cdn Fall	4.086397	3	0.2523
2H Cdn Fall	2.41696	3	0.4905
2J3KLMNO Cdn Fall	1.28838	3	0.7319
2J3KL (Engel) Cdn Fall	7.91685	3	0.0478
3LNO (Camp.) Cdn Spring	0.95514	3	0.8121
3L (Engel) Cdn. Spring	50.31789	3	0.0000
EU 3M	0.59187	3	0.8983

*Indicates the survey with 1-variance parameter estimated; all others have 4 (1 at each age), so the Null Model has 25 total df.

Table 2b. Likelihood Ratio Test to evaluate effect of reducing the number of variance parameters estimated for the Canadian spring Div. 3L series (1977-95).

Null Model	-2RLL*	df	Alternate Model	-2RLL	df	Test Statistic	df	p-value
A	491.3144	8	C	470.1061	28	21.2083	20	0.3850
B	487.3823	10	C	470.1061	28	17.2762	18	0.5042
A	491.3144	8	B	487.3823	10	3.9322	2	0.1400

*-2RLL - Residual LogLikelihood x (-2).
A - 8 vp model: 2 vp's for Div. 3L_SPR index, remaining 6 surveys have 1 vp each.
B - 10 vp model: 4 vp's for Div. 3L_SPR index, remaining 6 surveys have 1 vp each.
C - 28 vp model ("full" model): 4 vp's each for the 7 surveys.

Table 3. Estimated year-class strength from the preferred model (8-variance parameters).

Year-class	Estimate	Error	DF	t Value	Pr > |t|
1975	8.2513	0.5409	192	15.26	<.0001
1976	8.5942	0.5343	192	16.08	<.0001
1977	8.1592	0.4166	192	19.59	<.0001
1978	8.6277	0.3572	192	24.15	<.0001
1979	8.6875	0.3341	192	26	<.0001
1980	8.5299	0.3149	192	27.09	<.0001
1981	8.0299	0.3157	192	25.43	<.0001
1982	8.0038	0.3046	192	26.28	<.0001
1983	8.4928	0.2934	192	28.95	<.0001
1984	9.2491	0.2922	192	31.65	<.0001
1985	9.1284	0.2922	192	31.24	<.0001
1986	8.6165	0.2922	192	29.48	<.0001
1987	8.506	0.2922	192	29.11	<.0001
1988	8.1167	0.2606	192	31.15	<.0001
1989	8.0369	0.2363	192	34	<.0001
1990	9.0066	0.217	192	41.5	<.0001
1991	8.8798	0.2087	192	42.56	<.0001
1992	9.0911	0.1615	192	56.3	<.0001
1993	9.6876	0.1417	192	68.34	<.0001
1994	10.0925	0.1314	192	76.82	<.0001
1995	9.9121	0.1205	192	82.27	<.0001
1996	9.1009	0.1243	192	73.2	<.0001
1997	8.8237	0.1253	192	70.42	<.0001
1998	8.6554	0.1447	192	59.83	<.0001
1999	9.1579	0.1777	192	51.53	<.0001
2000	9.5425	0.2325	192	41.05	<.0001

Table 4. Variance estimates for the final (8-variance parameters) model. Confidence intervals are 95% intervals.

Group	**Estimate**	**Lower**	**Upper**
2G_CAMP	0.759	0.3849	2.1343
2H_CAMP	0.207	0.1103	0.5216
2J3KLMNO_CAMP	0.09277	0.04927	0.2353
2J3KL_ENGL	0.3435	0.2318	0.5612
3LNO_CAMP	0.1899	0.1038	0.4534
3L_SPR_ENGL_1	11.8368	6.5416	27.6227
3L_SPR_ENGL_234	0.7772	0.5121	1.3191
EU_3M	0.2831	0.1779	0.5197

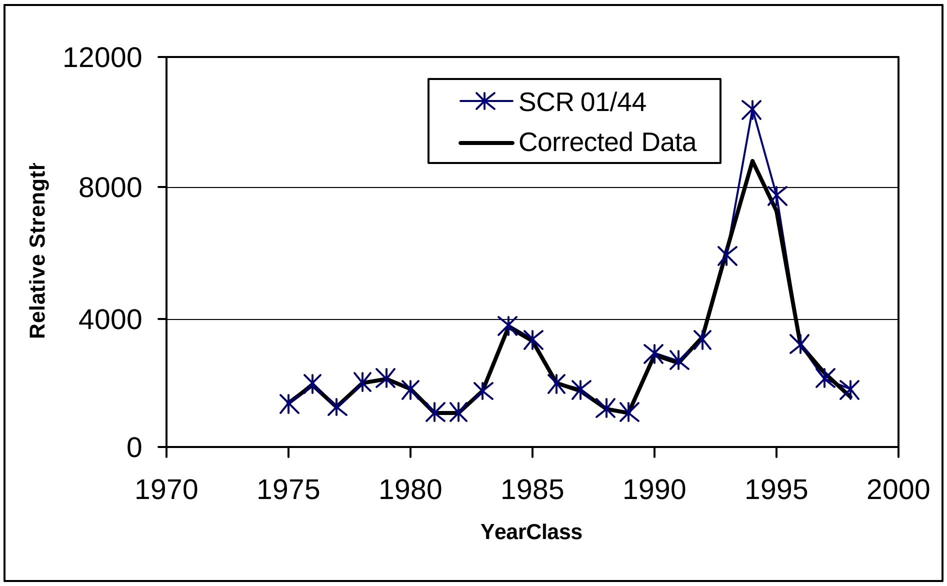

Fig. 1. Estimates from Healey *et al*. (2001) final model with corrected indices.

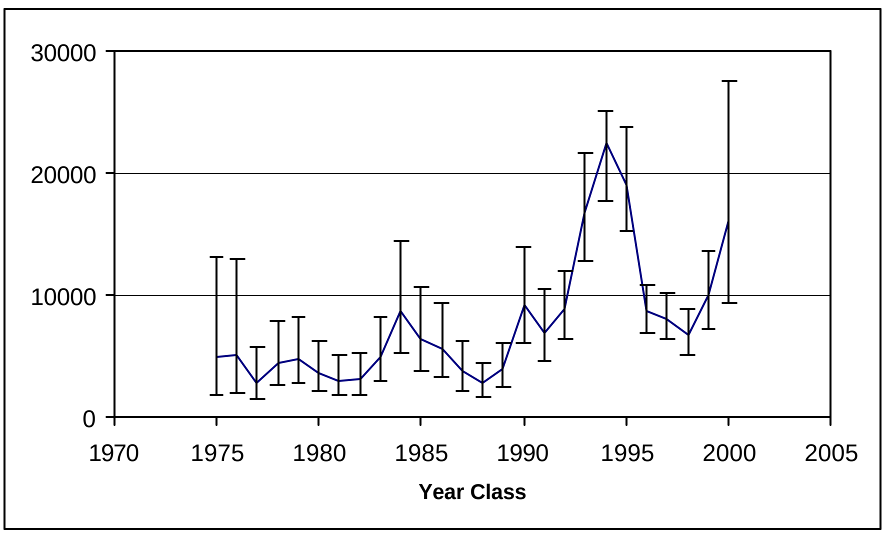

Fig. 2. Year-class strength estimated from the "full" (28-variance parameter) model, +/- 2 S.E.

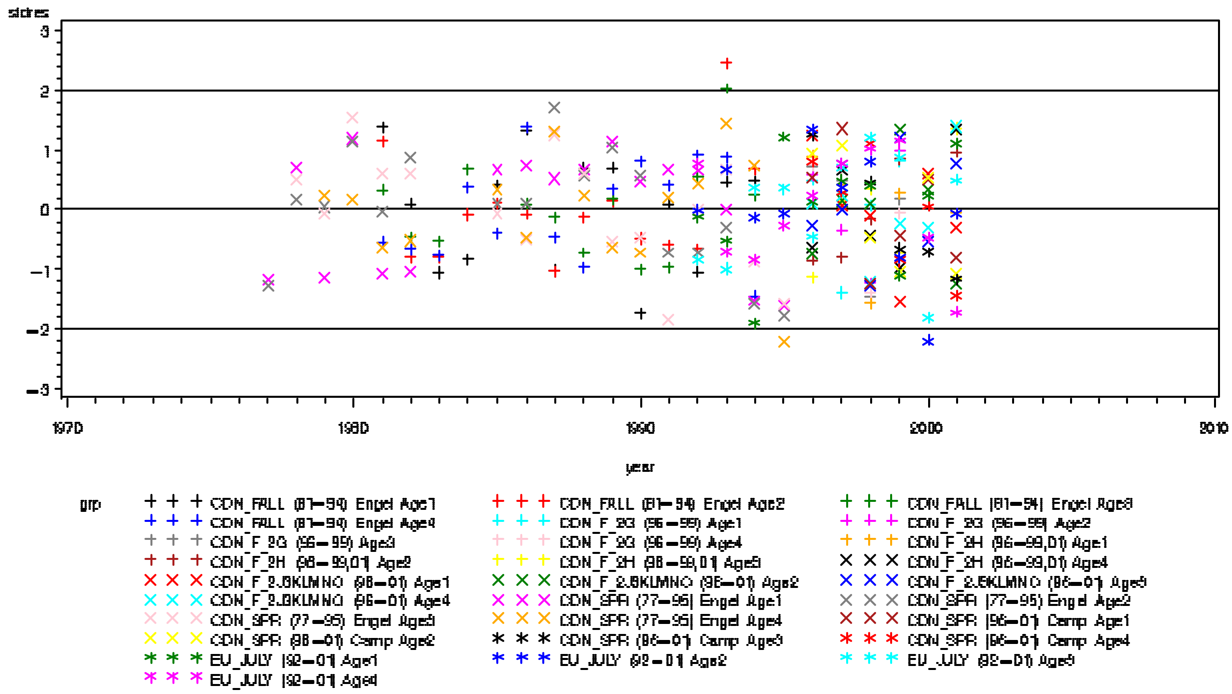

Fig. 3. Standardized residuals from the “full” (28-variance parameter) model.

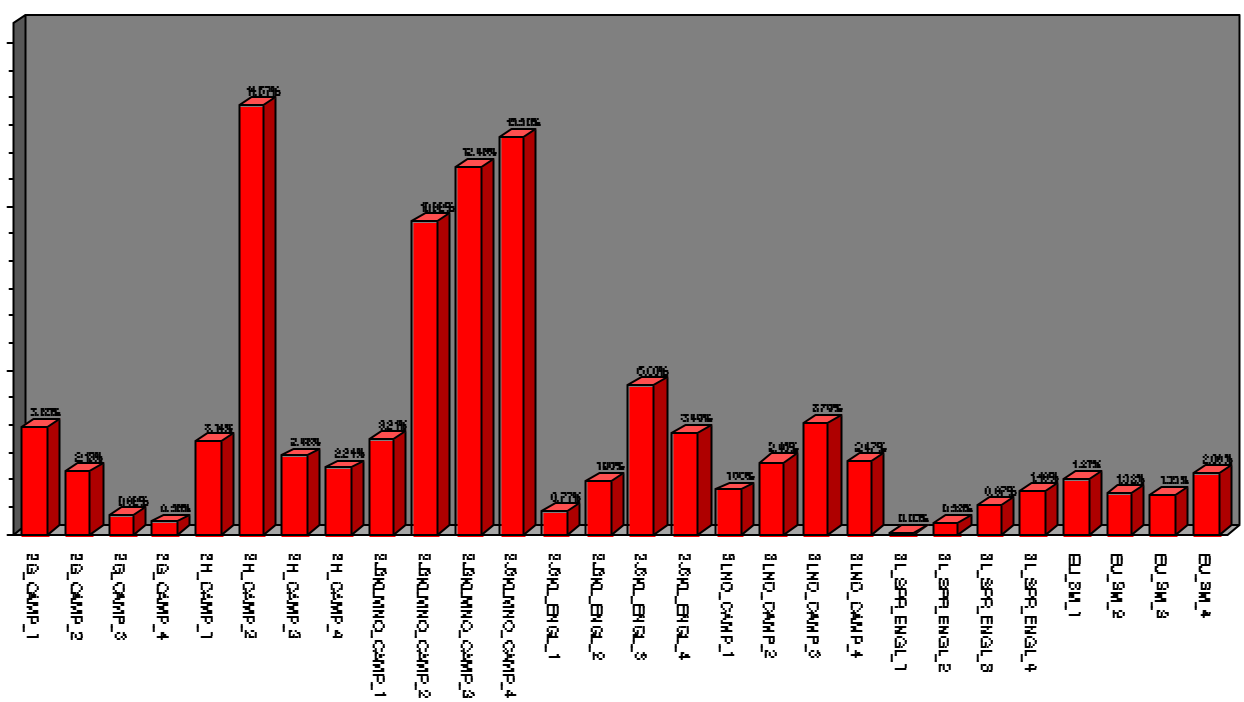

Fig. 4. Estimated weights from the “full” model run with 28-variance parameters.

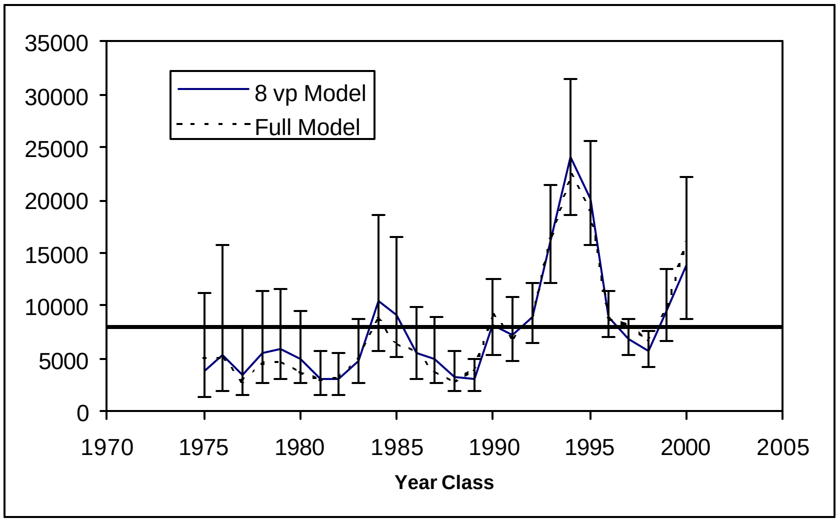

Fig. 5. Year-class strength Estimate from final model with 8-variance parameters – 2 for the Canadian Div. 3L Spring Series (age1 and ages 2-4 combined); one for each of the other 6 surveys, +/- 2 S.E. Full Model estimate included for comparison. Horizontal line is mean year-class strength.

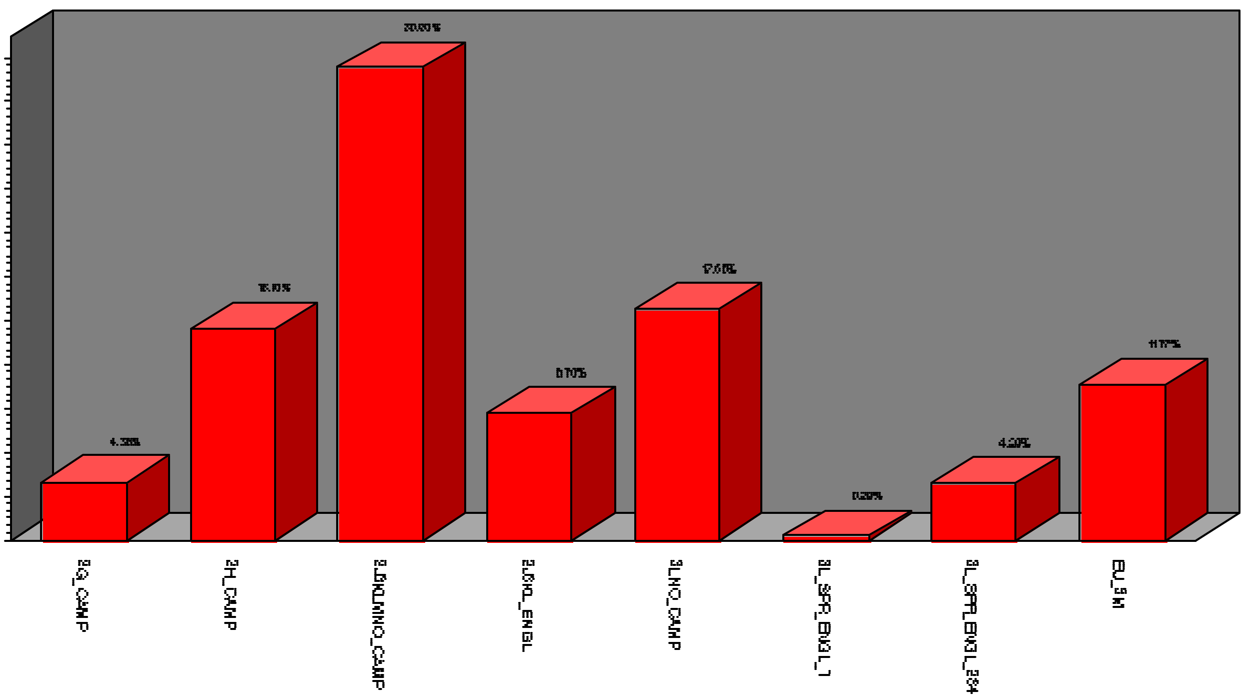

Fig. 6. Estimated weights from the final model (8-variance parameters).

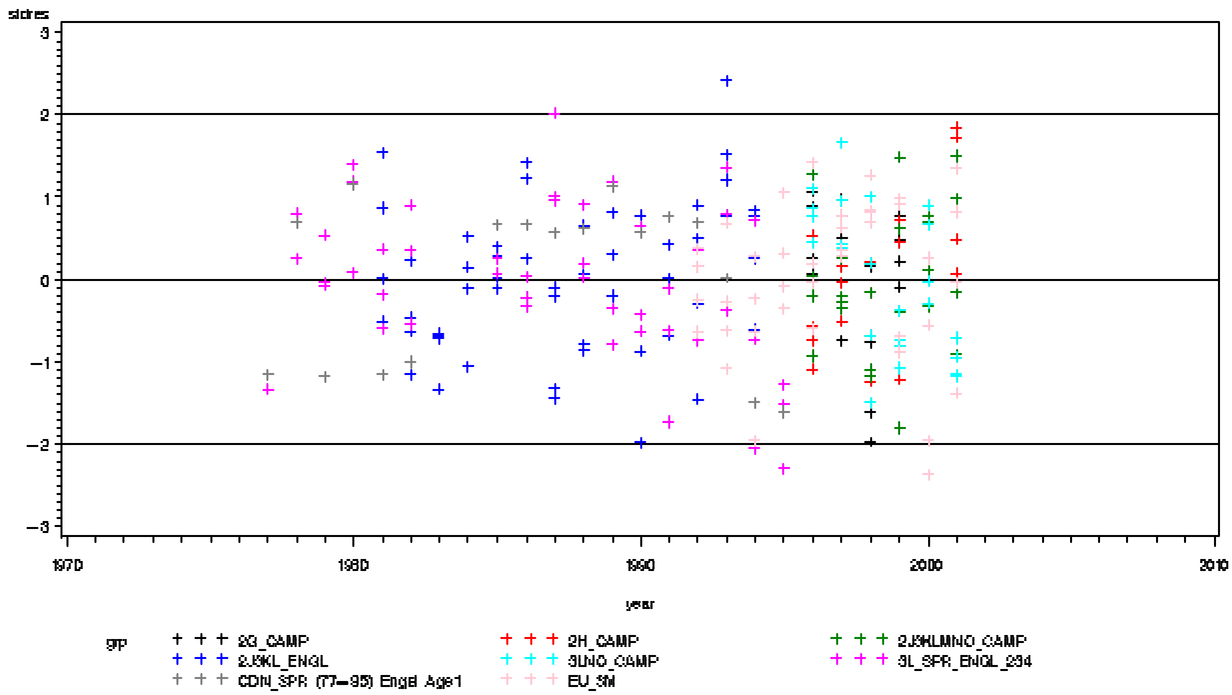

Fig. 7. Standardized residuals from the final model (8-variance parameters).

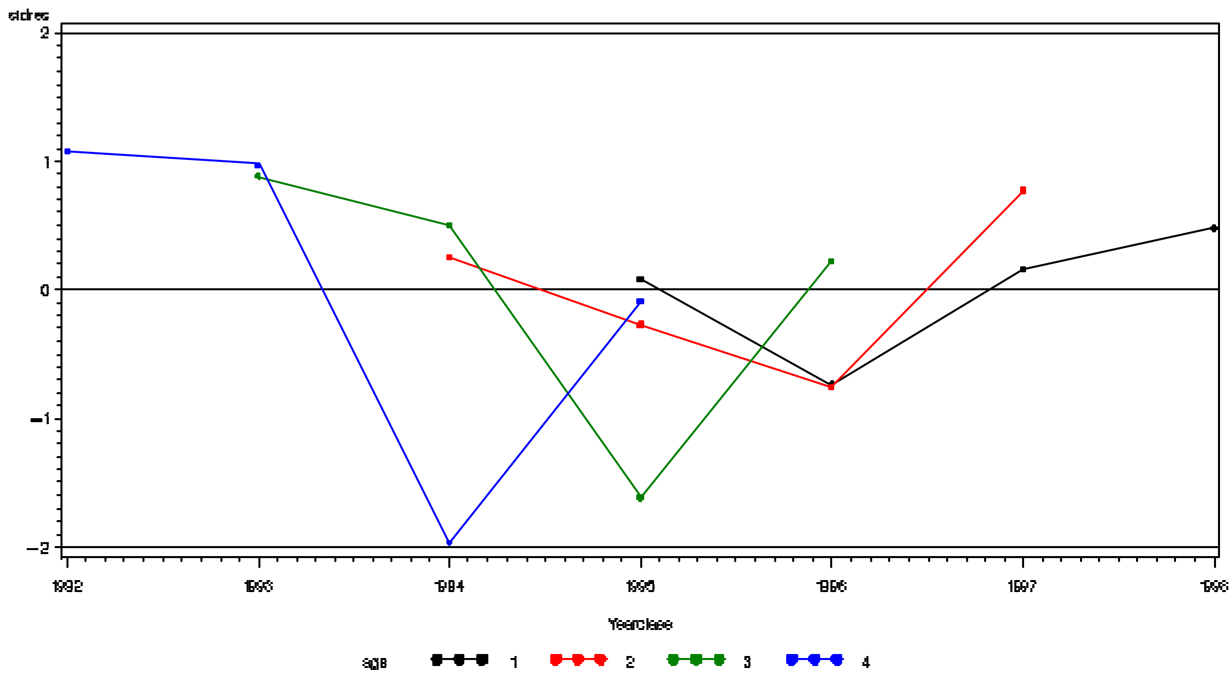

Fig. 8a. Time series of standardized residuals (by survey): from Canadian fall Div. 2G series (Campelen trawl; 1996-1999)

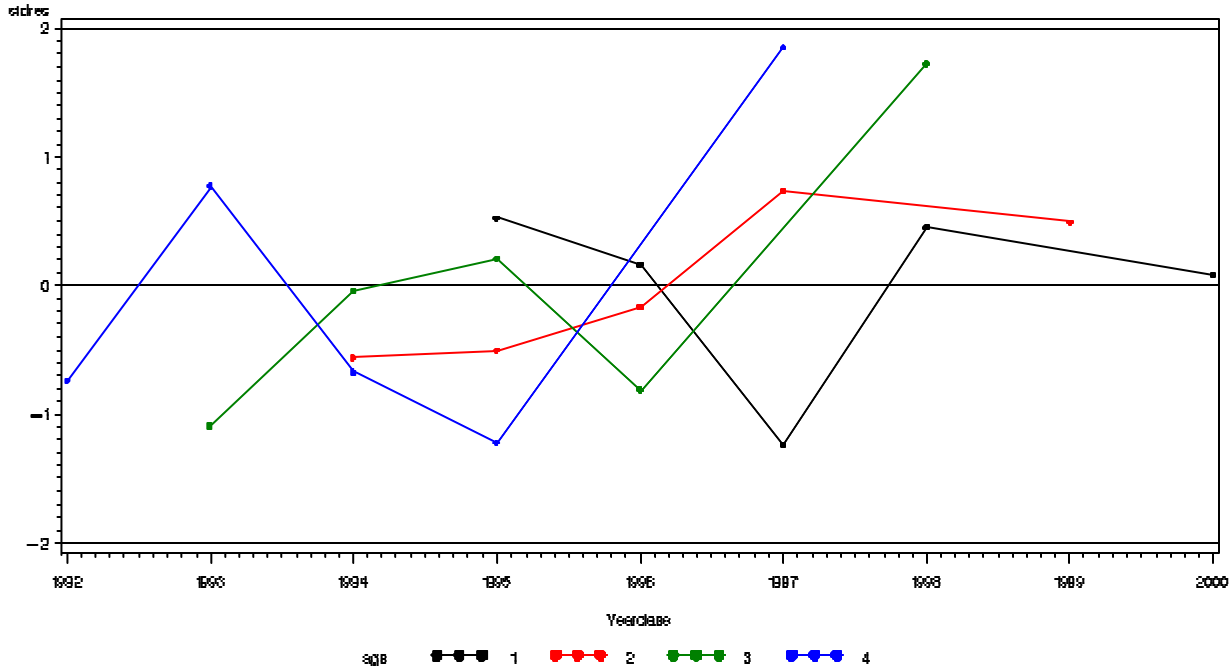

Fig. 8b. Time series of standardized residuals (by survey): from Canadian fall Div. 2H series (Campelen trawl; 1996-1999, 2001)

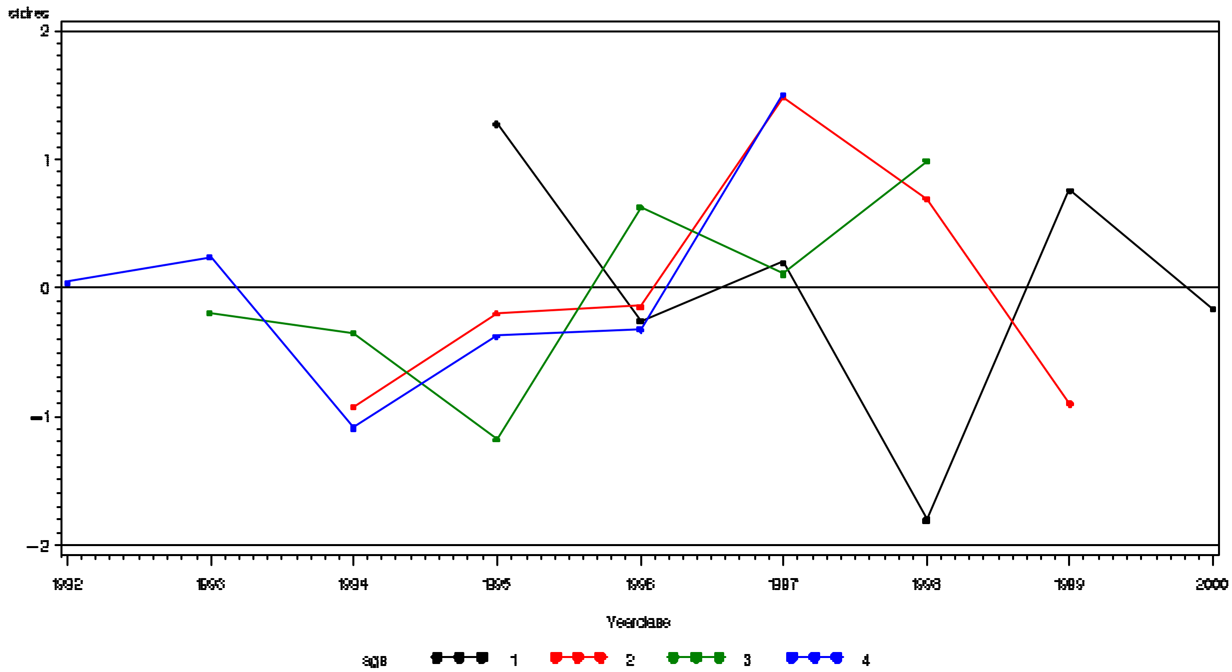

Fig. 8c. Time series of standardized residuals (by survey): from Canadian fall Div. 2J3KLMNO series (Campelen trawl; 1996-2001).

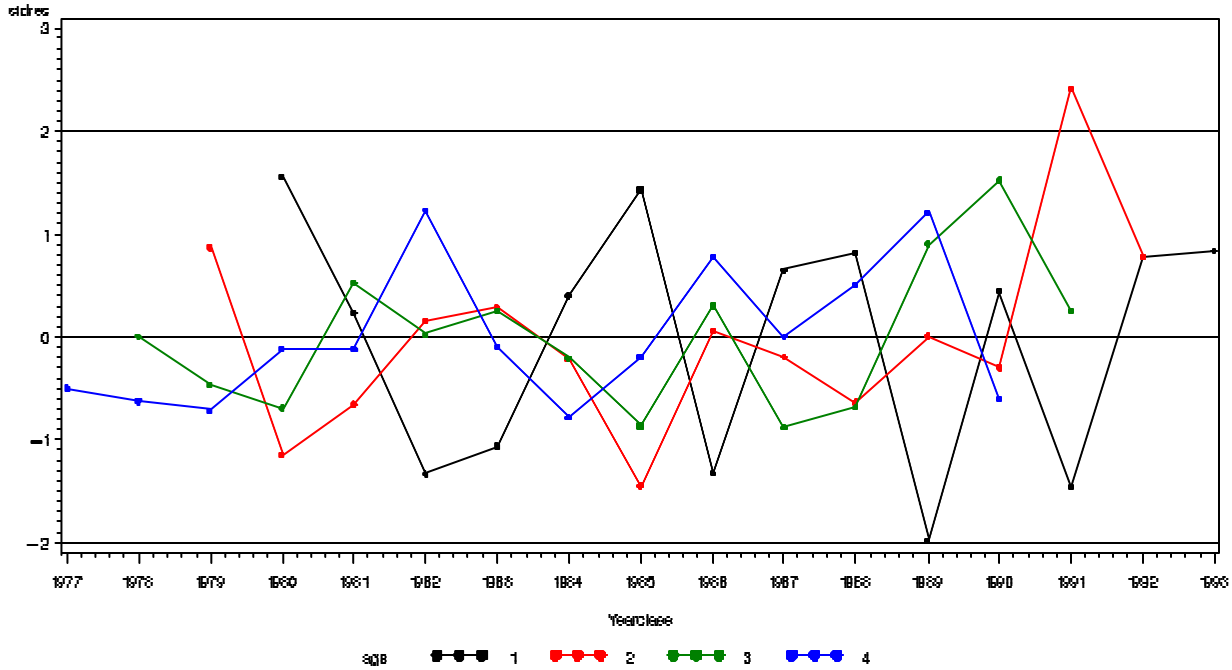

Fig. 8d. Time series of standardized residuals (by survey): from Canadian fall Div. 2J3KL series (Engel trawl; 1981-1994).

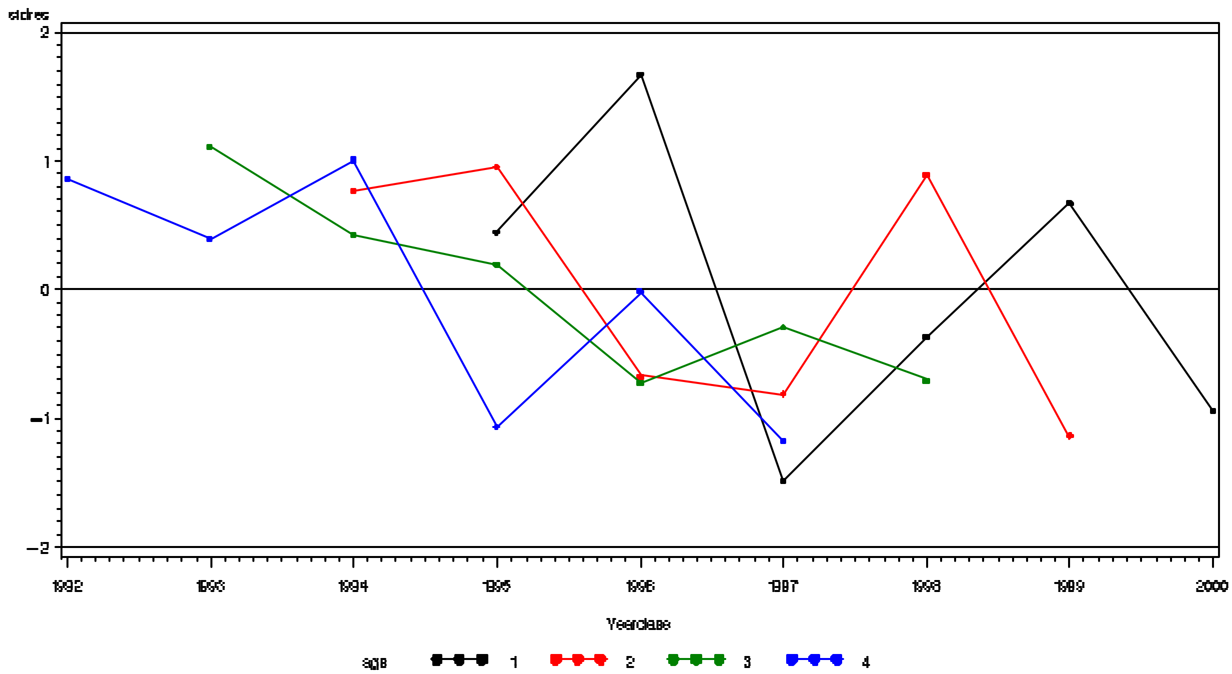

Fig. 8e. Time series of standardized residuals (by survey): from Canadian spring Div. 3LNO series (Campelen trawl; 1996-1999).

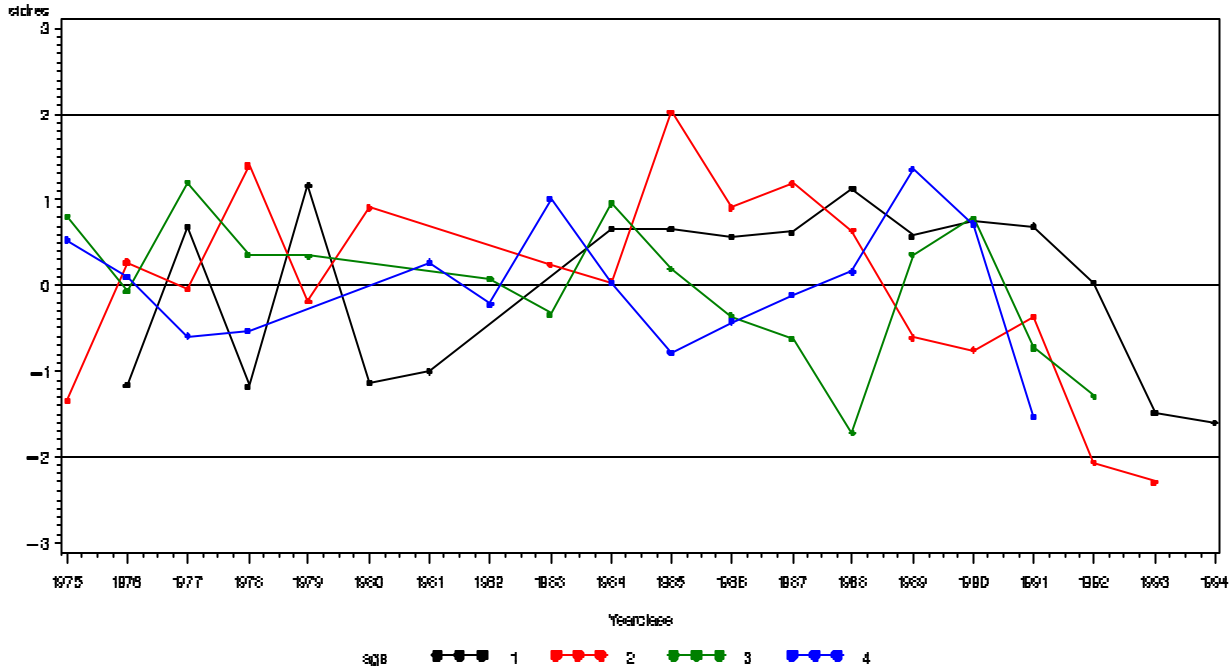

Fig. 8f. Time series of standardized residuals (by survey): from Canadian spring Div. 3L series (Engel trawl; 1977-95).

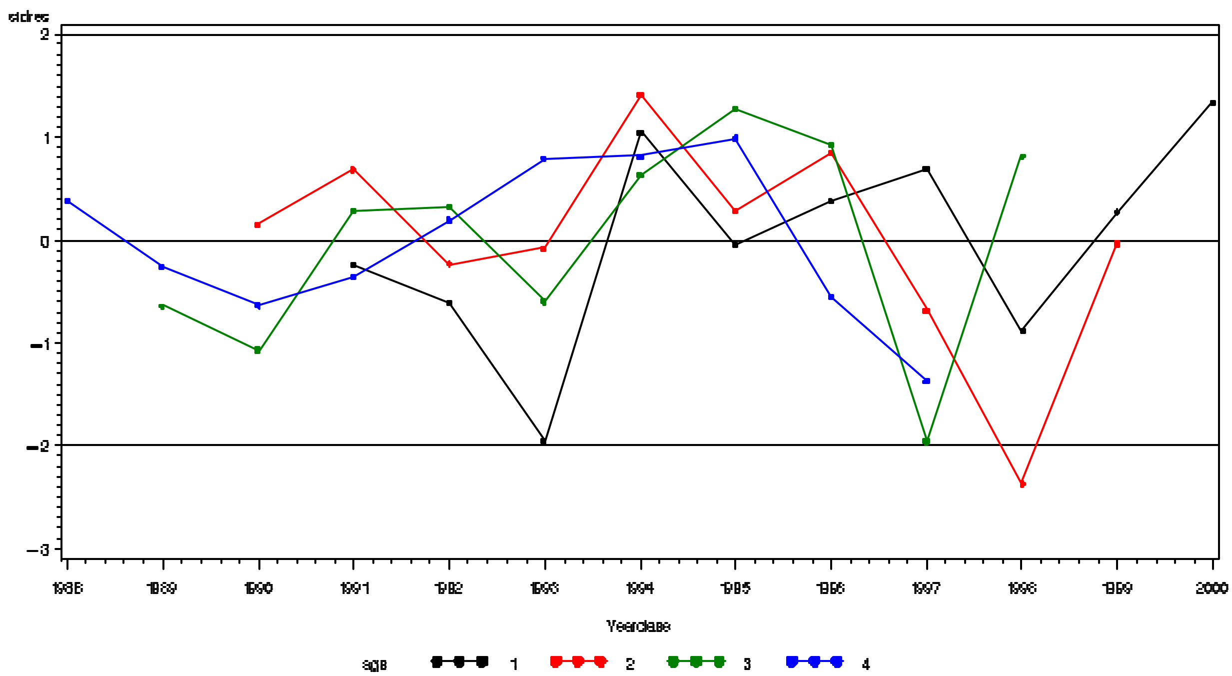

Fig. 8g. Time series of standardized residuals (by survey): from EU July Div. 3M series (1992-2000).