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

by

B. P. Healey, N. G. Cadigan, and W. B. Brodie

Science Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland, Canada AlC-5Xl

Abstract

Research survey data are analyzed to predict year-class strength from 1975 to 1998. Log-additive models with fixed 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. 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 that the most recent estimate of year class strength (1998) is below both mean and median year-class strengths.

Introduction

In the assessment of the Subarea 2 + Div. 3KLMNO Greenland halibut stock in 2000, several models and formulations of sequential population analyses (SPA) were attempted (Bowering et al, 2000). Results from these analyses 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. 2GH, Div 3LNO spring). A mixed linear model is employed to calculate an index of year class strength from these survey datasets.

Methods and Materials

Description of research vessel surveys

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 1995-2000, 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. For details on the trawls used in these surveys, see McCallum and Walsh (1996). Warren (1996) outlined the conversion factors used for G.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).

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 1996-99, and Div. 3N and 3O from 1996-99.

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 metres. For a description of the methodology and results, see Vazquez (2000). Abundance at age data were used from 1992-2000, due to some questions with age interpretations in the earlier surveys.

Thus, there are six independent data series (Table 1) available for analysis: (i) the Canadian fall 2GH series (Campelen trawl; 1996-1999), (ii) the Canadian fall 2J3KLMNO series (Campelen trawl; 1996-2000), (iii) the Canadian fall 2J3KL series (Engel trawl; 1981-1994), (iv) the Canadian spring 3L series (Yankee 41.5 trawl 1977-82; Engel trawl; 1984-95), (v) the Canadian spring 3LNO series (Campelen trawl; 1996-1999), and (vi) the EU July 3M series (1992-2000). 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 (YC) having more than three observations were included in the analysis.

Model Description

A multiplicative model was used to estimate the relative year class strength produced by the spawning stock. Similar approaches have been implemented by Shelton and Stansbury (2000) for cod in Div. 2J3KL, and by Morgan et al. (1999) for American plaice in Div. 3LNO.

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 $\varepsilon_{s,a,y}$~$N(0,\sigma^2_{group})$, (independently and identically) 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). Shelton and Stansbury (2000) selected group=survey*age, estimating a variance parameter for each survey-age combination.

The estimation of year class effects is iteratively re-weighted, using an inverse-variance weighting scheme. Lower bounds are placed on the variance parameters to prevent group estimations weights from becoming extreme. Year class and survey-age effects are also estimated. Estimates were produced using PROC MIXED in SAS version 8 (SAS Inst. Inc., 1999). This procedure provides two iterative estimation methods: maximum likelihood (ML), and restricted maximum likelihood (REML). REML seemed more appropriate because there were problems with low weights using the ML method. For further details on REML, see Searle et al (1992).

In the Canadian spring 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. To gauge the sensitivity of this assumption, model estimates were also produced by replacing zeroes with 5% of the minimum (non-zero) observation from this index, and, as there was no appreciable change (Figure 1), we applied the 1% adjustment in all subsequent analysis.

Results and Discussion

Relative Year Class Strength

The initial model used 24 covariance parameters – one for each survey*age combination (6 surveys x 4 ages). The estimated year class strength (measured by the least-squares means for YC effects) indicates moderate recruitment pulses around 1984 & 1990 (Figure 2). However, the most prominent feature of this figure is the recruitment pulse that peaks in 1994. The predicted YC strength of the 1998 YC remains at the level of the moderate 1984 & 1990 recruitment pulses. A scatter plot of standardized (by the appropriate variance parameter) residuals versus year (Figure 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 last Canadian 3L Spring survey with the Engel trawl (1995) stands out. Three of the variance parameters had active lower bounds; a chart of the corresponding weights (the maximum weight was fixed at 40) applied to the data (Figure 4) indicates that they correspond to the age 1 and 3 indices from the recent (Campelen) Canadian Fall Survey in 2GH, and the age 1 index from the (Campelen) Canadian Fall Survey in 2J3KLMNO. These indices receive over 52% of the estimation weight, and as such, they dominate this estimate of YC 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 6 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 parameter, leaving 21 variance parameters (the other 5 surveys still had a variance parameter fit to each of the 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) loglikilihood is asymptotically χ^2 distributed, with the 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 3L series (1977-95). This suggests that the other five surveys can have their survey*age variance parameters collapsed to a single parameter for each survey, but the 3L spring series cannot. The year class strength predicted by this model (9 variance parameters; Figure 5) shows similar trends to that produced from the “full” model (24 variance parameters), with a few notable differences. In the reduced model, the estimated YC strengths are higher over 1975-81, the predicted pulse in 1984 is stronger relative to neighbouring year classes than predicted in the full model; the pulse in 1994 is not as marked as in the full model; and in the reduced model, the 1998 year class is predicted to be weaker than the 1997 year class – the full model suggests it is stronger.

The variance estimates for the Canadian spring 3L series from the 9-parameter model vary across ages: the estimate for age 1 (12.00) is much larger than the estimates for ages 2-4 (1.31, 0.57, & 0.46, respectively). This discrepancy in estimates may be a result of index values of zero at age 1. This fact lead to formulating a model in which there are seven variance parameters: five variance parameters for the five surveys which had no significant differences in survey*age variance, and for the 3L spring series, a variance parameter for age 1, and a combined parameter for ages 2-4. Estimates of year class strength for this model (7 variance parameters; Figure 6; Table 3) are significant. Notable differences between the full and current model are 1) the recruitment pulse centered around 1994 is not as strong relative to the other year classes, and 2) the 1998 estimate of year class strength has declined to the level of pre-1990 predictions. In addition, the estimated YC strength in the reduced model is in general stronger for the 1975-1989 YC’s. This model is not significantly different from the “full” model, or from the previous model with 9 variance parameters (LRT; Table 2b). The estimated weights (Figure 7) indicate the variance estimate for age 1 of the Canadian spring 3L series is relatively large (and hence its estimation weight is quite small). Downweighting the survey*age index with many zeros is intuitively reasonable because the values we replace the zeros with are rather arbitrary. None of the other five surveys (each of which have one variance parameter) are estimated to have radically different variances (Table 3) – so no particular survey is dominating the estimation. We suggest this as the most parsimonious representation of these data.

A scatter plot of standardized residuals (Figure 8) 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 (Figure 9) indicate no serious departures, 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 YC strength. The model over-predicts the YC strength for the Engels data (for 1994-95) (Figure 9e) whereas the YC strength at the beginning of the subsequent Campelen series is under-predicted (1996-97; Figure 9d). Fortunately, the EU July 3M index has been consistent over the Canadian gear changeover period. The residuals from the EU survey (Figure 9f) do not follow the same pattern as the Canadian Engels/Campelen data.

Comparison to VPA

Estimates of year class strength were also produced using the same indices that were used to tune the VPA (ADAPT Formulation 1) in the 2000 assessment of this stock (Bowering et al, 2000). These estimates are highly correlated with the number of age 2's estimated in the VPA (ρ=0.935, Figure 10). However, the strength of the 1995 year-class relative to the 1994 year class is quite different in each of the analyses.

References

Bowering, W. R., W.B. Brodie, M.J. Morgan, D. Power, and D. Rivard. 2000. An assessment of Greenland halibut in NAFO Subarea 2 and Divisions 3KLMNO. NAFO SCR Doc. 00/43.

Brodie, W.B., W.R. Bowering, M.J. Morgan, D. Power, and G. Boland. 1999. Analysis of survey data for Greenland halibut in NAFO Subarea 2 and Divisions 3K. NAFO SCR Doc. 99/38, Ser. No. N4097.

Brodie, W.B., W.R.Bowering, D.Power, and D.Orr. 1997. An assessment of the Greenland halibut in NAFO Subarea 2 and Divisions 3KLMNO. NAFO SCR Doc. 97/52, Ser. No. N2886.

McCallum, B.R. and S.J. Walsh. 1996. Groundfish survey trawls used at the Northwest Atlantic Fisheries Centre, 1971 to present. NAFO SCR Doc. 96/50, Ser. No. N2726.

Morgan, M.J., W.B. Brodie, and W.R. Bowering. 1999. An Assessment of American plaice in NAFO Divisions 3LNO. NAFO SCR Doc. 99/40, Ser. No. N4099.

SAS Inst. Inc. 1999. SAS/STAT User's Guide, Version 8. SAS Institute Inc., Cary, NC, USA.

Searle, S.R., G. Casella, and C.E. McCulloch. 1992. Variance Components. New York: John Wiley & Sons, INC.

Shelton, P.A. and D.E. Stansbury. 2000. Northern cod recruitment before, during and after collapse. DFO Can. Stock. Assess. Sec. Res. Doc. 2000/089.

Vazquez, A. 2000. Results from bottom trawl survey on Flemish Cap in July, 1999. NAFO SCR Doc 00/9, Ser. No. N4228.

Warren, W.G. 1996. Report on the comparative fishing trial between the ***Gadus Atlantica*** and ***Teleost***. NAFO SCR Doc. 96/28, Serial No. N2701.

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

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

YC	Age			
	1	2	3	4
1992				21879
1993			36350	60926
1994		87771	72786	37250
1995	130386	69028	58380	30620
1996	43035	33550	19380	
1997	27710	43200		
1998	40760			

II. Canadian fall 2J3K Campelen Equivalents.*

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			

* Converted data - not used in final model.

III. Canadian fall 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			

IV. Canadian fall 2J3KLMNO series (Campelen trawl; 1996-2000).

YC	Age			
	1	2	3	4
1992				119538
1993			311981	230685
1994		503788	445849	658463
1995	847177	524914	1037073	154675
1996	236128	235549	189896	158675
1997	242891	235549	192896	
1998	242891	237549		
1999	243891			

V. Canadian spring 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 3LNO series (Campelen trawl; 1996-1999).

YC	Age			
	1	2	3	4
1992				22.53
1993			47.96	33.29
1994		43.86	53.48	65.27
1995	15.76	39.72	40.30	22.07
1996	11.91	8.67	12.00	
1997	2.28	6.19		
1998	3.14			

VII. EU July 3M series (1992-2000).

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	
1998	525	147		
1999	1602			

Table 2a. Likelihood Ratio Test to evaluate effect of reducing the number of variance parameters. The "full" model has 24 variance parameters (df), with –2 Restricted Loglikelihood= 396.8242.

Null Model*	Test Statistic	df	p-value
2GH Cdn Fall	5.97808	3	0.1127
2J3KLMNO Cdn Fall	3.18895	3	0.3634
2J3KL (Engel) Cdn Fall	6.44919	3	0.0917
3LNO (Camp.) Cdn Spring	2.89469	3	0.4081
3L (Yankee/Engel) Cdn. Spring	49.51392	3	**0.0000**
EU 3M	3.10511	3	0.3757

*Indicates survey with 1 variance parameter estimated; all others have 4 (1 at each age), so the Null Model has 21 total df.

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

Null Model	-2RLL*	df	Alternate Model	-2RLL	df	Test Statistic	df	p-value
A	422.0223	7	C	396.8242	24	25.1981	17	0.0904
B	410.3695	9	C	396.8242	24	13.5453	15	0.5603
A	422.0223	7	B	418.1717	9	3.8506	2	0.1458

*-2RLL - Residual LogLikelihood x (-2).
A - 7 vp model: 2 vp's for 3L_SPR index, other 5 surveys have 1 vp each.
B - 9 vp model: 4 vp's for 3L_SPR index, other 5 surveys have 1 vp each.
C - 24 vp model ("full" model): 4 vp's each for the 6 surveys.

Table 3. Estimated Year Class Strength from 7 variance parameter model.

Year class	Estimate	CV	DF	t Value	Pr > |t|
1978	2005.0	0.0463	160	21.61	<.0001
1979	2133.9	0.0428	160	23.37	<.0001
1980	1823.3	0.0411	160	24.35	<.0001
1981	1106.8	0.0441	160	22.68	<.0001
1982	1078.7	0.0427	160	23.43	<.0001
1983	1756.2	0.0384	160	26.05	<.0001
1984	3740.2	0.0347	160	28.8	<.0001
1985	3312.6	0.0352	160	28.38	<.0001
1986	1989.8	0.0376	160	26.59	<.0001
1987	1780.6	0.0382	160	26.21	<.0001
1988	1203.6	0.0353	160	28.32	<.0001
1989	1101.2	0.0321	160	31.19	<.0001
1990	2886.8	0.0257	160	38.95	<.0001
1991	2654.2	0.0249	160	40.22	<.0001
1992	3342.6	0.0201	160	49.65	<.0001
1993	5903.5	0.0170	160	58.81	<.0001
1994	10358.9	0.0150	160	66.69	<.0001
1995	7731.1	0.0143	160	70.12	<.0001
1996	3183.7	0.0170	160	58.96	<.0001
1997	2120.7	0.0210	160	47.56	<.0001
1998	1821.7	0.0273	160	36.58	<.0001

Table 4. Estimated Variance Parameters from the model with 7 variance parameters (2 for 3L Spring Engel Index; 1 for each of the other 5 surveys). Confidence intervals are 95% intervals.

Group	Estimate	Lower	Upper
2GH_CAMP	0.1350	0.06243	0.4771
2J3KLMNO_CAMP	0.1774	0.08942	0.5061
2J3KL_ENGL	0.3405	0.2301	0.5554
3LNO_CAMP	0.1697	0.08193	0.5368
EU_3M	0.2366	0.1395	0.4873
3L_SPR_1	11.9716	6.6167	27.9315
3L_SPR_234	0.7884	0.5201	1.3357

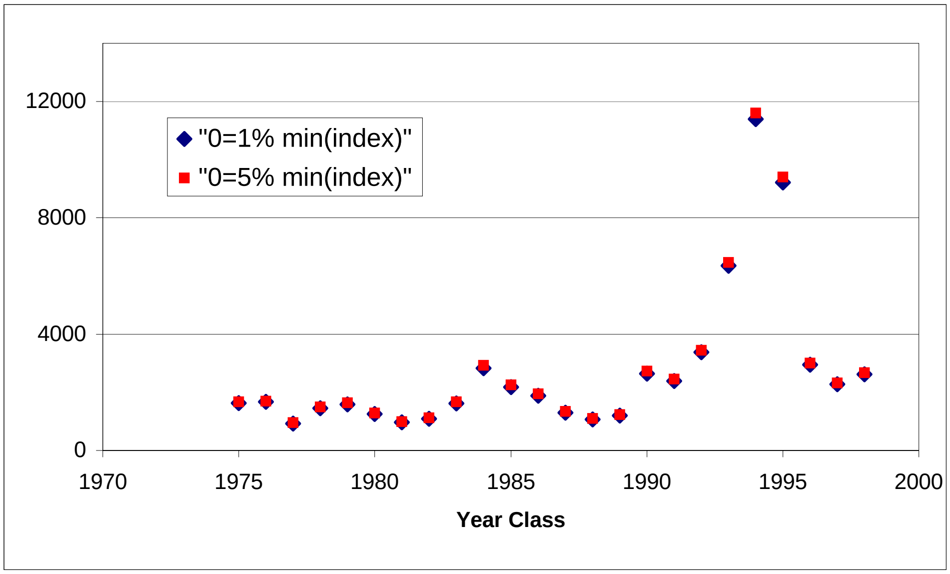

Figure 1 – Comparison of adjustments applied to zero indices for use in log-additive model.

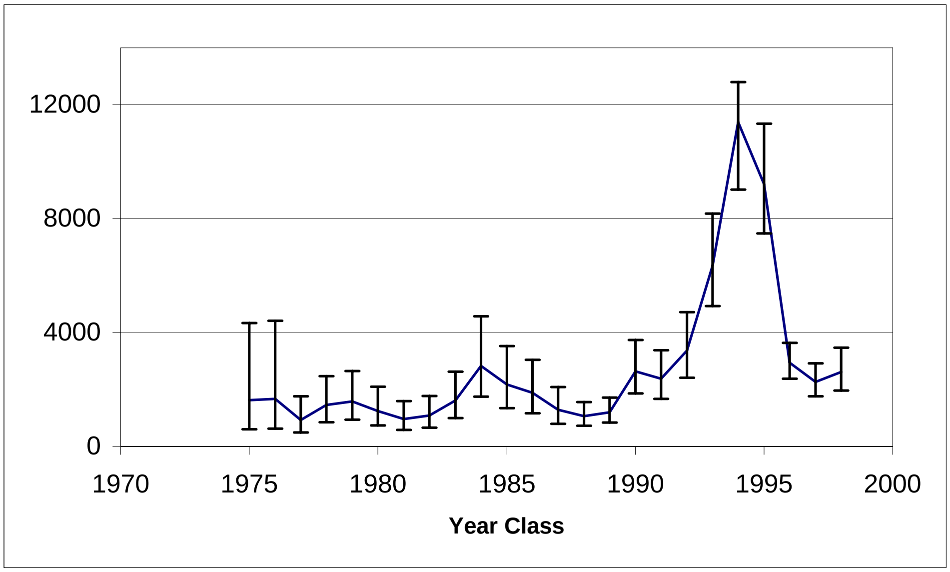

Figure 2 – YC Strength estimated from the "full" (24 variance parameter) model, +/- 2 S.E.

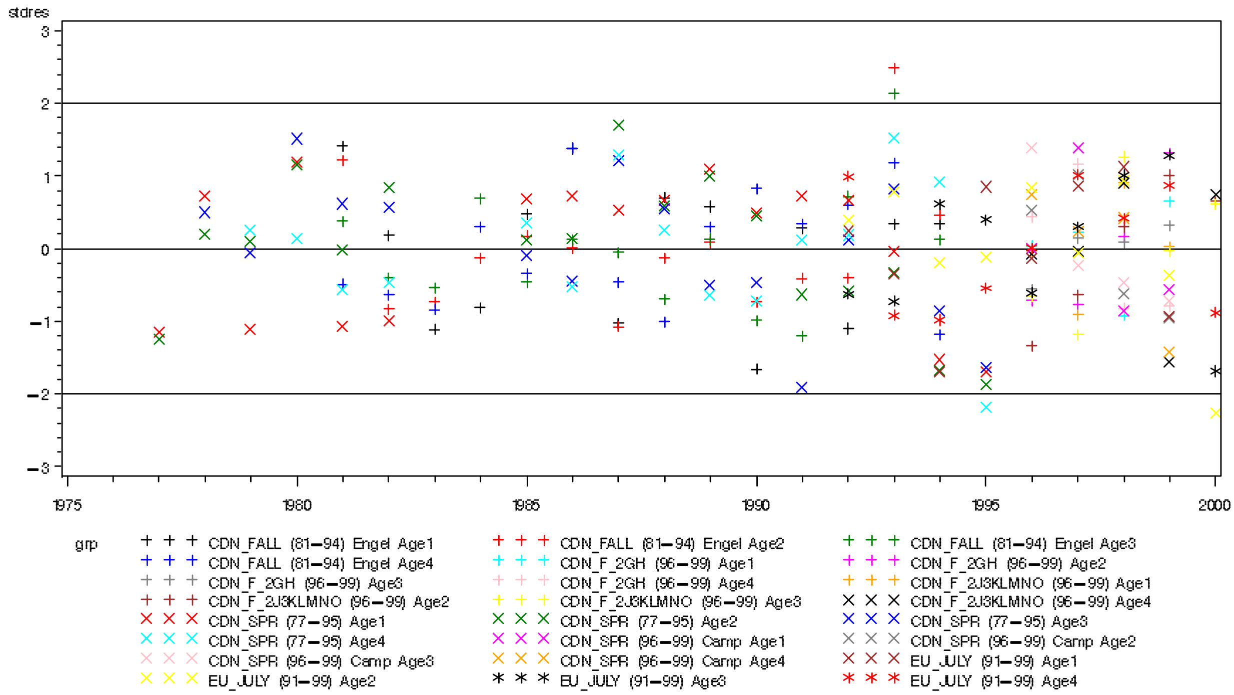

Figure 3 – Standardized Residuals from the "full" (24 variance parameter) model.

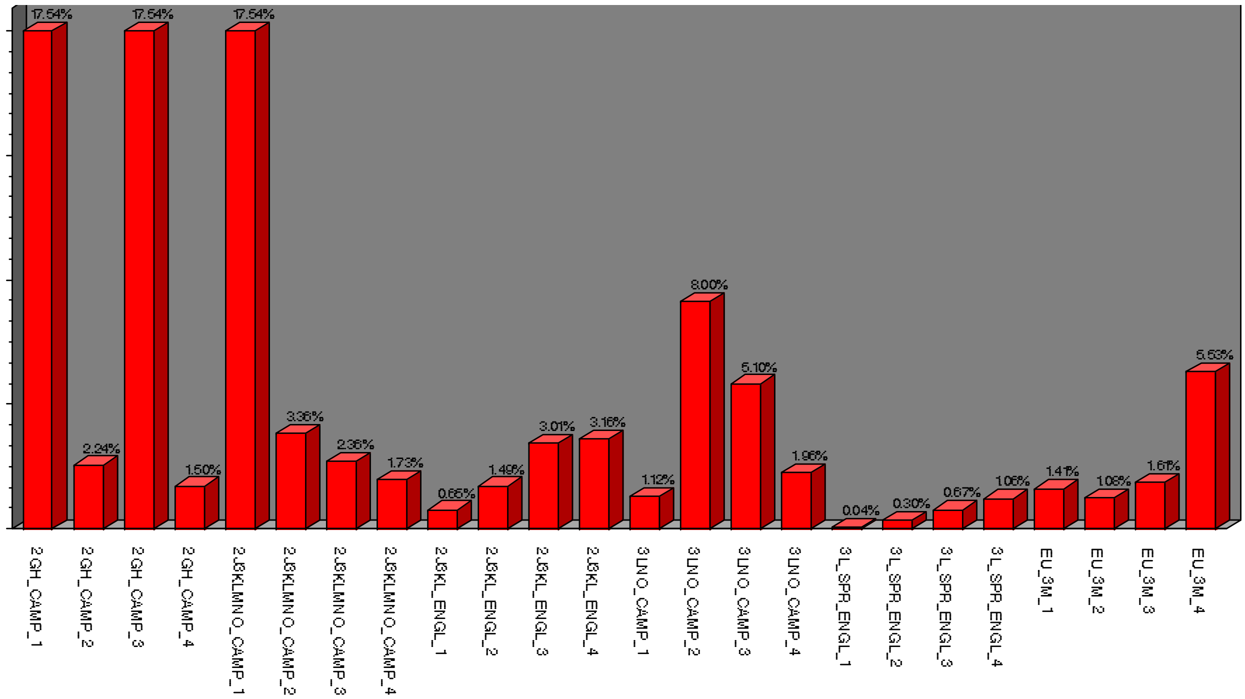

Figure 4 – Estimated weights from the "full" model run with 24 variance parameters.

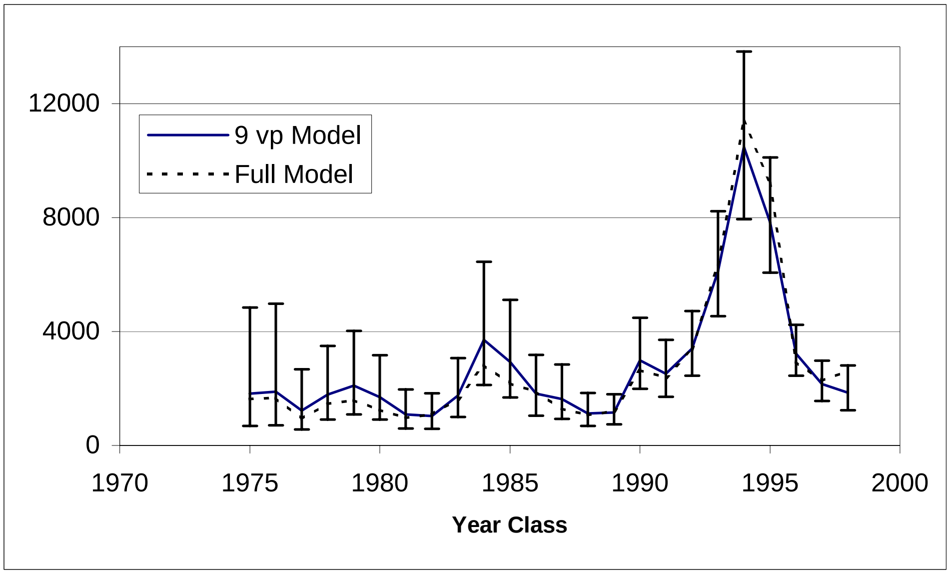

Figure 5 – YC Strength Estimate from model with 9 variance parameters – 4 for the Canadian 3L Spring Series; one for each of the other 5 surveys, +/- 2 S.E. Full model estimate included for comparison.

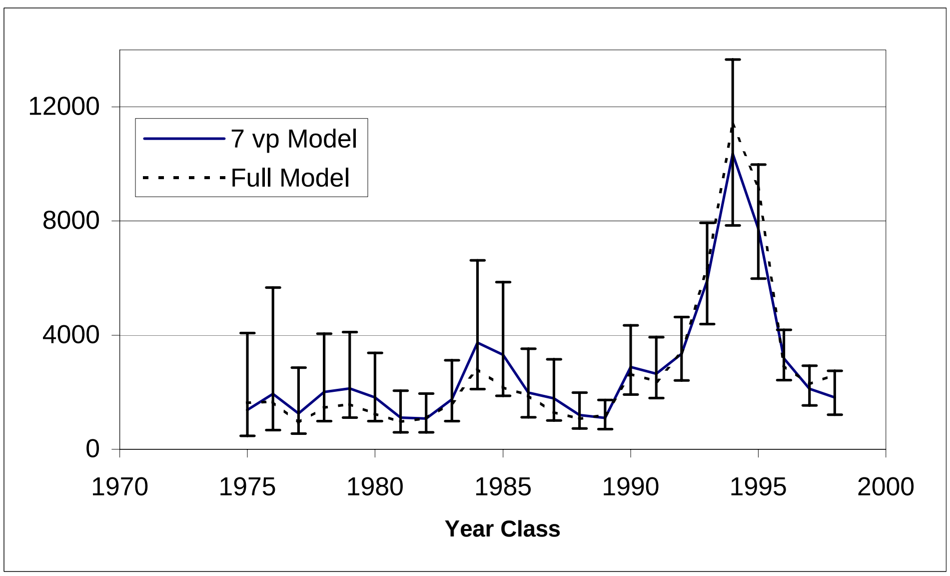

Figure 6 – YC Strength Estimate from model with 7 variance parameters – 2 for the Canadian 3L Spring Series (age1 & ages 2-4 combined); one for each of the other 5 surveys, +/- 2 S.E. Full Model estimate included for comparison.

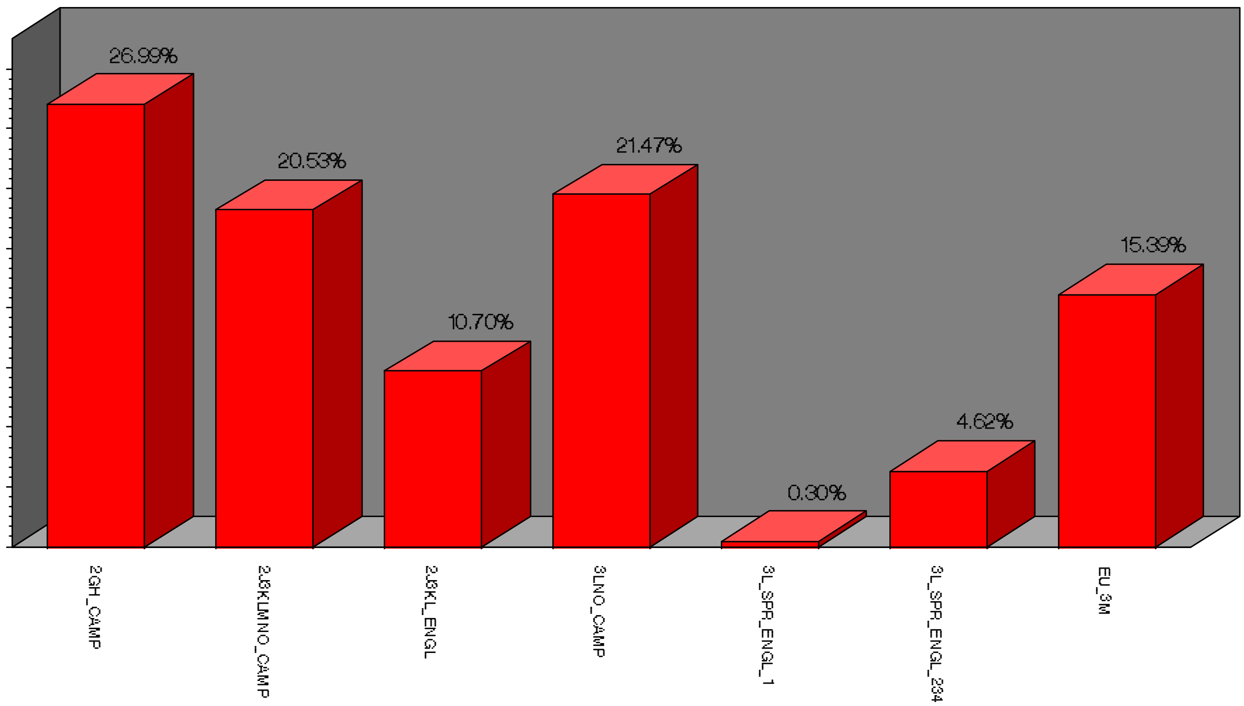

Figure 7 – Estimated weights from the7-variance parameter model.

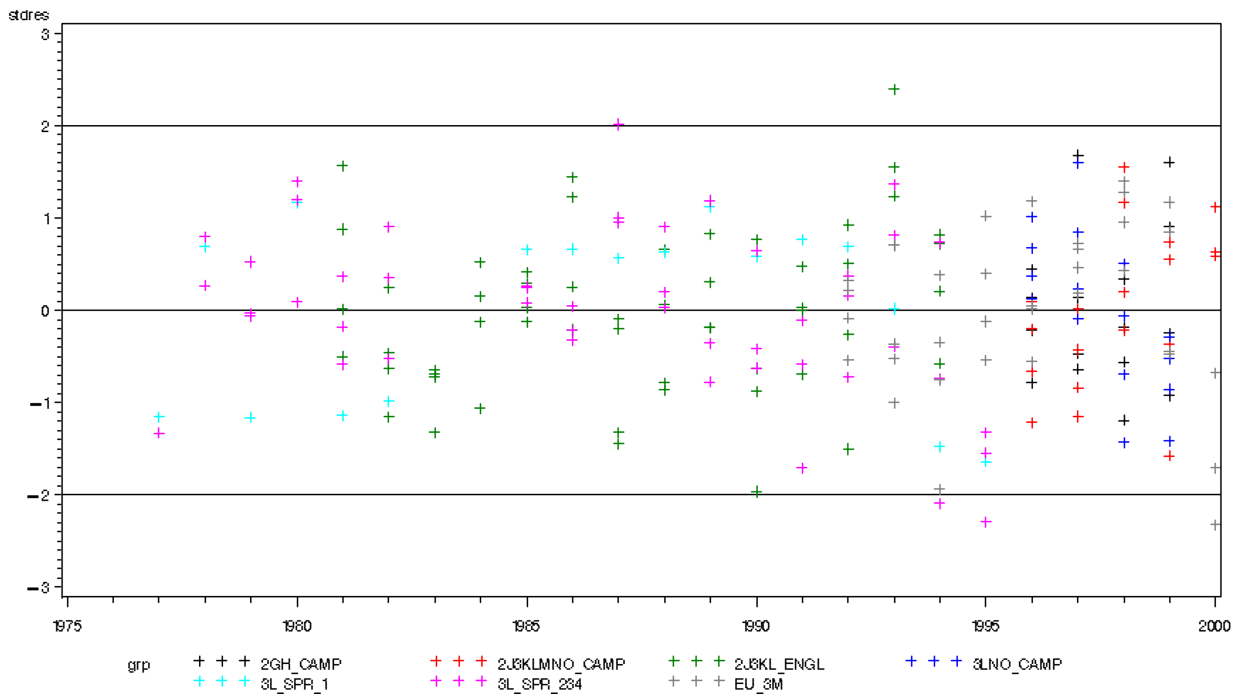

Figure 8 – Standardized Residuals from the 7-variance parameter model.

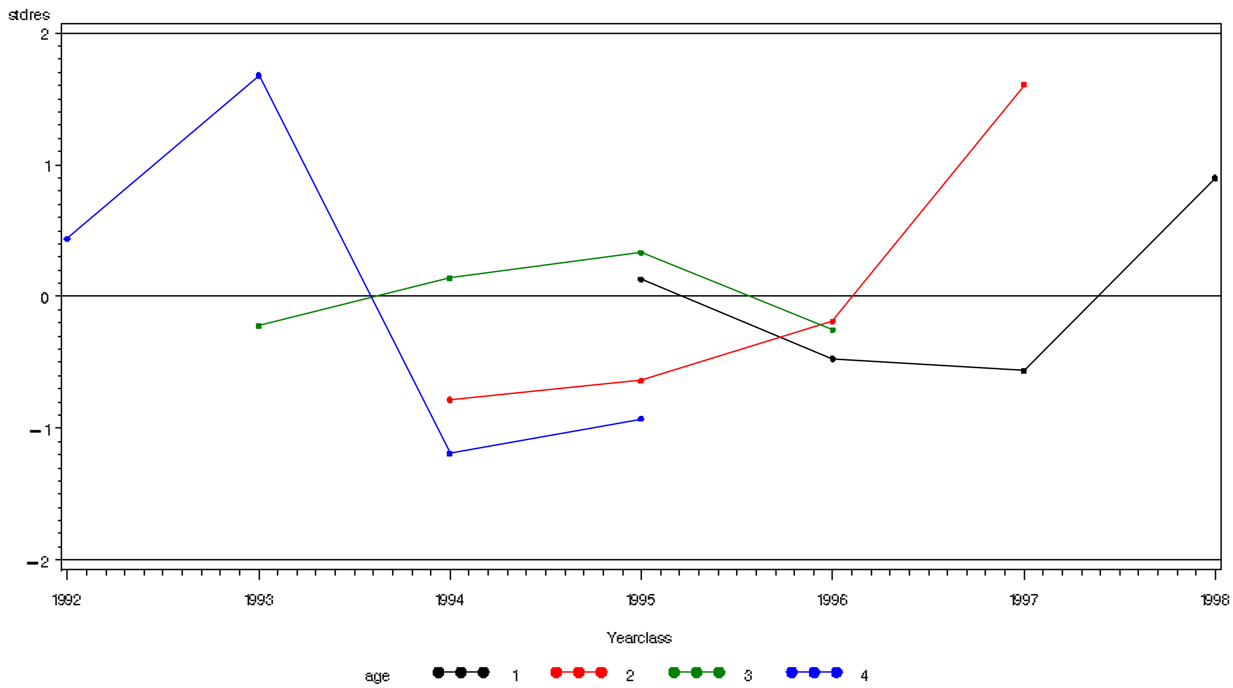

Figure 9a – Standardized Residuals from Canadian fall 2GH series (Campelen trawl; 1996-1999).

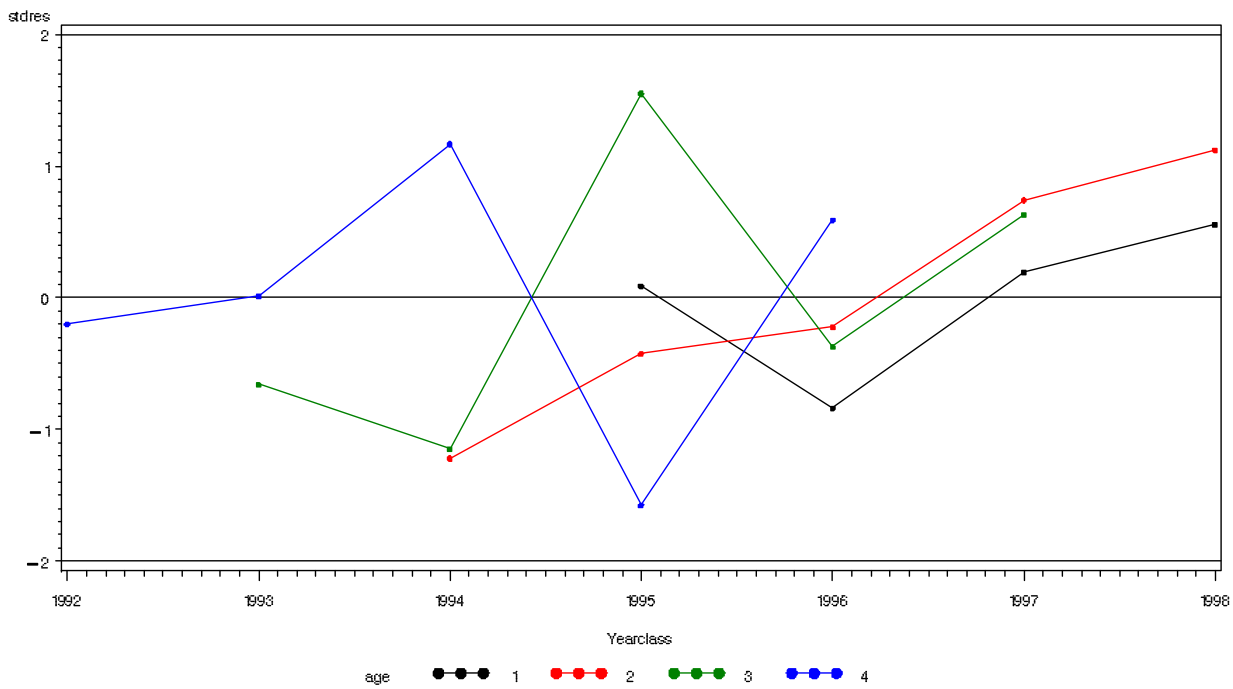

Figure 9b – Standardized Residuals from Canadian fall 2J3KLMNO series (Campelen trawl; 1996-2000).

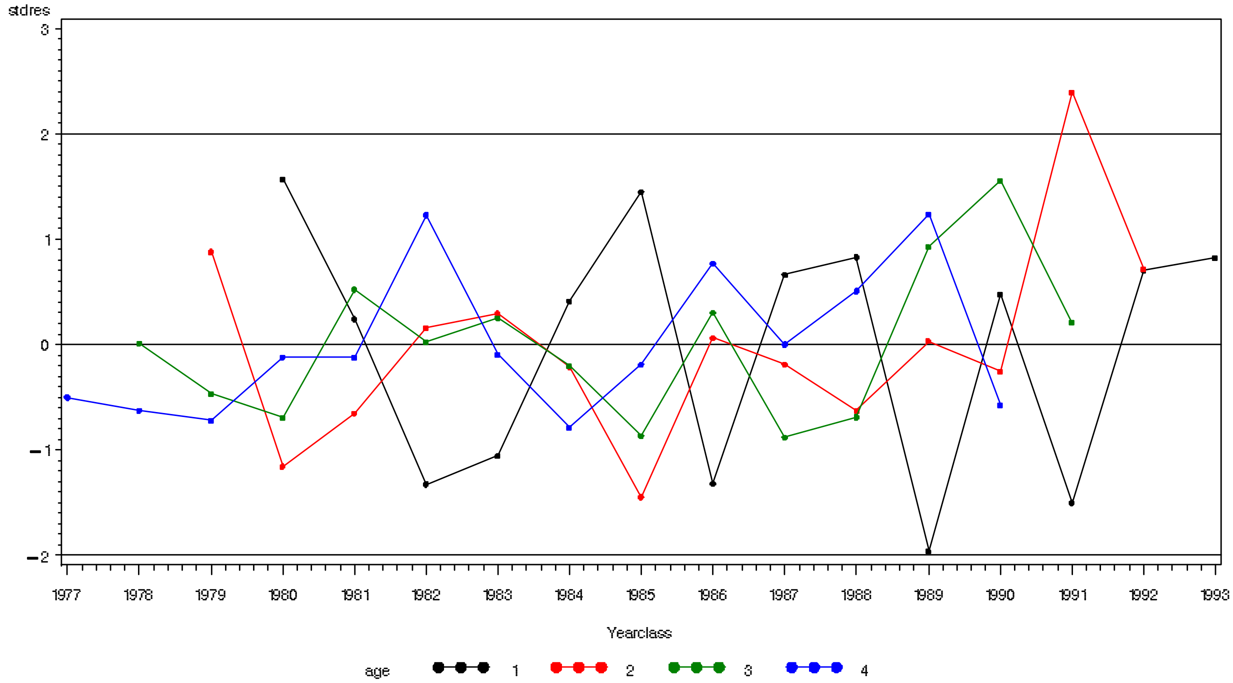

Figure 9c – Standardized Residuals from Canadian fall 2J3KL series (Engel trawl; 1981-1994).

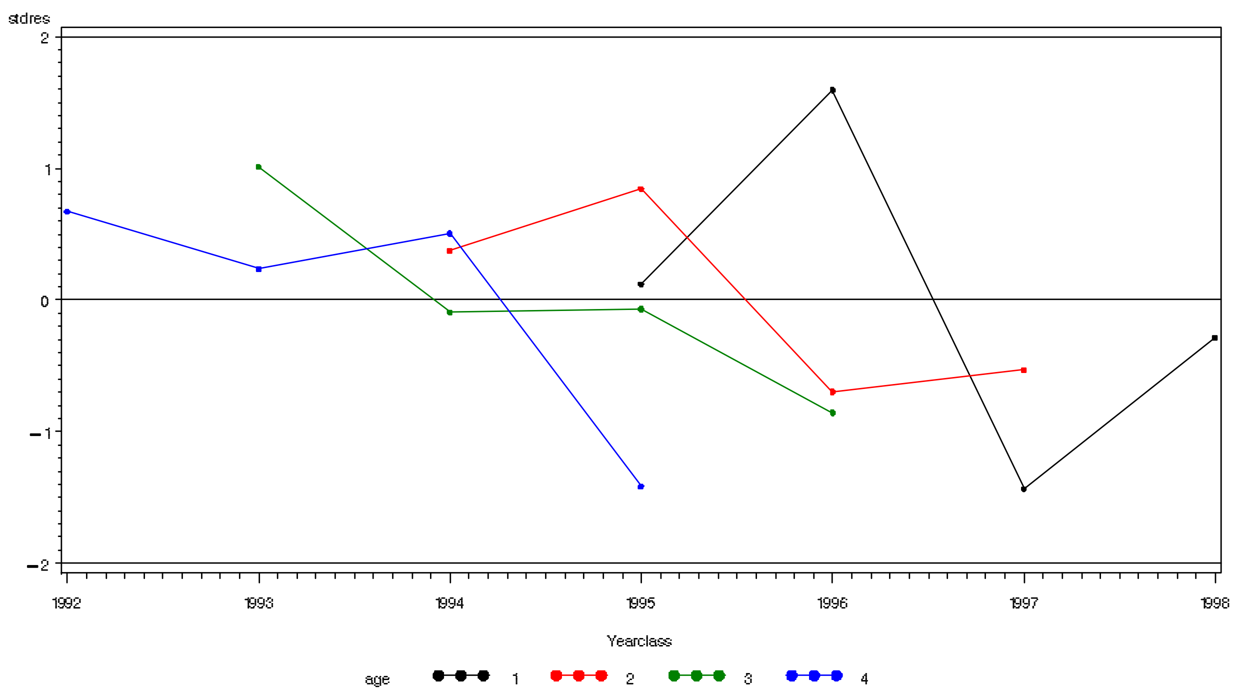

Figure 9d – Standardized Residuals from Canadian spring 3LNO series (Campelen trawl; 1996-1999).

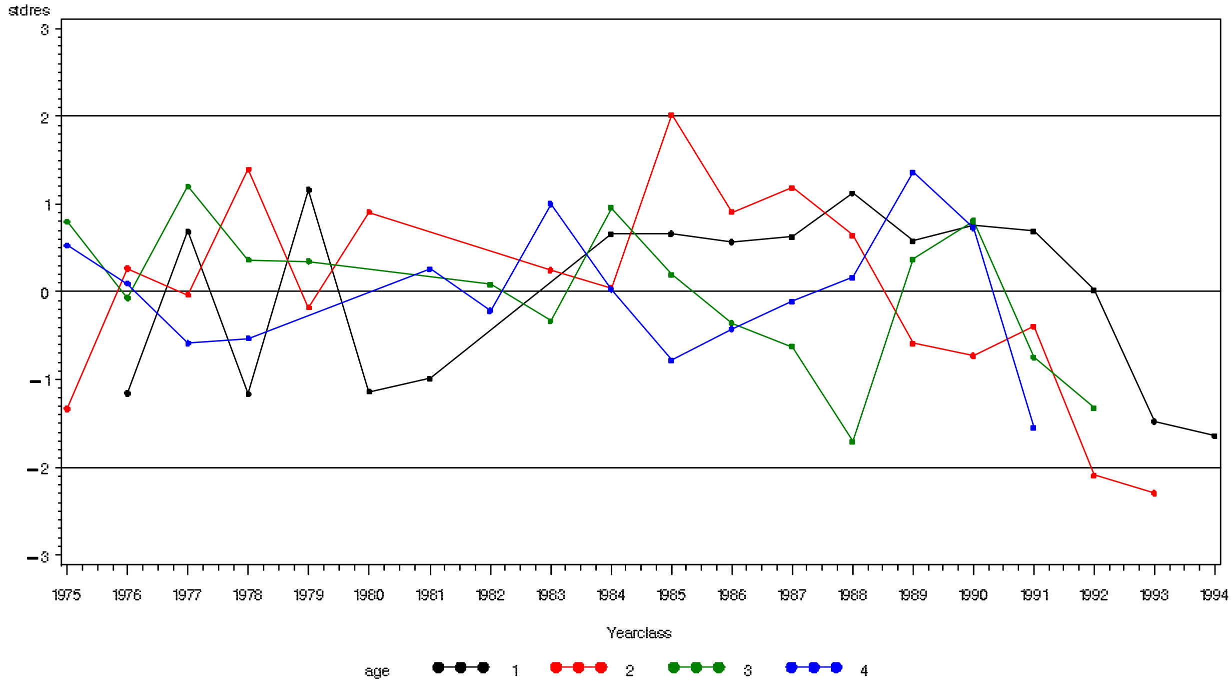

Figure 9e – Standardized Residuals from Canadian spring 3L series (Engel trawl; 1977-95).

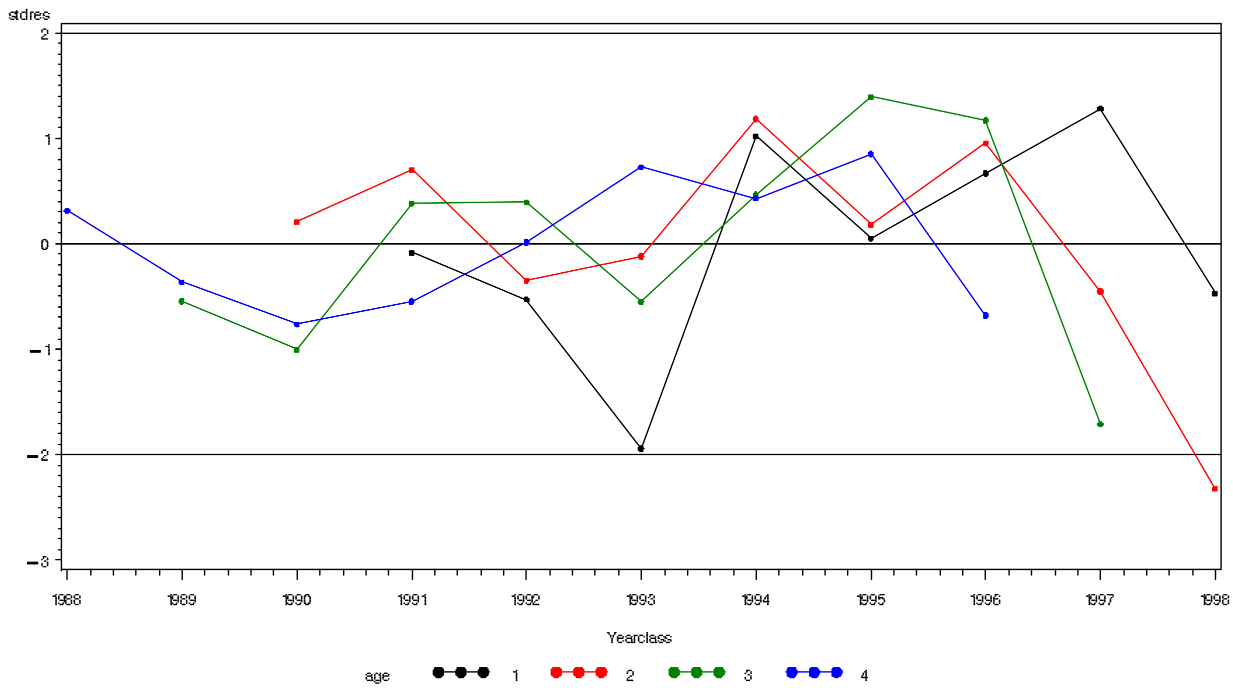

Figure 9f – Standardized Residuals from EU July 3M series (1992-2000).

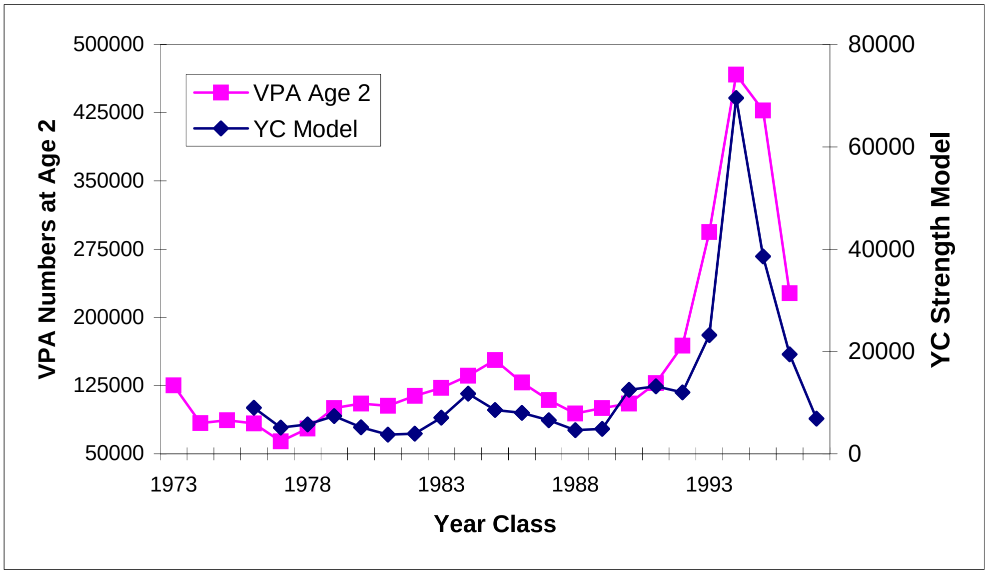

Figure 10 – Comparison of age 2 VPA estimates from Bowering et al. (2000) and YC Strength Model.