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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 have modeled survey indices of juveniles measured by several survey series throughout the stock area. In 2004, the final analysis examined the estimated trends as predicted from ages 3-5 indices. This analysis is updated with the latest available survey information. We also examine the inclusion of the age-aggregated Spanish survey results from Div. 3NO. Results indicate that the 1993-1995 year-classes were the strongest produced over the time period considered (1978-2004). The 1996-2000 year-classes are estimated to be of below average strength; the 2001 cohort is estimated to be slightly above average, albeit with wide confidence intervals.

Introduction

Recent assessments of Greenland Halibut in Subarea 2 and Div. 3KLMNO have included analysis of survey indices using multiplicative models to estimate the relative strength of recruiting year-classes. 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 1993-95 year-classes were the strongest of those estimated (1975-2002), and that the most recent year-classes may also be above average.

In 2004, an examination of the trends in recruitment as inferred from the survey data (Healey *et al*., 2004) suggested 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. It was concluded that modeling of age 3-5 survey indices is likely more suitable for predicting recruitment to the exploitable biomass. The resultant estimates of year-class strength are presented in Fig. 1.

In the current assessment, there are several issues requiring investigation. The Canadian autumn survey in 2004 was not completed (Brodie, 2005), and inclusion of the MNPT data from Div. 3L and from Div. 3NO is perhaps not advisable (see Healey and Dwyer, 2005, for discussion and justification). Secondly, the Spanish survey from Div. 3NO (González Troncoso *et al*., 2005) has been age-disaggregated and is examined for ability to detect strong year classes which have been observed in the other survey indices. Thirdly, we explore the impact of including the revised MNPT series from the EU survey of Div. 3M, which has been converted to account for a vessel change during the survey time series (Casas and González Troncoso, 2005, González Troncoso and Casas, 2005**).**

Survey indices (at age) – Examination of the data

The MNPT indices available for analysis are tabled by year-class in Table 1 for each survey. The available surveys are:

i) EU July 3M (1992-2004; Casas and González Troncoso, 2005),
ii) Canadian Fall 2J3K (1978-2004; Dwyer and Healey, 2005),
iii) Canadian Fall 3L (1995-2004; Dwyer and Healey, 2005),
iv) Canadian Fall 3NO, (1997-2004; Dwyer and Healey, 2005),
v) Canadian Spring 3LNO (1996-2004; Dwyer and Healey, 2005), and
vi) EU-Spain Summer 3NO (1997-2004, González Troncoso *et al.*, 2005).

Note that the 1999 age 5 data for the Canadian Fall 3NO series tabled in Healey *et al.* (2004) was incorrect; the correct value appears in Table 1.

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. Although the focus is upon ages 3-5, we include the data for ages 1 and 2 as well to indicate survey trends at the ages which aren't fully recruited to the survey gear.

The EU MNPT data from summer surveys in Div. 3M (Casas and González Troncoso, 2005) are presented in Fig. 2a. As noted previously, this index has been revised to account for vessel changes over the time series. This index has clearly observed the strong year-classes of 1993-1995. Ages 3 and 5 indicate that the 1999 cohort is 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 available (1978-2004), and it is from this series that the cohort strength estimates prior to the early 1990's are produced. Results indicate that all recent year-classes have been below average.

The year-class strength for ages 1-5 from Canadian fall MNPT in Div. 3L (Fig. 2c) clearly measures the 1993-1994 cohorts as being above average; the 1995 year-class is measured as average or below average. In addition, results indicate that the 2000 cohort is about average, following the below-average year-classes of the late 1990s.

The age 3-5 data from the Canadian fall MNPT from Div. 3NO (Fig. 2d) indicates that all recent year classes are below average.

The Canadian spring MNPT index from Divisions 3LNO (Figure 2e) also indicates that recent year-classes are all below average.

The Spanish summer MNPT index from Div. 3NO has recently been age-disaggregated (González Troncoso *et al.*, 2005); plots of this index at ages 1-5 (Fig. 2f) suggests some evidence of year-effects as with the Canadian autumn Div. 3NO index. For ages 3-5, the Spanish index indicates an fairly substantial increase from 1997 to 1998 and 1999, subsequent to which the index has been relatively low, yet showing an increasing trend since 2000. Of note, the 1994 cohort was below average at age 3, as was the 1993 cohort in the age 4 data.

Model of YC Strength – Analysis of MNPT for ages 3-5

Using a multiplicative model to estimate the relative year class strength produced by the spawning stock as indicated from survey indices (MNPT), at ages 3-5 inclusive, we repeat the analysis described in Healey *et al.* (2004). As pointed out in Healey *et al.* (2004), although age 5 fish are removed in the fishery, the estimated F at age 5 (see Table 7 in Darby *et al.*, 2004) is very small relative to M (0.2) throughout the time period of this analysis, with the exception of three years. In 1993, 1994, and 2003, the estimated values of F at age 5 are much larger than all other values ($F5$ = 0.24, 0.47, and 0.19, respectively).

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).

Due to the availability of the Spanish 3NO survey as an age-aggregated index (González Troncoso *et al*., 2005), the conversion (vessel change) of the EU survey (González Troncoso and Casas, 2005), and the problems noted with the 2004 Canadian autumn survey (Healey and Dwyer, 2005), some comparative analyses are required. The results for several datasets are inluded below.

Dataset #1

We begin by modeling the cohort strength using ages 3-5 from the following data series: the EU July 3M series, the Canadian autumn 2J3K, the Canadian autumn 3L series, excluding the 2004 data from 3L due to the problems noted in Healey and Dwyer (2005), the Canadian autumn 3NO series (also excluding the 2004 data), and the Canadian spring 3LNO series.

Following the established approach of this method, we fit a model first using 15 survey-age variance parameters (3 ages x 5 surveys). Subsequently, a model including a variance parameter for each survey, and an additional model with a common varaince parameter for all data are fitted to the data. Likelihood ratio tests (not shown) indicate that the model with a common variance parameter is not significantly different than the other two models. The estimates of relative year-class strength for this dataset (Fig. 3) are contrasted with the results from the final estimates from the previous assessment (Healey *et al*., 2004). Results indicate minimal difference between the estimates; i.e. the revised EU series does not change perceptions of year-class strength. The limited data available for the 2001 year-class (age 3 in the EU 3M survey, Canadian 2J3K autumn survey and the Canadian 3LNO spring survey) suggests that this year-class is stronger than recent cohorts, albeit with large confidence intervals.

Dataset #2

Healey and Dwyer (2005) discuss the variable depth coverage of the Canadian autumn surveys in Div. 3NO, and highlight the effect this has had upon survey results for juvenile Greenland Halibut. Following their recommendation, we exclude the entire series of Canadian autumn survey results from Div. 3NO. All other data series are as in dataset #1.

Again we fit a model first using survey-age variance parameters (12; 3 ages x 4 surveys), and also a model including a variance parameter for each survey. Likelihood ratio tests (not shown) indicate that a model with a common variance parameter is not significantly different than the other two models.

Exclusion of the entire time series of Canadian autumn data in Divs. 3NO series (Fig. 4), the estimates of year-class strength are highly consistent, with some slight revision to the estimated strength of the 1993 and 1994 cohorts.

Dataset #3

As previously noted, the Spanish survey in Div. 3NO has recently been age-disaggregated, and we consider a third and final dataset which includes this index. As in dataset #2, we exclude the following Canadian autumn survey data due to coverage problems: Div. 3NO (all years), and Div. 3L (2004). We consider this as the most appropriate dataset to use for the current assessment.

The initial model run with age 3-5 data from dataset #3 estimates 15 variance parameters (3 ages x 5 survey series). Note that using ages 3-5, the final year-class which is estimable is the 2001 year-class (from age 3 data in 2004 surveys). The estimated year-class strength for this dataset is given in Fig. 5; results indicate that the estimates of mid-1980s and mid-1990s are the strongest in the time series. Successive year classes after the 1993-1995 year-classes have been weak. However, although not as strong, the 1997-2001 cohorts are estimated to be stronger relative to these prior year classes. The estimated weights (survey-ages) for this run are presented in Fig. 6.

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	22.4827	14	0.0692
Common vp	8.7521	4	0.0676

*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 of dataset #3 (Fig. 7) is similar to the model using 15 variance parameters, notably that estimates of year-class strength from the earliest part of the time series (determined from the Canadian Div. 2J3K series) are rescaled relative to recent year-classes. Further, the 2001 year-class is estimated to be stronger as compared to that in the full variance parameter model due to equal weighting of the indices. Of the four data points which provide the estimate of the 2001 year-class (recall the 3L 2004 data has been excluded), only the EU 3M index suggests above average recruitment (refer to Fig. 2a). With equal weighting in the final model run, this index receives a larger weight resulting in the higher overall estimate. However, we note the large variability of this estimate. Standardized residuals for this model run are presented in Fig. 8, which indicate no systemic problems in the estimation.

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. 7 that the 2001 year-class size is estimated from information at age 3 only, and the 2000 estimate is determined from ages 3 and 4 indices only. In Figure 9, the single variance parameter model estimate (labeled "Final Run") is compared to the estimates obtained by removing the most recent years' data successively, conducting the analysis with 2003 back to 2000 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 scale of the estimates from the 1970s and 1980s cohorts relative to those of the 1990s and 2000s.

Acknowledgements

The authors gratefully acknowledge the efforts of EU colleagues in providing survey data in advance of the June meeting of Scientific Council.

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

i) EU Div. 3M Survey (July; 1992-2004).

YC	1	2	3	4	5
1986					2.645
1987				1.414	2.293
1988			0.310	1.293	1.280
1989		0.259	0.557	0.837	1.906
1990	1.628	1.566	0.935	1.806	2.471
1991	2.075	1.583	1.715	1.904	4.232
1992	1.796	1.280	2.271	3.022	6.737
1993	1.723	2.508	2.462	6.674	12.318
1994	12.480	7.963	6.404	11.055	13.565
1995	5.879	3.813	7.687	10.389	6.888
1996	3.299	2.120	2.999	2.111	2.767
1997	2.739	0.725	0.599	0.971	3.868
1998	1.064	0.306	1.819	1.671	2.465
1999	3.733	1.410	2.795	1.517	7.334
2000	8.080	2.948	0.614	1.977	
2001	4.104	1.008	4.419		
2002	2.194	3.342			
2003	2.200				

ii) Div. 2J+3K Canadian Autumn RV (Campelen or Equivalent; 1978-2004).

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	9.21
2000	43.90	24.08	11.69	12.31	
2001	40.67	26.67	13.89		
2002	45.70	32.93			
2003	32.49				

iii) Div. 3NO Canadian Autumn RV (Campelen; 1997-2004).

YC	1	2	3	4	5
1992					0.909
1993				2.026	2.651
1994			3.517	2.435	0.686
1995		2.576	1.819	0.467	0.703
1996	0.591	0.783	0.5	0.19	0.357
1997	0.363	0.201	0.058	0.343	0.491
1998	0.035	0.055	0.333	0.472	0.281
1999	0.07	0.114	0.523	0.347	0.654
2000	0.08	0.191	0.361	0.472	
2001	0.256	0.241	0.432		
2002	0.315	0.371			
2003	0.466				

iv) Div. 3L Canadian Autumn RV (Campelen; 1995-2004).

YC	1	2	3	4	5
1990					1.658
1991				0.769	2.307
1992			1.331	2.478	4.306
1993		3.252	5.886	4.65	6.186
1994	4.489	4.569	4.777	5.153	3.228
1995	5.259	3.68	2.686	1.485	2.227
1996	1.856	2.141	0.659	1.309	1.568
1997	1.18	0.896	0.721	1.845	1.833
1998	0.108	1.853	1.159	1.545	2.001
1999	3.234	0.8	1.284	2.756	2.423
2000	2.745	1.239	2.51	3.157	
2001	2.402	1.8	2.23		
2002	3.131	2.306			
2003	2.04				

v) Div. 3LNO Canadian Spring RV (Campelen; 1996-2004).

YC	1	2	3	4	5
1991					0.827
1992				2.183	1.461
1993			4.599	3.227	4.955
1994		4.241	5.16	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	0.22	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	1.161
2000	0.565	0.572	1.663	1.184	
2001	0.642	2.137	1.181		
2002	0.926	0.572			
2003	0.662				

vi) Divs. 3NO Spanish Survey (1997-2004).

YC	1	2	3	4	5
1992					0.928
1993				1.432	3.285
1994			1.835	5.536	3.657
1995		3.379	6.932	5.402	1.507
1996	4.958	4.556	4.367	0.545	1.316
1997	1.149	2.945	0.417	0.500	1.158
1998	1.689	0.245	0.725	0.765	1.660
1999	0.955	3.516	1.262	2.362	1.310
2000	4.337	0.736	2.252	2.326	
2001	2.839	3.378	2.397		
2002	4.084	7.829			
2003	1.220				

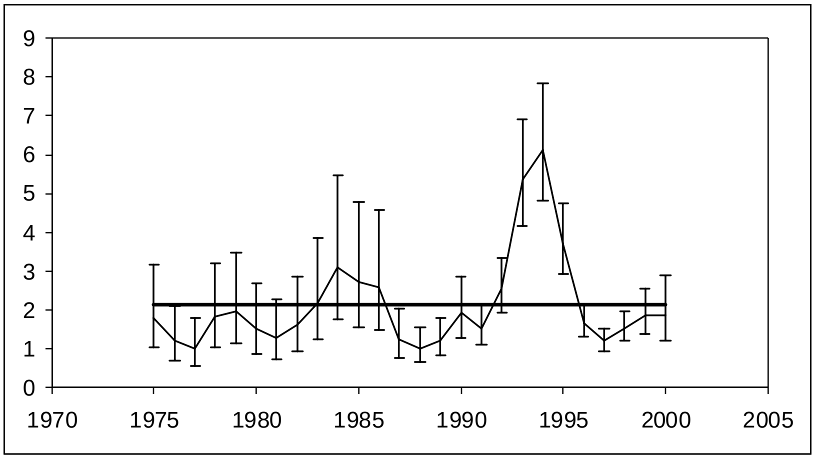

Fig. 1. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's) with a single variance parameter estimated (from Healey et al., 2004). The horizontal line is the mean estimate of year-class strength from the single variance parameter model.

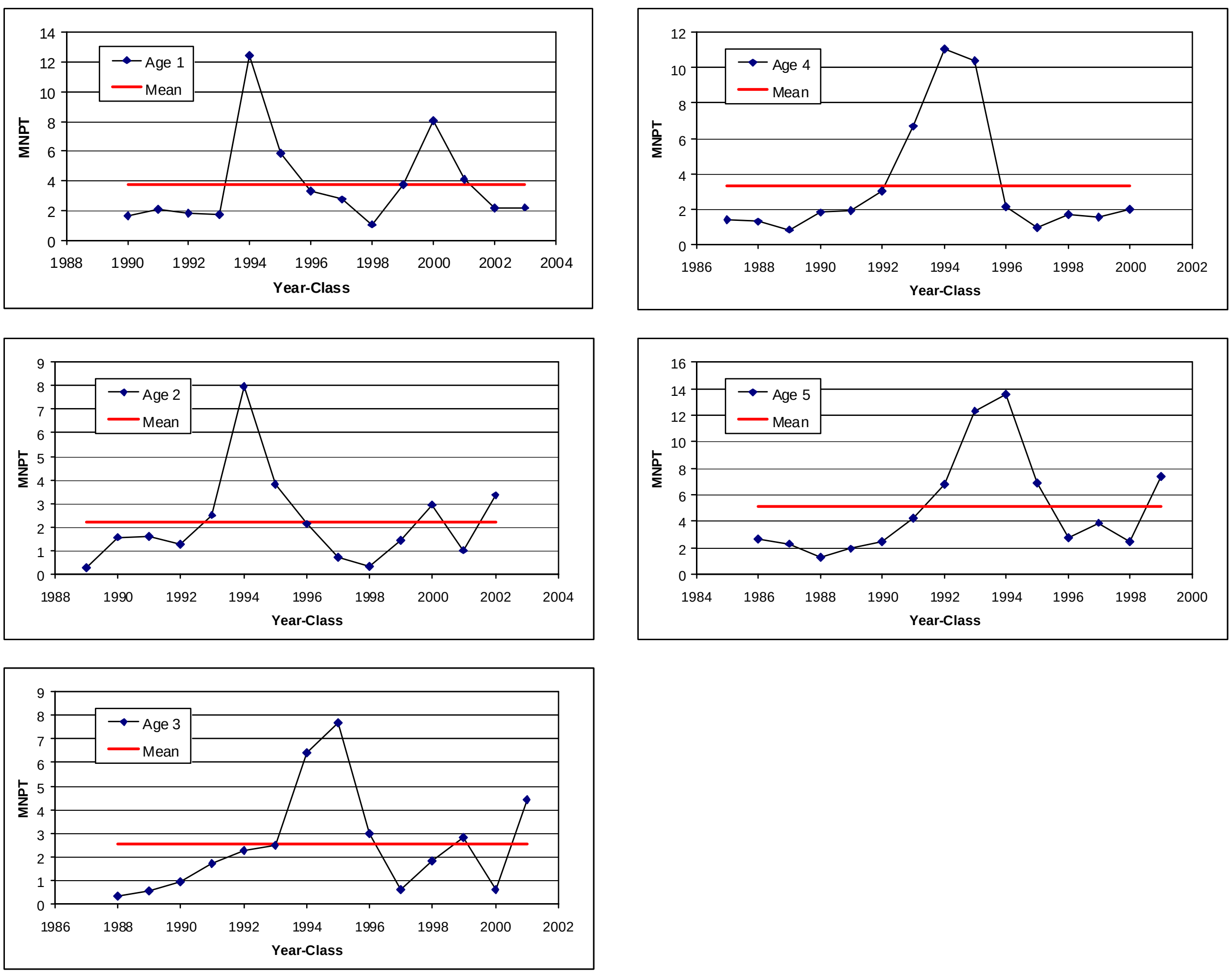

Fig. 2a. EU Div. 3M Survey data (July; 1992-2004) at ages 1-5.

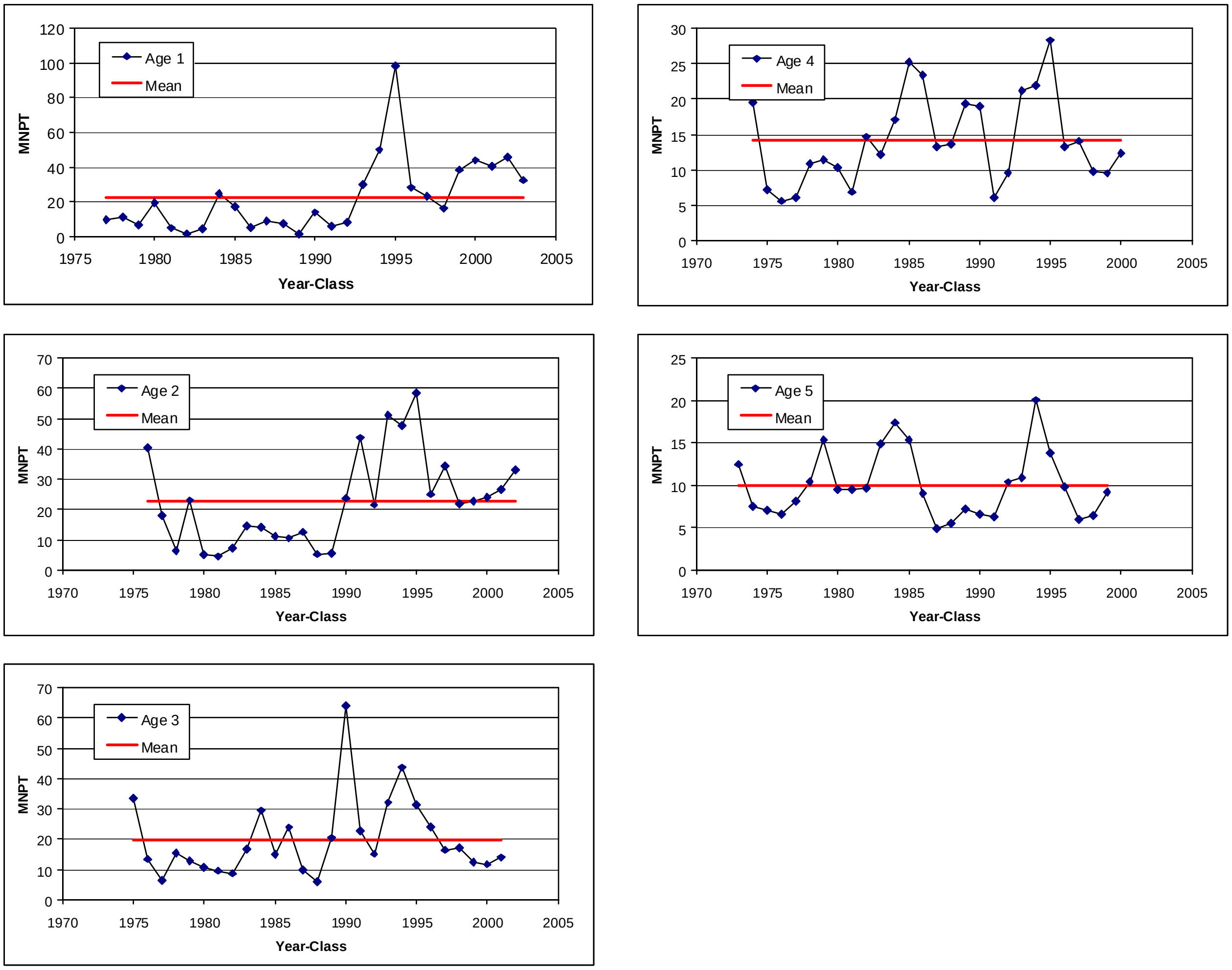

Fig. 2b. Canadian Div. 2J3K data (Autumn; 1978-2004) at ages 1-5.

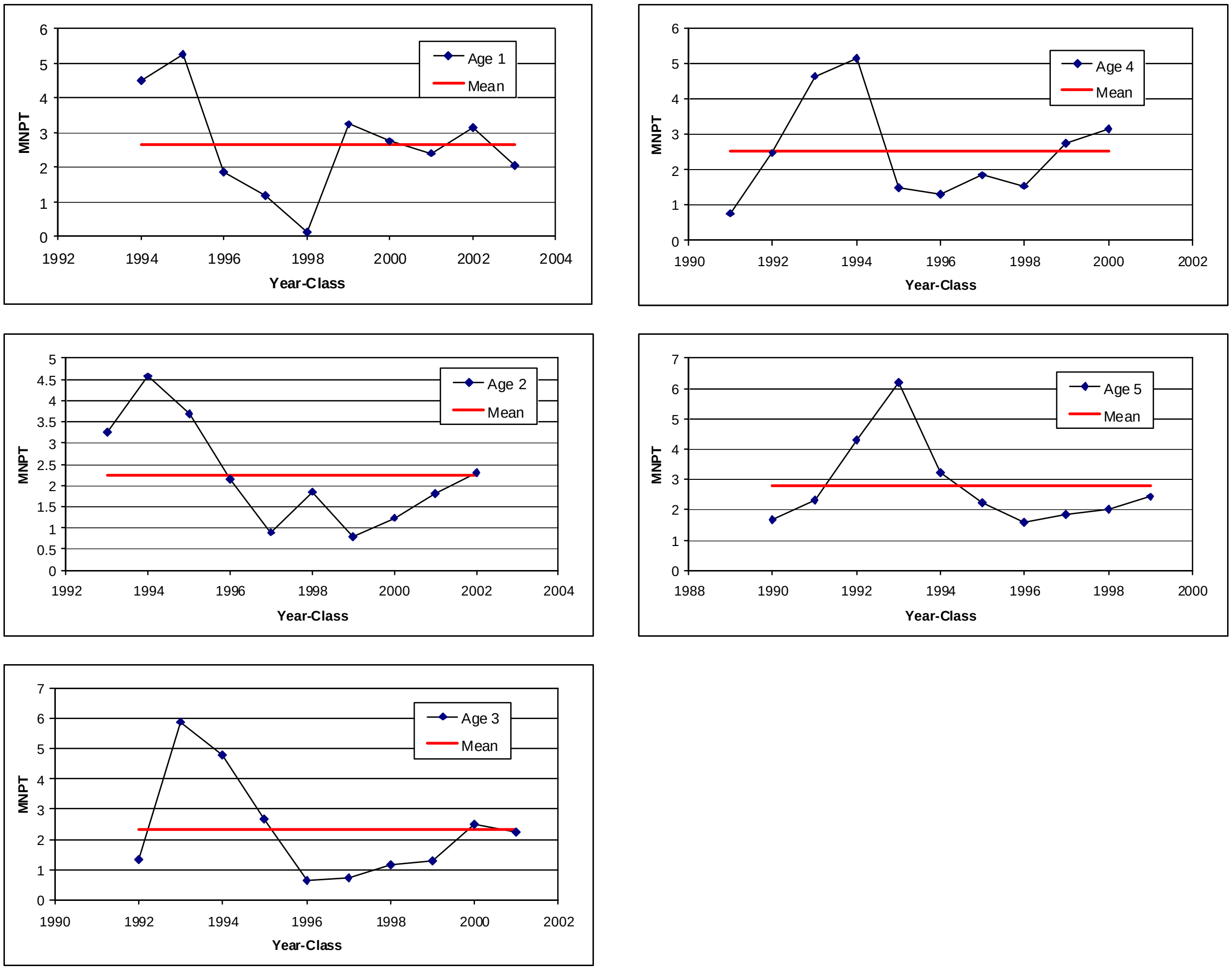

Fig. 2c. Canadian Div. 3L data (Autumn; 1996-2004) at ages 1-5.

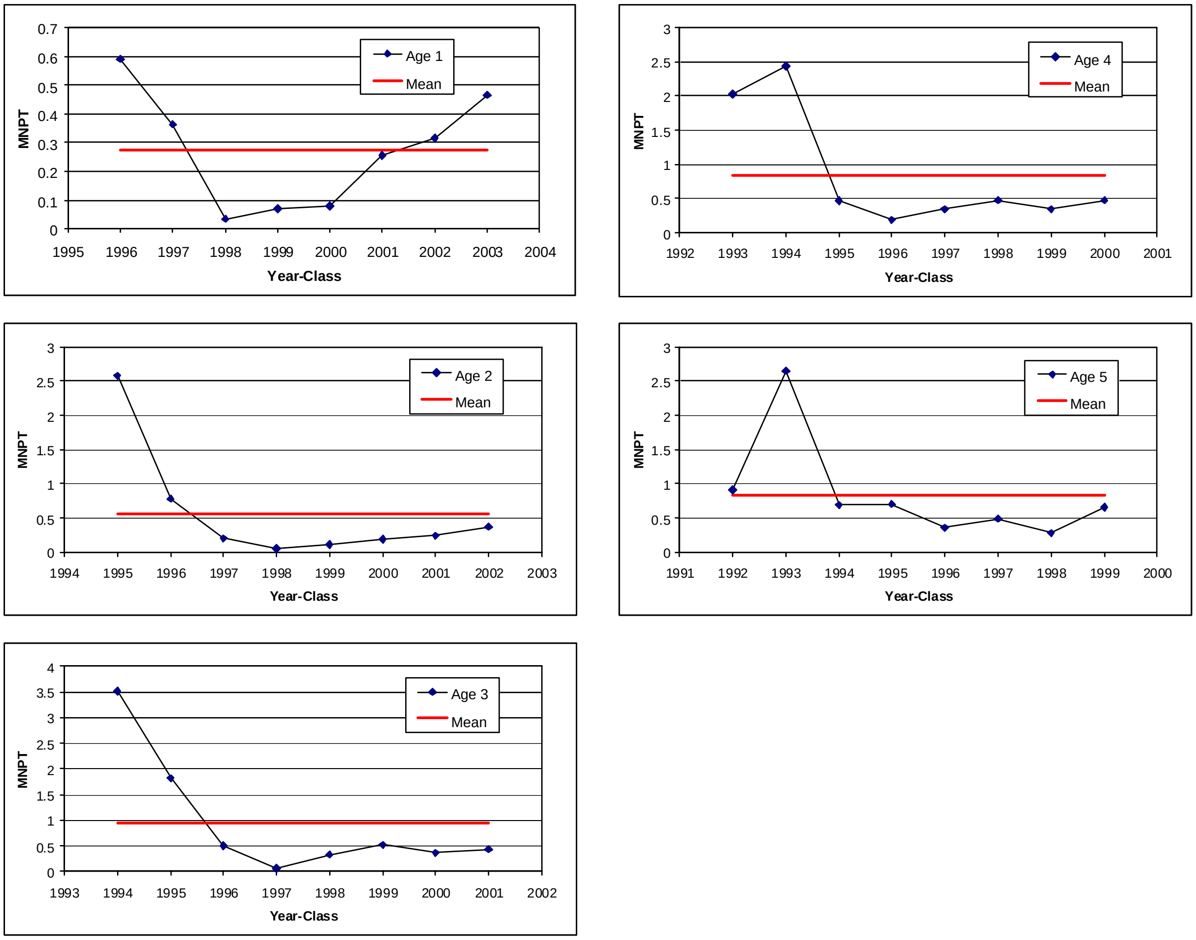

Fig. 2d. Canadian Div. 3NO data (Autumn; 1996-2004) at ages 1-5.

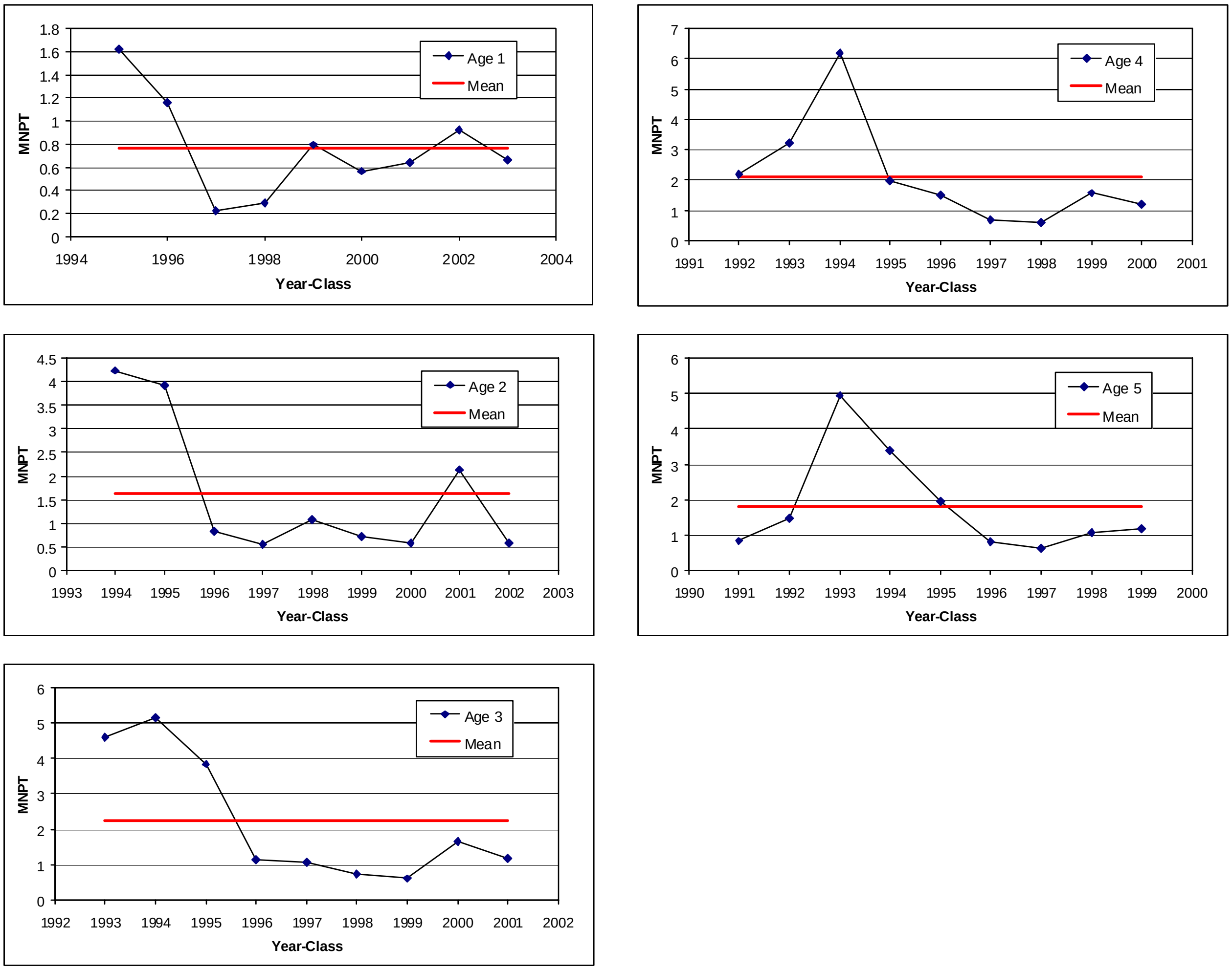

Fig. 2. Canadian Div. 3LNO data (Spring; 1996-2004) at ages 1-5.

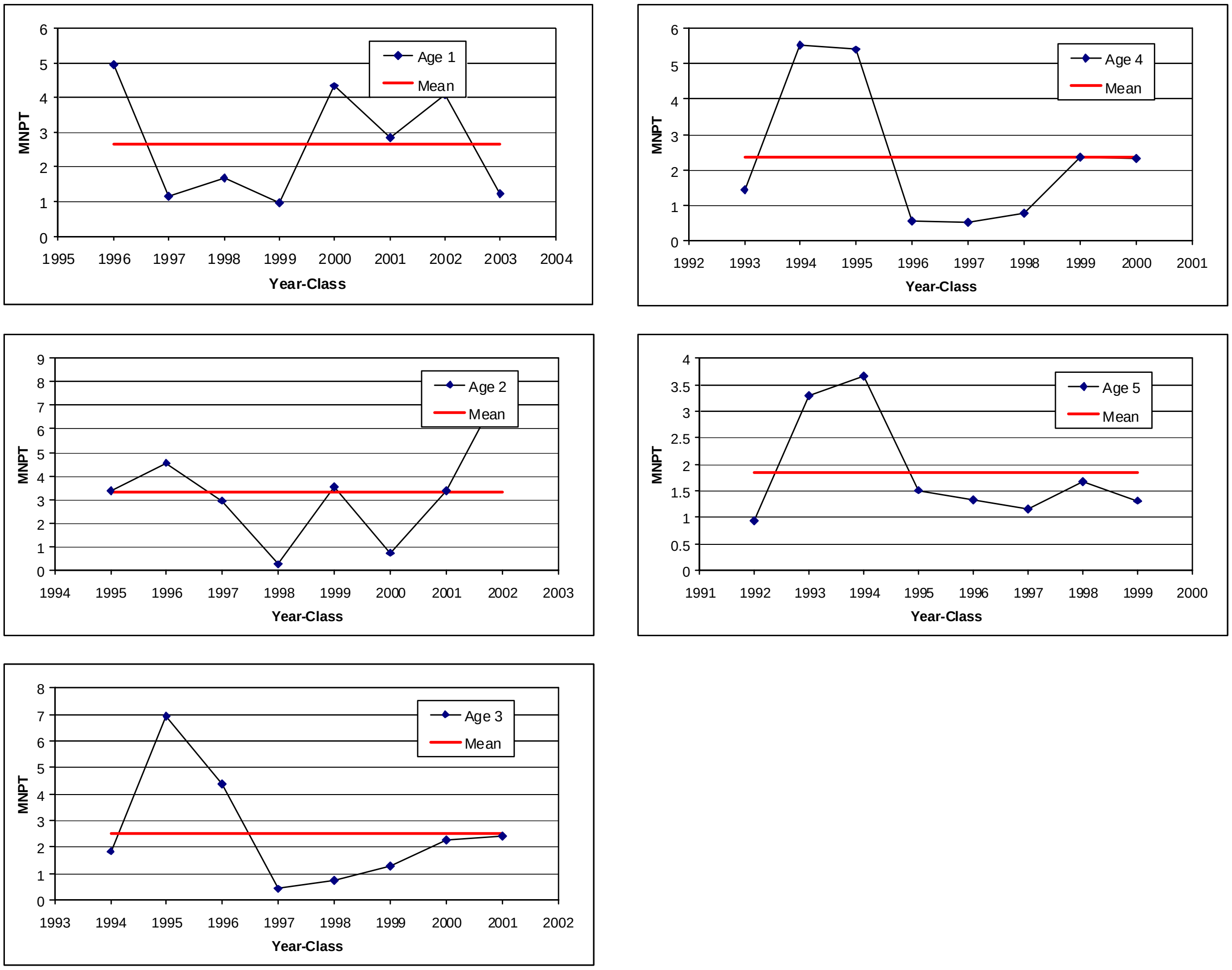

Fig. 2f. EU-Spain Div. 3NO data (Summer; 1997-2004) at ages 1-5.

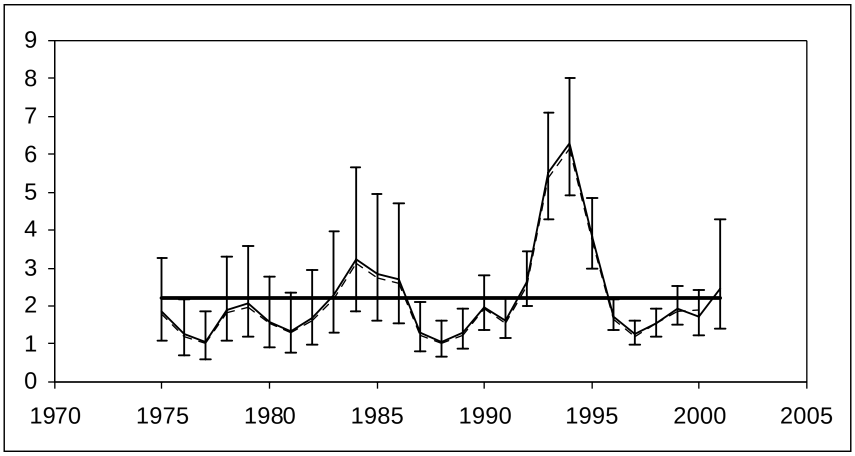

Fig. 3. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's), dataset 1. The solid horizontal line is the mean year-class strength, and the dashed line is the 2004 estimate taken from Healey et al. (2004).

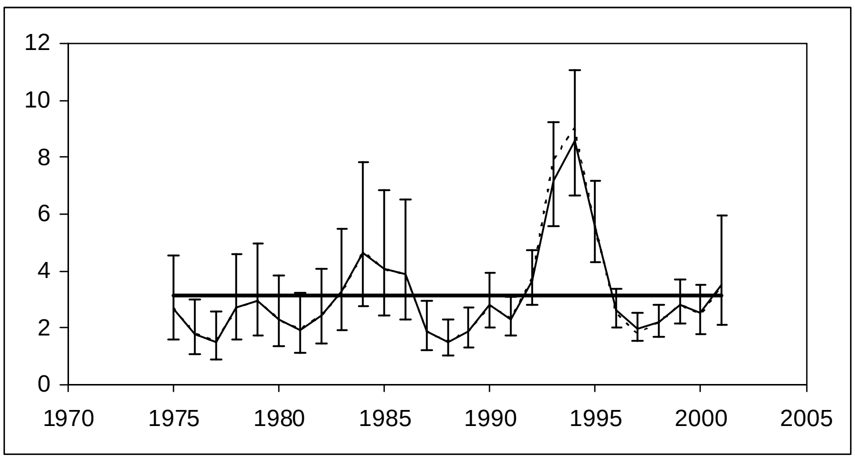

Fig. 4. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's), dataset 2. The solid horizontal line is the mean year-class strength, and the dashed line is the estimate (rescaled) using dataset 1.

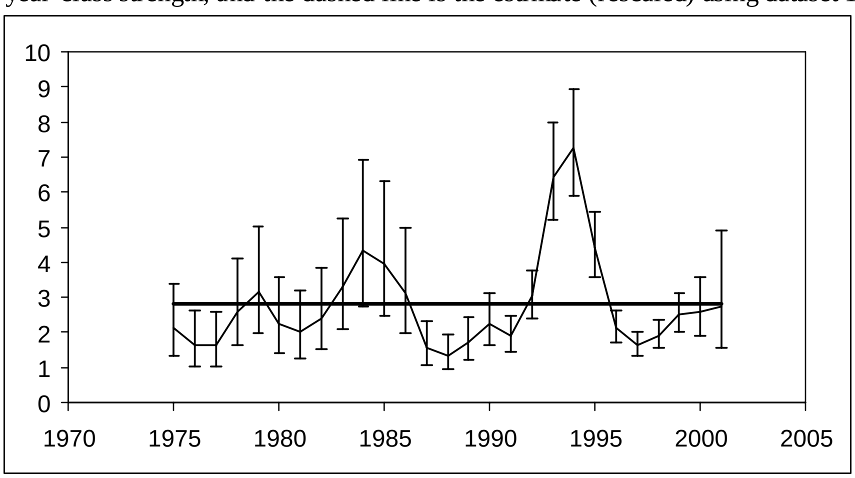

Fig. 5. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's), dataset 3, from the full variance parameter model. The solid horizontal line is the mean year-class strength.

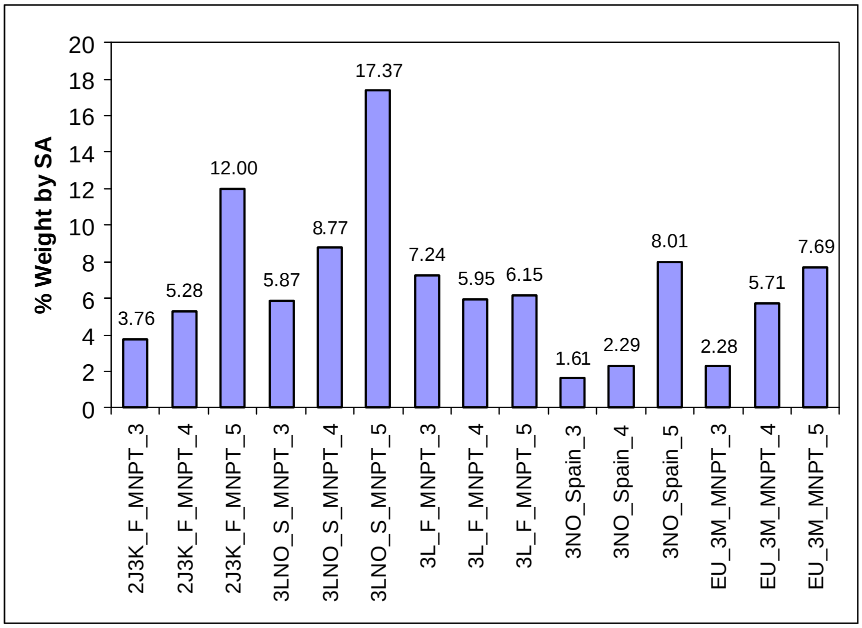

Fig. 6: Estimated survey-age weights (%) using age 3-5 MNPT from dataset 3.

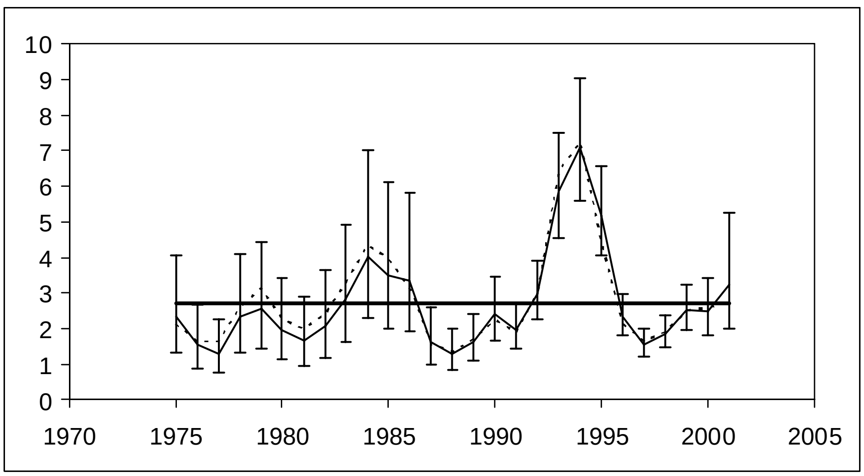

Fig. 7. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's) with a single variance parameter estimated. The dashed line indicates the model fit using 15 variance parameters. The solid line is the mean estimate of year-class strength from the single variance parameter model.

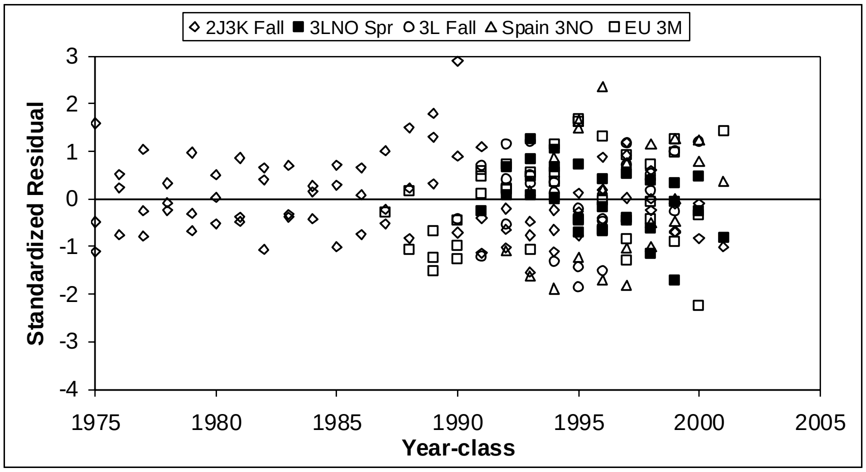

Fig. 8: Standardized residuals of final estimates of year-class strength (dataset #3; 1 variance parameter).

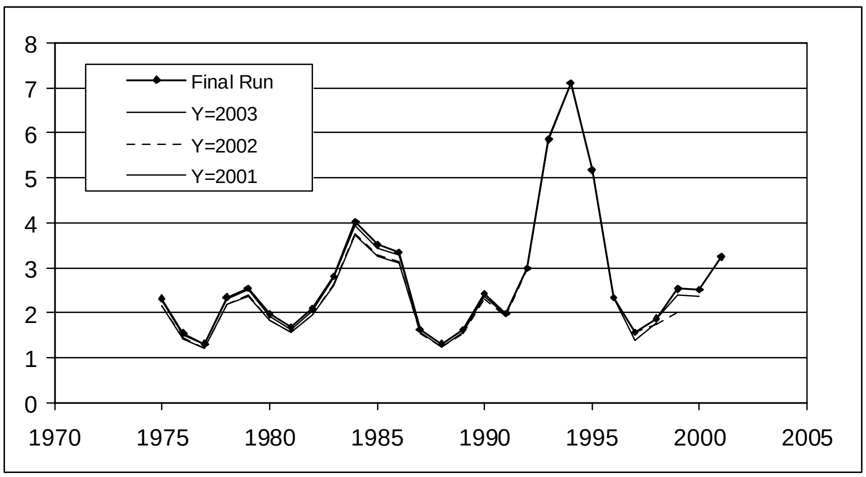

Fig. 9: Restrospective analysis of estimated year-class strength from models fitted to MNPT data at ages 3-5.