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Greenland Halibut (*Reinhardtius hippoglossoides*) in Subarea 2 and Divisions 3KLMNO: Trends in Recruitment based upon Research Vessel Survey Data

by

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Abstract

Recruitment analyses of Sub-area 2 and Divisions 3KLMNO Greenland Halibut in recent assessments have modeled survey indices at ages 1-4, as measured by several survey series throughout the stock area. The current analysis is updated with the latest available survey information. Results indicate that the 1993-1995 year-classes were the strongest produced over the time period considered (1978-2003). Recent year-classes also appear to be relatively strong, but estimates are based on information at younger ages only (primarily ages 1-3). Examination of the data from individual survey series by age indicates that the relative strengths of good year-classes tend to be much higher at the youngest ages compared to ages just prior to entry to the fishery. To evaluate the model effect we compare model estimates of year-class strength using ages 3-5 data and ages 1-4 data The results are generally similar in that the mid-1990's year-classes are still estimated to be the strongest in the time series. However, in the ages 3-5 analysis the mid-1980's year-classes are also above average and the overall year-class strengths relative to the mean are much less variable.

Introduction

Recent assessments of Greenland Halibut in Subarea 2 and Div. 3KLMNO have included analyses of recruitment using multiplicative models to model survey indices. Prior to 2003, this analysis was conducted using abundance at age data for ages 1-4 from several survey series conducted in the stock area (e.g. Healey et al. 2002). In 2003, to eliminate potential biases associated with using the abundance indices, the method was applied to standardized mean numbers per tow (MNPT; Healey *et al*., 2003), again using ages 1-4 from the same survey series. The model results using either of these data sources indicated that the estimated 1993-1995 year-classes were the strongest of those estimated (1975-2002), and that the most recent year-classes may also be above average.

In this paper we update the multiplicative analysis using an additional year of survey data. Trends in recruitment by age as inferred from the raw survey data from each survey series in this analysis are examined and discussed. This examination suggests that ages 1-4 may not be the most appropriate age range to consider for estimating year-class abundance as recruitment to the fishery. In particular, trends in recruitment at ages 1 and 2 are generally not consistent with subsequent observations of the same year-class at ages 3-5. We suggest that modeling of age 3-5 survey indices is likely more suitable for predicting recruitment to the exploitable biomass.

Model of YC Strength – Analysis of MNPT for ages 1-4

We repeat the analysis as described in Healey *et al.* (2003), using a multiplicative model to estimate the relative year class strength produced by the spawning stock as indicated from survey indices (MNPT), at ages 1-4 inclusive. The MNPT indices used in this analysis are tabled by year-class in Table 1 for each survey. Survey series included in the analysis are:

i) EU July 3M (1992-2003; Casas, 2004),
ii) Canadian Fall 2J+3K (1978-2003; Dwyer *et al*., 2004),
iii) Canadian Fall 3L (1995-2003; Dwyer *et al*., 2004),
iv) Canadian Fall 3NO, (1997-2003; Dwyer *et al*., 2004), and
v) Canadian Spring 3LNO (1996-2003; Dwyer *et al*., 2004).

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 (MNPT)
Y = year class effect
SA = Survey * Age effect, and
ε = error term.

Estimation of model parameters performed using PROC MIXED in SAS/OR software (using method=REML).

We begin by estimating a separate variance parameter for each of the 20 survey-age combinations (4 ages x 5 survey series). Subsequent to this, a model with a single variance parameter for all observations was fitted to the data. Although likelihood ratio tests (not shown) indicate that the fit of the single-variance parameter model is significantly different than the model using 20 survey-age parameters, the resulting estimates of year-class strength are virtually identical. The estimated least-square means of the year-class estimates using each of the two variance structures are plotted in Fig. 1. Results indicate that the estimated strength of almost all year-classes prior to the 1993 year-class are below average; the 1993-1995 are substantially better than all other year-classes in the time-period, and that the most recent year-classes also appear to be above average. However, the most recent estimates are based on information at the younger ages only. The estimated year-class strength of the mid-1990's year-classes is approximately 3.5 times greater than that of the mid-1980's..

Survey indices (at age) – Examination of the data

The survey indices considered in these recruitment analyses are plotted by age in Fig. 2. The horizontal line in each panel is the mean of the index for that particular age. The EU MNPT data from summer surveys in Div. 3M (Casas, 2004) are presented in Fig. 2a. For this index, the perceptions on year-class strength are fairly consistent from ages 1-5, with the exception of the 1993 year-class. Observations at ages 1-3 indicate that this year-class is either average or below average. However, the surveys at ages 4 and 5 would indicate that these year-classes are well above average.

The Canadian fall MNPT indices (Campelen or equivalent) from Div. 2J+3K are presented by age in Fig. 2b. This is the longest time series considered (1978-2003), and it is in this series that we see considerable differences in the perceptions of year-class strength at age. In particular, the relative strength of the mid-1980's year-classes as compared to that of the mid-1990's year-classes are not consistent across ages. At ages 1 and 2, the mid-1990's year-classes dominate the series; yet at ages 3-5 the difference between the strengths of the mid-1980's year-classes and the mid-1990's year-classes is slight.

The year-class strength for ages 1-5 from Canadian fall MNPT in Div. 3LNO (Fig. 2c) also varies considerably by age. In particular,1995 year-class ranges from exceptionally high at age 1 to below average at ages 4 and 5.

The Canadian spring MNPT index from Div. 3LNO (Fig. 2d) appears to be quite consistent over ages 1-5 with respect to tracking year-classes. Of note, the 1996 year-class appears as the strongest at several ages. This year-class is not considered to be strong in the other survey series.

The index data as analysed in previous recruitment studies of Greenland Halibut (e.g. Healey *et al*. 2003) indicate that ages 1-4 contain varying perceptions on the relative strength of year-classes. In particular, the Canadian fall index data from Div. 2J+3K, the only source of data prior to the 1990's is not consistent in measuring year-classes strengths. The data for ages 1 and 2 indicate considerable differences in the strength of year-classes, most particularly the differences between the mid-1980's and mid-1990's year-classes. The age 3-5 data suggest that the mid-1980's and mid-1990's year-classes were all strong year-classes, which is not reflected in the age1-4 analysis (see Fig. 1). Furthermore, correlation analyses of the survey data (Table 5 of Darby *et al.*, 2003, presented here as Table 2) reveal that the indices have improved internal consistency for ages 3-5 as compared to ages 1 and 2. This may be due in part to the fact that the younger fish may be poorly selected by the survey gear.

Model of YC Strength – Ages 3-5

Considering the age-specific differences in perceptions of year-class strength outlined in the previous section, we re-computed estimates of year-class strength. Using the same model formulation previously described, year-class strength estimates are determined from data for ages 3-5 only as these data are more consistent with the patterns observed in the recruitment to the fishery. Although age 5 fish are removed in the fishery, the estimated F at age 5 (see Table 9 in Darby *et al*., 2003) is very small relative to M throughout the time period of this analysis, with the exception of two years. In 1993 and 1994, the values of F at age 5 are much larger than all other values ($F_5 = 0.23$, and 0.46, respectively).

The initial model run with age 3-5 data estimates 15 variance parameters (3 ages x 5 survey series). The estimates of year-class strength from this model are presented in Fig. 3. Note that using ages 3-5, the final year-class which is estimable is the 2000 year-class (from age 3 data in 2003 surveys). The estimated weights for this run are given in Fig. 4.

The model was subsequently run using fewer numbers of variance parameters, and likelihood ratio tests indicate that a model with a single variance parameter is not significantly different than the full model run.

Null Model*	Test Statistic	df	p-value
One vp for each survey	21.7025	14	0.0849
Common vp	8.4429	4	0.0766

*Indicates the model compared to the full 15 variance parameter model.
(vp = variance parameter)

The estimated year-class strength for the single variance parameter run (Fig. 5) is the most parsimonious representation for the age 3-5. As noted, the 2000 year-class is estimated using age 3 data from 2003 surveys only. The 2000 year-class estimate in the weighted (15 variance parameter) model is somewhat more optimistic than the single variance parameter model. This is because the 3L Canadian Fall age 3 survey series is weighted relatively high and the 2003 value for this series at age 3 was the strongest observed since the 1993-1995 year-classes. Standardized residuals for this model run are presented in Fig. 6, which indicate no systemic problems in the estimation. As noted above, two estimates of fishing mortality at age 5 in the XSA analysis are not insignificant. The model was re-run excluding the age 5 data from these years. The difference in estimated year-class strength (not shown) is near zero for all year-classes except the 1988 and 1989 year-classes, which show slight changes due to the removal of the age 5 data used to predict these year-classes.

In comparing the results of the ages 3-5 analysis to those of the ages 1-4 run (Fig. 7), it is immediately evident that the perception of the strength of the mid-1990's year-classes relative to all others is altered. The 1993-1995 year-classes still are estimated to be the strongest over the entire time-period, about twice average, compared to about 3.5 times average in the ages 1-4 analysis. This is more consistent with the development of these year-classes in the fishery. The ages 3-5 analysis also suggests that the mid-1980's year-classes are quite strong relative to most other year-classes, and that the recent year-classes may be near average.

Retrospective Analysis

A retrospective analysis was conducted to examine the effect of excluding successive years of data. In this analysis, the interest is in year-class effects. The most recent estimates of year-class effects are computed using partial information, similar to the "incomplete" year-classes in a VPA. Consider in Fig. 5 that the 2000 year-class size is estimated from information at age 3 only, and the 1999 estimate is determined from ages 3 and 4 indices only. In Figure 8, the single variance parameter model estimate (labeled "Y=2003") is compared to the estimates obtained by removing the most recent years' data successively, conducting the analysis with 2002 back to 1999 as the terminal year. The retrospective analysis results indicate that the annual estimates are highly consistent from year to year, with slight revision to the estimates of the 1993, 1994 and 1997 year-classes as additional information is utilized.

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Table 1 – Mean Numbers per set data (ages 1-5) used to model YC Strength of Greenland Halibut.

i). Div. 3M EU July Survey (1992-2003)

YC	1	2	3	4	5
1987				1.23	1.99
1988			0.29	1.07	1.20
1989		0.00	0.36	0.71	1.70
1990	0.43	0.99	0.75	1.52	2.13
1991	1.15	1.16	1.34	1.55	3.82
1992	1.17	0.88	1.70	2.57	6.49
1993	1.03	1.74	1.90	6.41	11.40
1994	7.66	5.74	5.46	9.75	12.21
1995	3.57	2.63	6.40	8.93	6.91
1996	1.98	1.58	2.37	1.75	2.54
1997	1.79	0.53	0.39	0.85	3.40
1998	0.65	0.18	1.43	1.37	4.12
1999	1.99	1.04	2.01	2.54	
2000	5.17	2.04	0.98		
2001	2.44	1.38			
2002	2.10				

ii). Div. 2J+3K Canadian Autumn RV (Campelen or Equivalent; 1978-2003).

YC	1	2	3	4	5
1973					12.5
1974				19.52	7.47
1975			33.37	7.15	7.07
1976		40.24	13.47	5.58	6.58
1977	9.61	18.07	6.20	6.01	8.09
1978	10.81	6.53	15.42	10.81	10.45
1979	6.78	22.99	12.78	11.41	15.34
1980	19.39	5.10	10.56	10.29	9.50
1981	4.75	4.45	9.56	6.87	9.49
1982	1.66	7.11	8.71	14.64	9.62
1983	4.47	14.67	16.62	12.17	14.90
1984	24.59	13.96	29.44	17.03	17.40
1985	17.21	11.21	15.04	25.22	15.38
1986	5.04	10.54	23.84	23.39	9.05
1987	8.82	12.54	9.95	13.32	4.84
1988	7.10	5.26	6.08	13.59	5.56
1989	1.34	5.59	20.40	19.28	7.22
1990	13.80	23.78	64.00	18.90	6.63
1991	5.69	43.64	22.61	6.03	6.28
1992	8.08	21.62	15.13	9.54	10.37
1993	29.79	51.10	32.01	21.13	10.86
1994	49.93	47.82	43.61	21.87	20.04
1995	98.68	58.62	31.19	28.28	13.76
1996	28.05	25.07	24.07	13.20	9.77
1997	23.35	34.42	16.43	14.07	6.03
1998	15.99	21.94	17.00	9.68	6.39
1999	38.57	22.72	12.50	9.49	
2000	43.90	24.08	11.69		
2001	40.67	26.67			
2002	45.70				

Table 1 (cont.)

iii). Div. 3NO Canadian Autumn RV (Campelen; 1997-2003).

YC	1	2	3	4	5
1992					0.997
1993				2.026	2.492
1994			3.517	2.435	0.709
1995		2.576	1.819	0.467	0.629
1996	0.591	0.783	0.500	0.190	0.399
1997	0.363	0.201	0.058	0.343	0.453
1998	0.035	0.055	0.333	0.472	0.273
1999	0.070	0.114	0.523	0.281	
2000	0.080	0.191	0.347		
2001	0.256	0.361			
2002	0.241				

iv). Div. 3L Canadian Autumn RV (Campelen; 1995-2003).

YC	1	2	3	4	5
1991					0.827
1992				2.183	1.461
1993			4.599	3.227	4.955
1994		4.241	5.160	6.186	3.388
1995	1.621	3.924	3.847	1.982	1.954
1996	1.162	0.814	1.149	1.506	0.796
1997	0.220	0.552	1.068	0.676	0.608
1998	0.292	1.069	0.739	0.581	1.055
1999	0.793	0.714	0.603	1.569	
2000	0.565	0.572	1.663		
2001	0.642	2.137			
2002	0.926				

v). Div. 3LNO Canadian Spring RV (Campelen; 1996-2003).

YC	1	2	3	4	5
1991				0.769	2.307
1992			1.331	2.478	4.306
1993		3.252	5.886	4.650	6.186
1994	4.489	4.569	4.777	5.153	3.228
1995	5.259	3.680	2.686	1.485	2.227
1996	1.856	2.141	0.659	1.309	1.568
1997	1.180	0.896	0.721	1.845	1.833
1998	0.108	1.853	1.159	1.545	2.001
1999	3.234	0.800	1.284	2.756	
2000	2.745	1.239	2.510		
2001	2.402	1.800			
2002	3.131				

Table 2. Internal consistency - Correlation coefficients Ln(Na+1,y+1)/Ln(Na,y). (Table 5 of Darby *et al.*, 2003).

	Can RV0		Can RV4		Can RV5		EU Surv.	
	R	N	R	N	R	N	R	N
Age1/2	0.22	16	0.66	7	0.60	6	0.72	11
Age2/3	0.38	16	0.80	7	0.85	6	0.68	10
Age3/4	0.38	16	0.80	7	0.92	6	0.88	11
Age4/5	0.26	16	0.70	7	0.87	6	0.87	11
Age5/6	0.65	16	0.73	7	0.76	6	0.86	11
Age6/7	0.74	16	0.29	7	0.44	6	0.84	11
Age7/8	0.80	16	0.36	7	-0.03	6	0.20	11
Age8/9	0.91	16	-0.50	7			-0.57	11

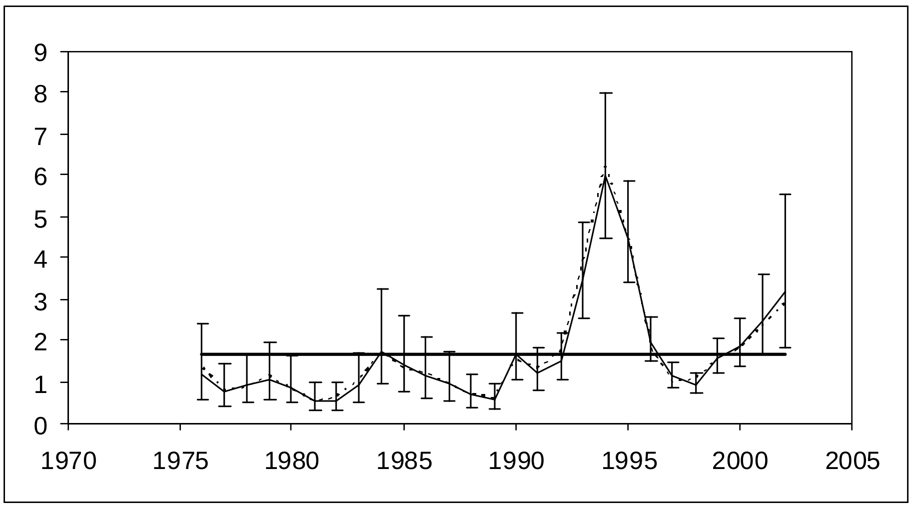

Fig. 1. Estimated year-class strength for Greenland halibut using survey indices ages 1-4. The solid line and error bars are from the model run using a single variance parameter. The dashed line indicates the model fit from the formulation using 20 variance parameters. The thick horizontal line demarcates the mean year-class strength.

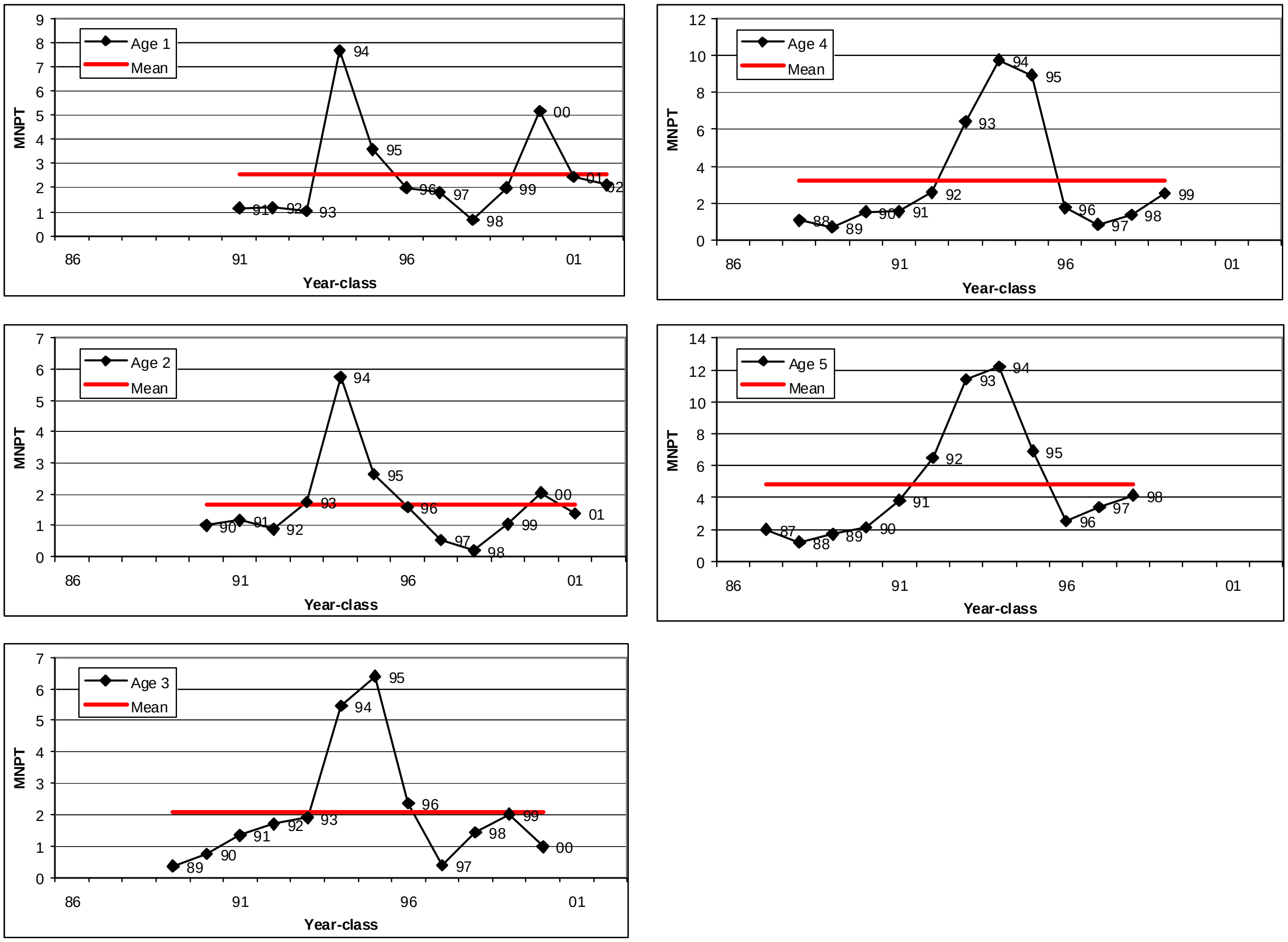

Fig. 2a: EU Div. 3M Survey data (July; 1992-2003) at ages 1-5.

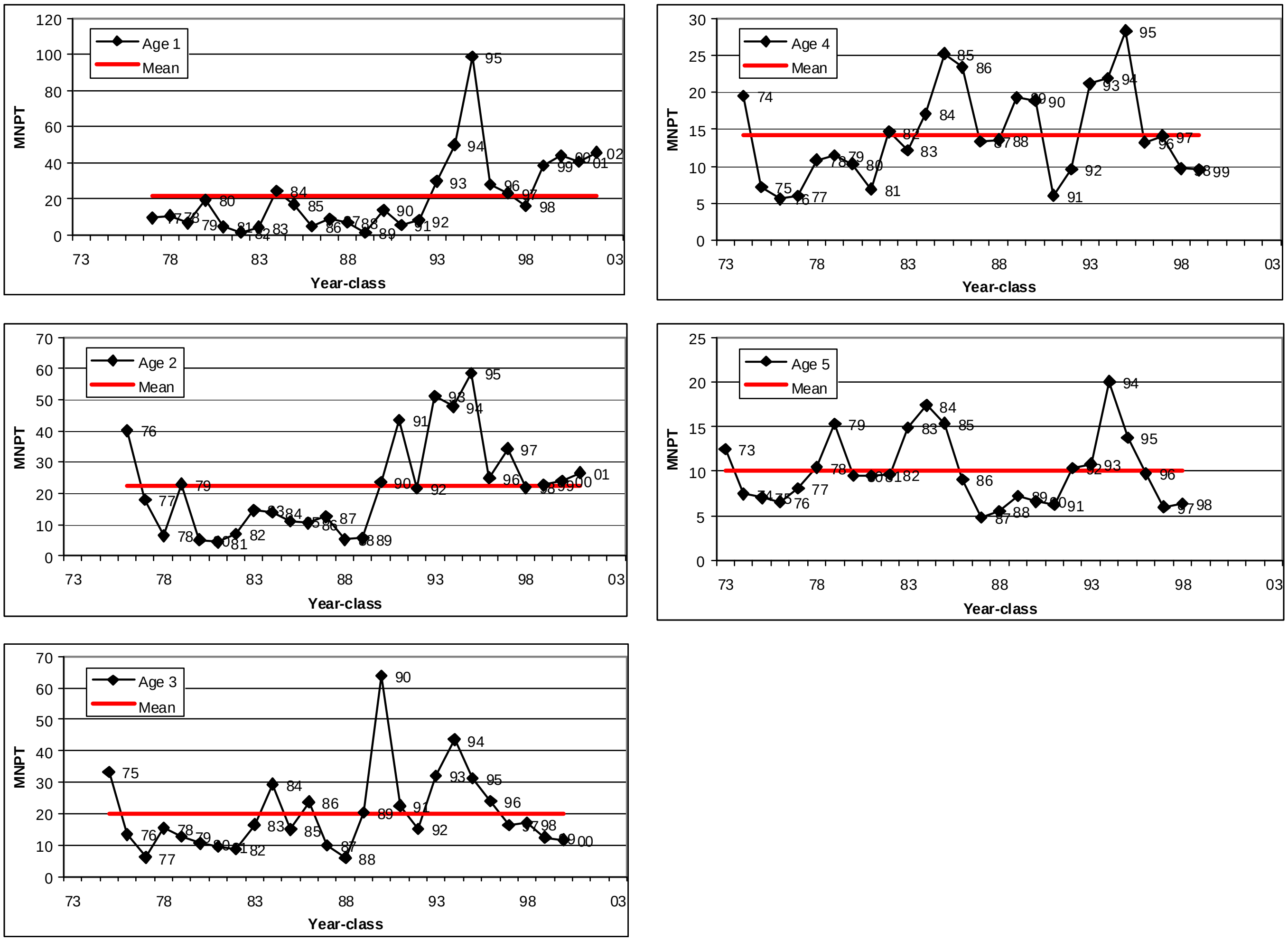

Fig. 2b: Canadian Div. 2J3K data (Autumn; 1978-2003) at ages 1-5.

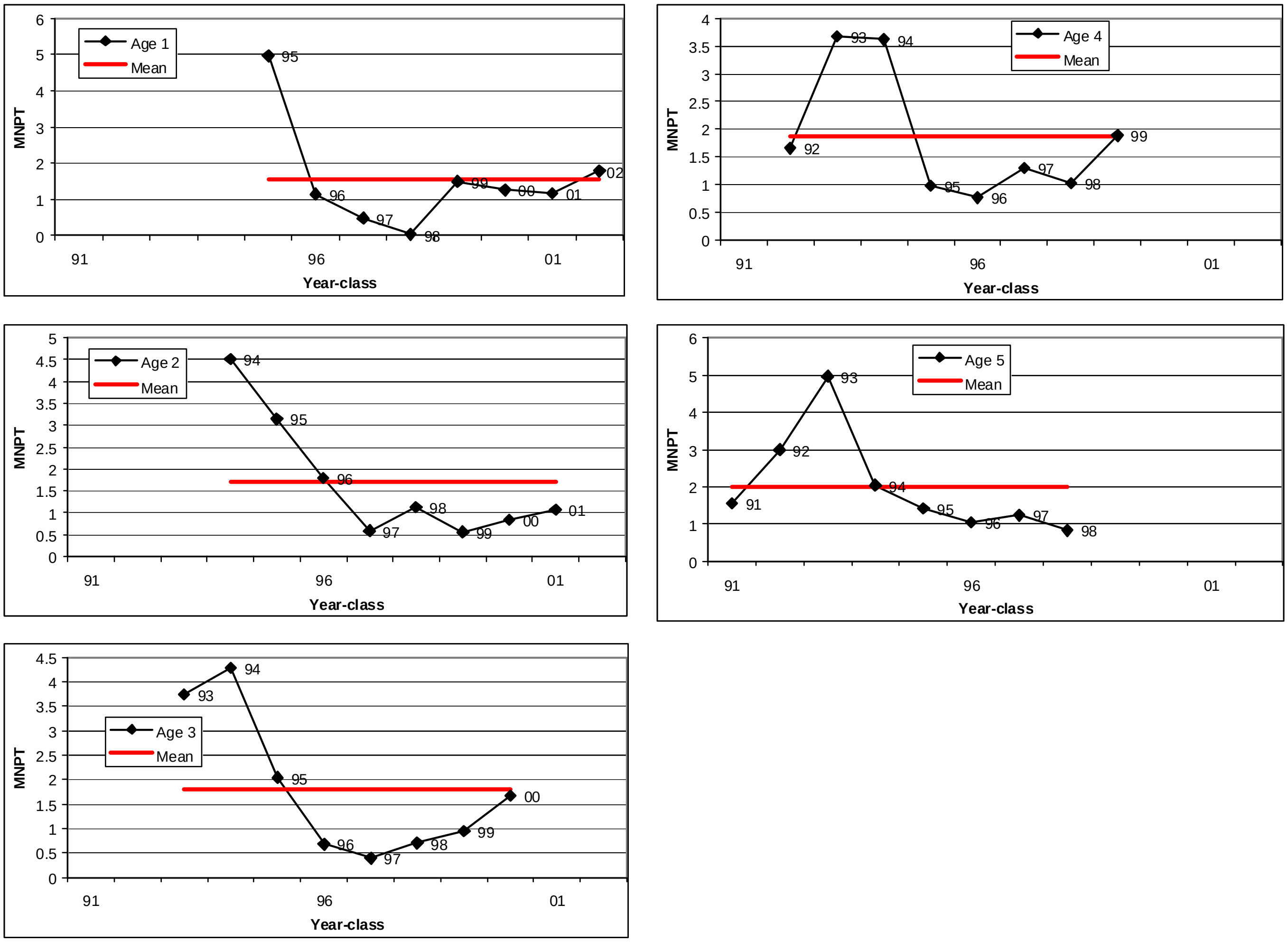

Fig. 2c: Canadian Div. 3LNO data (Autumn; 1996-2003) at ages 1-5.

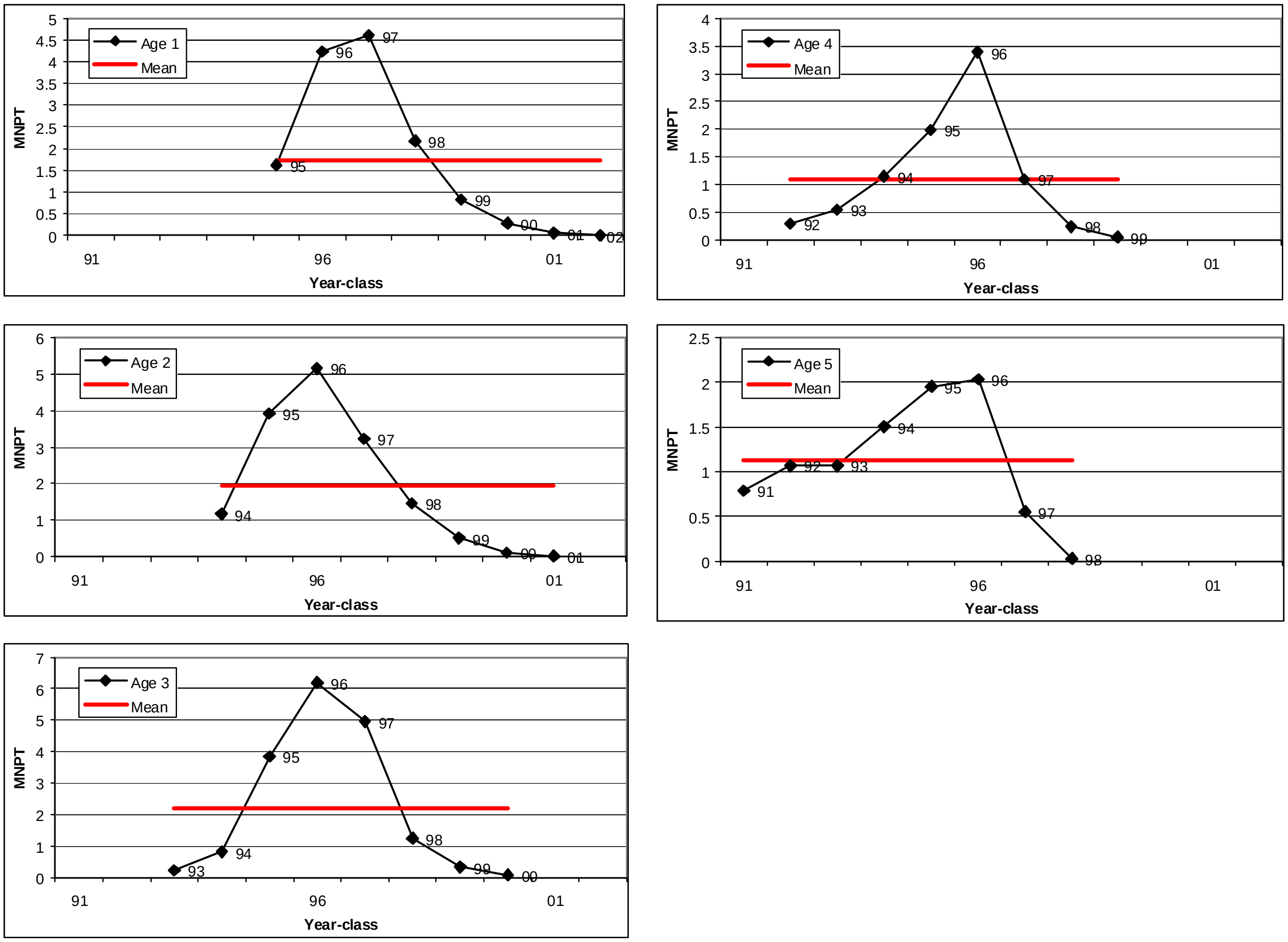

Fig. 2d: Canadian Div. 3LNO data (Spring; 1996-2003) at ages 1-5.

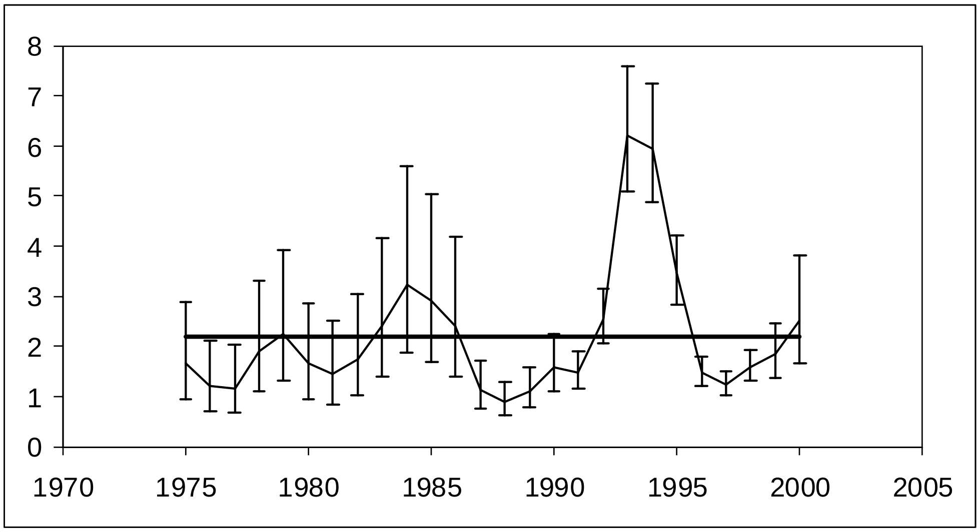

Fig. 3. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's); 15 survey-age variance parameters estimated. The solid horizontal line is the mean year-class strength.

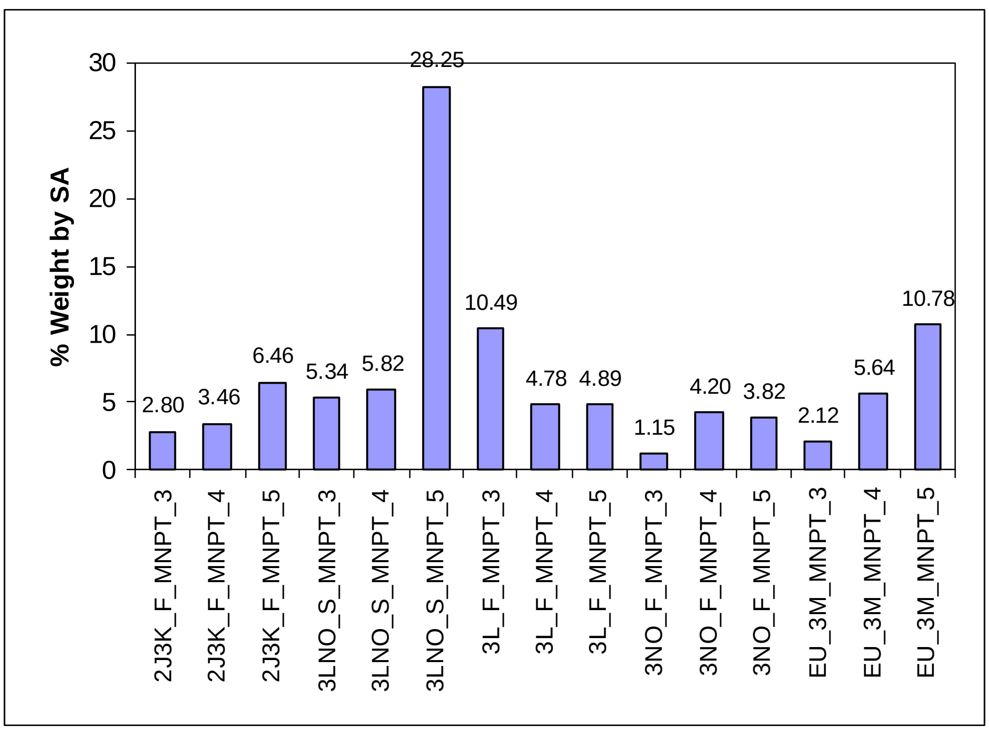

Fig. 4: Estimated survey-age weights (%) using age 3-5 MNPT.

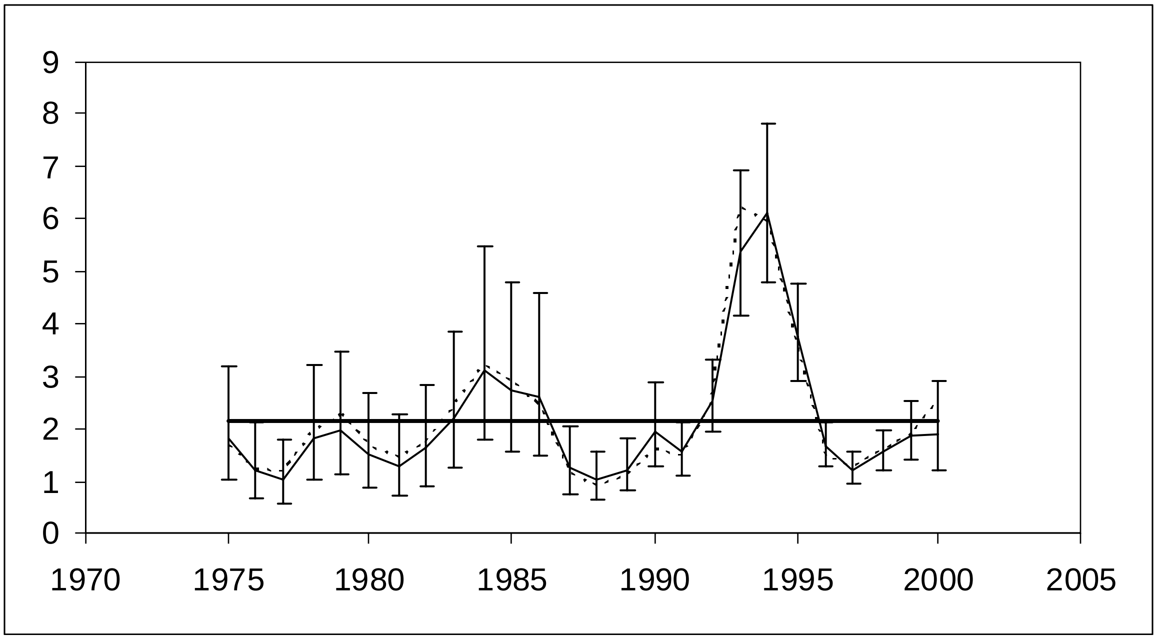

Fig. 5. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's) with a single variance parameter estimated. The dashed line indicates the model fit using 15 variance parameters. The solid line is the mean estimate of year-class strength from the single variance parameter model.

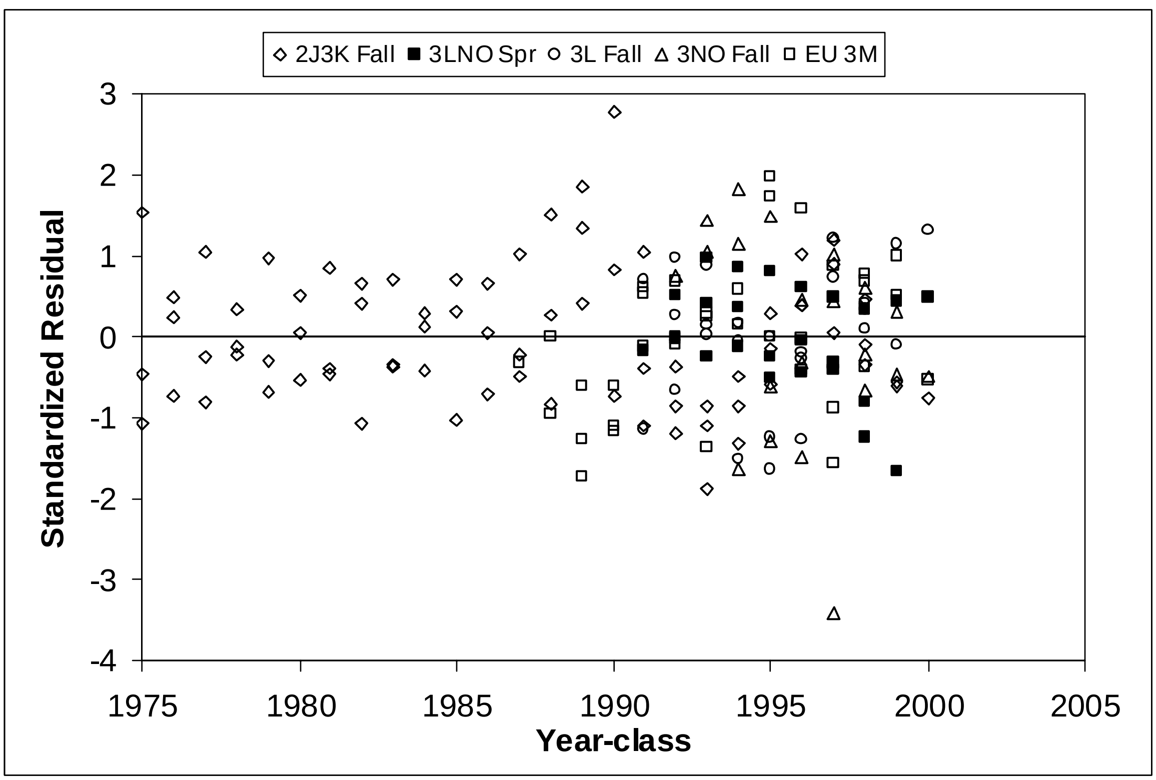

Fig. 6. Standardized residuals of final estimates of year-class strength (ages 3-5 MNPT data; 1 variance parameter).

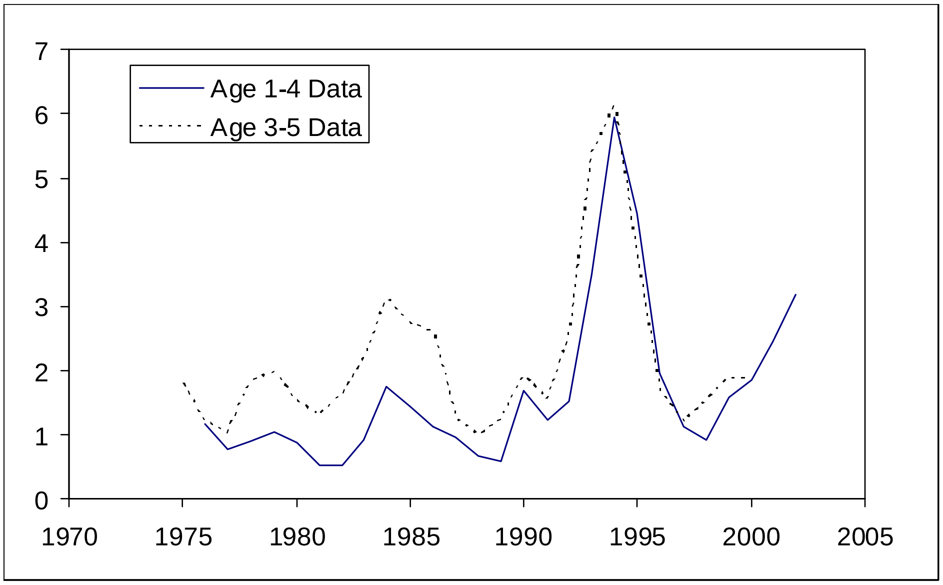

Fig. 7. Comparison of estimates of year-class strength from models fitted to MNPT data at ages 1-4 and ages 3-5.

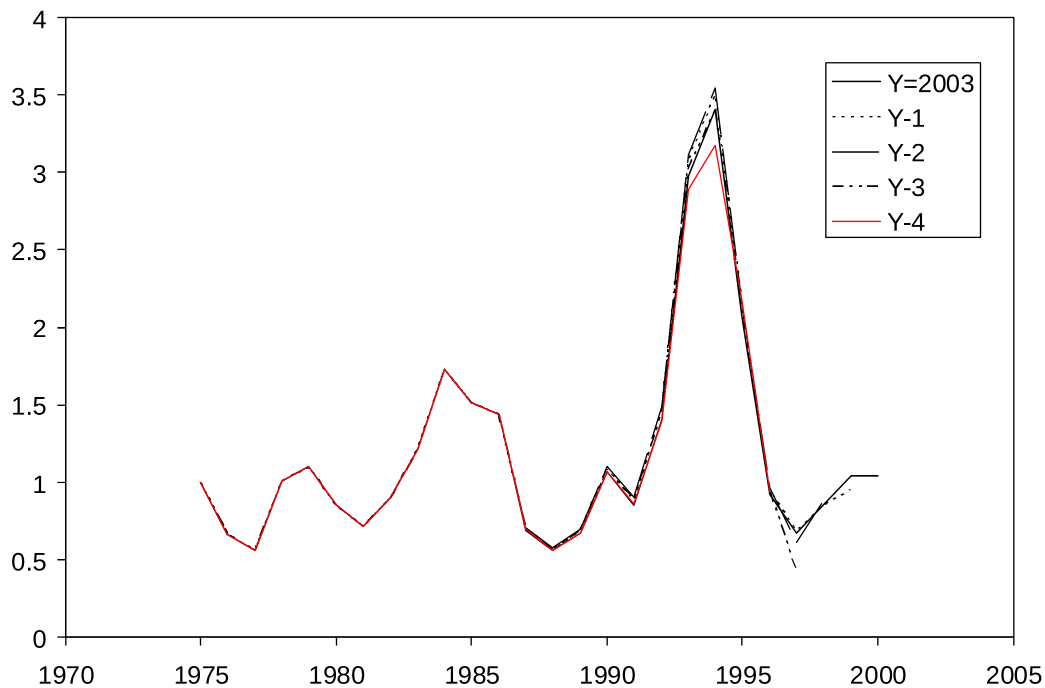

Fig. 8. Restrospective analysis of estimates of year-class strength from models fitted to MNPT data at ages 3-5. For ease of comparison, the 1975 year-class is scaled to one in each series.