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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 2005, the final analysis examined the estimated trends as predicted from ages 3-5 indices. We review the rationale for using these ages, and subsequently propose using the age 1-4 data in the current assessment. Estimates of year-class strength indicate that the 1993-1995 year-classes were the strongest produced over the time period considered. The 2000-2002 year-classes are estimated to be of about average strength, and based upon the available data, the 2003 and 2004 cohorts are estimated to be poor.

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. This exercise was initiated in 2001, at a time when the VPA results were considered uncertain, and only the trends in the VPA estimates of fishing mortality and biomass were considered reliable (NAFO, 2001).

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.

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.

Several analyses of year-class strength were considered in the 2005 assessment (Healey and Dwyer, 2005a). The impact of the problems with the Canadian survey in the fall of 2004 (Healey and Dwyer, 2005b), and the revision of the EU mean numbers per tow (MNPT) time series for Div. 3M (Casas and González Troncoso, 2005) necessitated some additional investigations. Further, STACFIS agreed at the 2005 meeting that the autumn Canadian and summer Spanish survey series from Div. 3NO be excluded from the analyses. These series were excluded due to variable depth coverage, and a lack of consistency in tracking year-classes, respectively. Noting that the Spanish survey in Div. 3NO covers a limited portion of the stock area, further concerns were expressed on using this index to predict recruitment. Finally, the Canadian data for Div. 3L in the fall of 1995 was excluded as it covered only part of the survey area. Only survey data at ages 3-5 were used in modeling. The estimated year-class strength from the final run in the 2005 assessment is presented in Fig. 1. The results indicate that the 1993-1995 cohorts were exceptionally strong and that subsequent recruitment was generally at or below the long-term average. The final estimated cohort (2001) indicated above-average recruitment, but was based upon limited data (observe the large confidence interval for this estimate).

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 (1991-2005; González Troncoso *et al*., 2006a),
- ii) Canadian Fall 2J3K (1978-2005; Healey *et al*., 2006),
- iii) Canadian Fall 3L 3NO, (1997-2005; Healey *et al*., 2006),
- iv) Canadian Fall (1995-2005; Healey *et al*., 2006),
- v) Canadian Spring 3LNO (1996-2005; Healey *et al*., 2006), and
- vi) EU-Spain Summer 3NO (1997-2005, González Troncoso *et al.*, 2006b).

González Troncoso et *al*. (2006b) describe revisions to the entire Spanish 3NO time-series.

The survey indices considered in these recruitment analyses are plotted by age (ages 1-5) in Fig. 2. The horizontal line in each panel is the mean of the index for that particular age. We display the data separately for each age group to examine the consistency within and between each survey (for additional detail, see González Costas and González Troncoso, 2005).

The EU MNPT data from summer surveys in Div. 3M are presented in Fig. 2a. This index has clearly measured the strong year-classes of 1993-1995. For the recent cohorts, improvements are evident up until about the 2000 or 2001 cohorts. The age 1 data in particular exhibit substantial declines for the more recent cohorts.

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 (1978-2005), and it is from this series that the cohort strength estimates prior to the early 1990s are produced. Results generally indicate that all recent year-classes have been below average; however, the trends at age 1 and age 2 suggest that recent cohorts are above the long term average. In addition, we note that there are different interpretations of the relative strength of the mid-1980s cohorts compared to the mid-1990s cohorts at ages 1-2 compared to that for ages 3-5. A likely explanation for this phenomenon is poor Engels to Campelen conversion factors for Greenland Halibut at ages 1 and 2 within Canadian surveys. More particularly, this is most likely caused by multiplicative conversions. The Campelen 1800 shrimp trawl is more efficient at catching juvenile Greenland Halibut: the Engels gear used in the Canadian surveys was a modified commercial groundfish otter-trawl. Use of multiplicative conversion factors means that the zero catches in the Engels time series will be "converted" to Campelen zeroes, which is undoubtedly an under-correction. Some discussion of this situation is presented by Warren (1996).

The year-class strength for ages 1-5 from Canadian fall MNPT in Div. 3L (Fig. 2c) clearly show that the 1993-1994 cohorts were above average. The 1995 year-class is above average at ages 1-2, but at ages 3-5, this cohort was 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 1-5 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 Div. 3LNO (Fig. 2e) measured the 1993 and 1994 year-classes as being above average; with some evidence of a year-effect in 2003.

The Spanish summer MNPT index from Div. 3NO has recently been age-disaggregated (González Troncoso and Casas, 2005). At ages 1-5, this index (Fig. 2f) suggests some evidence of year-effects as with the Canadian autumn Div. 3NO index. The age 1 and 2 data are especially variable. Of note, the 1994 cohort was measured to be average at age 3, as was the 1993 cohort in the age 4 data, whereas other survey series and fishery data indicate that these cohorts have been among the strongest in the recent period.

Input Data

As noted, the most recent assessments of this stock have used only survey data at ages 3-5 to estimate year-class strength. The following argument for this choice of ages was put forth by Healey *et al.* (2003): "*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*". We propose and subsequently applied an alternative approach – to exclude converted data from the Canadian fall survey, and return to ages 1-4 for modeling. Only within the converted time series is it that the perceptions of year-class strength are different at ages 1-2 compared to ages 3-5 (although we note the variability in the Spanish Div. 3NO index at ages 1 and 2). We advise exclusion of the age 5 data in estimation as the XSA results from the previous assessment (Healey and Mahé, 2005) indicate that fishing mortality at age 5 is non-negligible for a number of years. Although we advocate using ages 1-4 in the modeling, in the next section, we also describe comparative analysis and determine how the estimated strength of year-classes changes when based upon the age 1-5 data and also age 3-5 data. Note that the usage of additional age groups permits estimation of more recent cohorts.

Model of YC Strength – Analysis of MNPT

We use a multiplicative model to estimate the relative year-class strength produced by the spawning stock as indicated from survey indices (MNPT). 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).

Following the established approach of this method, we fit a model first using 16 survey-age variance parameters (4 ages x 4 surveys). Subsequently, a model including a variance parameter for each survey, and an additional model with a common variance parameter for all data are fitted to the data. Likelihood ratio tests (below) indicate that the model with a common variance parameter is not significantly different than the other two models.

Null Model	Test Statistic	df	p-value
One vp for each survey	21.013	12	0.050187
Common vp	6.643	3	0.084183

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

The estimates of relative year-class strength for this dataset, using the single variance parameter model, are presented in Fig. 3. Results indicate that the 1993-1995 cohorts were the strongest in the series. Year-classes from 1998-2002 had shown an improving trend, but the available data for the 2003 and 2004 year-classes suggest that these are relatively poor. We note that the 2001 cohort, which was estimated to be above average in the previous assessment (again with the proviso regarding limited data to estimate this cohort), is currently estimated to be of average strength. Standardized residuals are presented in Fig. 4.

The sensitivity of the model estimates to the age-ranges included in the input data set were evaluated. In Fig. 5, relative year-class strength estimated using: (i) ages 1-4, (ii) ages 1-5, and (iii) ages 3-5 are presented. For ease of comparison, the 1990 estimate is scaled to 1 for each series. Results are quite robust; the trends are highly correlated over the time period considered.

The sensitivity of the estimates to the inclusion/exclusion of the Canadian Divs. 2J+3K Campelen-converted data was also explored. In Fig, 6, the resulting estimates are presented. In addition, we compare each of these results to the estimated recruitment from the previous assessment. Observe that the estimated year-class strength is largely insensitive to the exclusion of the converted data. (The 1976-1989 cohorts are no longer estimated because the Div. 2J+3K converted data is the only source of data for these years.) Also, from 1990 onward, the estimates of relative year-class strength are very similar to the age 1 recruits estimated from XSA. This is hardly surprising, as the input two datasets are quite similar.

Conclusion

Relative year-class strength estimated from this approach indicates that the 1993-1995 cohorts are the strongest over the entire time period considered. The 1998-2001 cohorts showed an improving trend, but subsequent recruitment is estimated to have been declining.

Acknowledgements

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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; 1991-2005).

YC	1	2	3	4	5
1986					2.869
1987				1.311	2.303
1988			0.433	1.272	1.269
1989		0.257	0.556	0.861	1.921
1990	1.619	1.566	0.966	1.785	2.656
1991	2.085	1.548	1.697	1.909	4.203
1992	1.769	1.238	2.230	3.036	7.105
1993	1.777	2.543	2.415	6.497	12.334
1994	12.407	7.969	5.996	10.996	13.413
1995	5.843	3.775	7.685	10.468	7.092
1996	3.325	2.134	3.008	2.165	2.788
1997	2.735	0.700	0.595	0.993	3.786
1998	1.059	0.292	1.811	1.668	2.476
1999	3.748	1.433	2.795	1.514	6.965
2000	8.031	2.939	0.608	1.971	6.885
2001	4.081	1.000	4.373	2.496	
2002	2.198	3.288	3.176		
2003	2.192	0.811			
2004	0.544				

ii) Canadian Div. 2J+3K Autumn RV (Campelen or Equivalent; 1978-2005).

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	10.30
2001	40.67	26.67	13.89	13.40	
2002	45.70	32.93	8.40		
2003	32.49	16.12			
2004	15.49				

iii) Canadian Div. 3NO Autumn RV (Campelen; 1997-2005).

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	0.39
2001	0.256	0.241	0.432	0.173	
2002	0.315	0.371	0.202		
2003	0.466	0.133			
2004	0.064				

iv) Canadian Div. 3L Autumn RV (Campelen; 1995-2005).

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	2.588
2001	2.402	1.8	2.23	2.807	
2002	3.131	2.306	1.142		
2003	2.04	1.317			
2004	1.307				

v) Canadian Div. 3LNO Spring RV (Campelen; 1996-2005).

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	1.372
2001	0.642	2.137	1.181	0.946	
2002	0.926	0.572	1.09		
2003	0.662	0.306			
2004	0.353				

vi) Spanish Divs. 3NO Survey (1997-2005).

YC	1	2	3	4	5
1992					2.242
1993				3.806	5.058
1994			3.489	8.468	6.286
1995		5.523	9.085	9.307	3.842
1996	9.922	5.242	7.207	1.389	2.838
1997	1.711	4.805	0.800	1.070	1.139
1998	4.380	0.489	1.183	0.695	1.578
1999	2.917	5.901	1.023	1.910	1.238
2000	8.869	0.641	1.685	2.060	1.248
2001	2.911	2.399	2.086	1.116	
2002	3.564	6.957	1.554		
2003	1.218	1.220			
2004	0.7632				

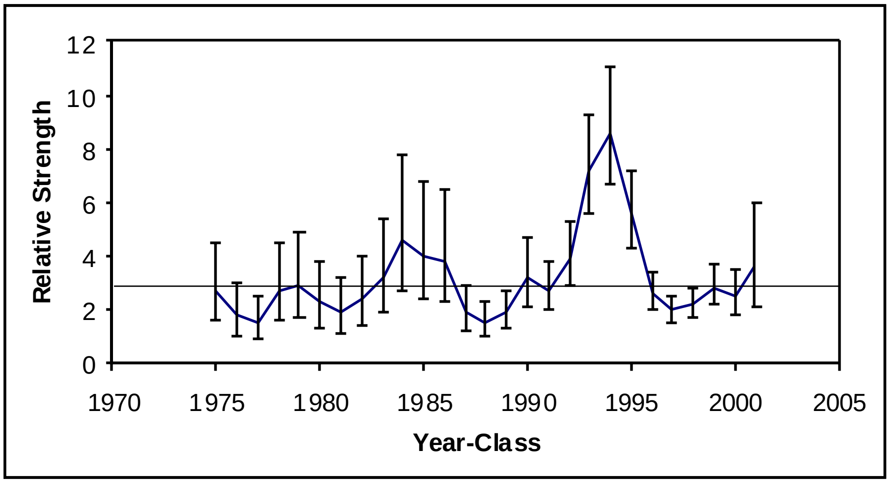

Fig. 1. Estimated year-class strength using age 3-5 MNPT data (+/- 2 SE's), from Healey and Dwyer (2005b). The solid horizontal line is the mean year-class strength.

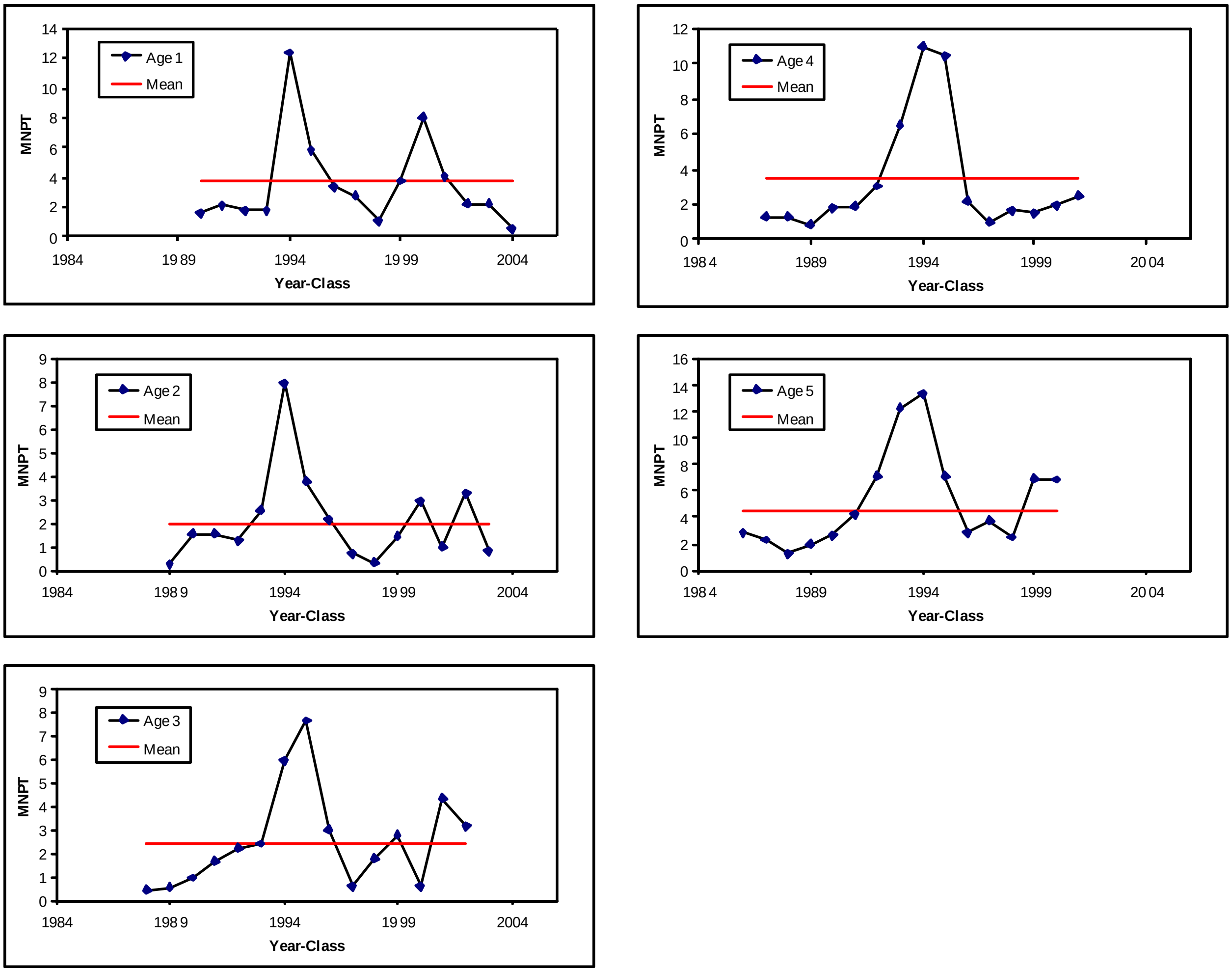

Fig. 2a. EU Div. 3M Survey data (July; 1991-2005) at ages 1-5, by cohort.

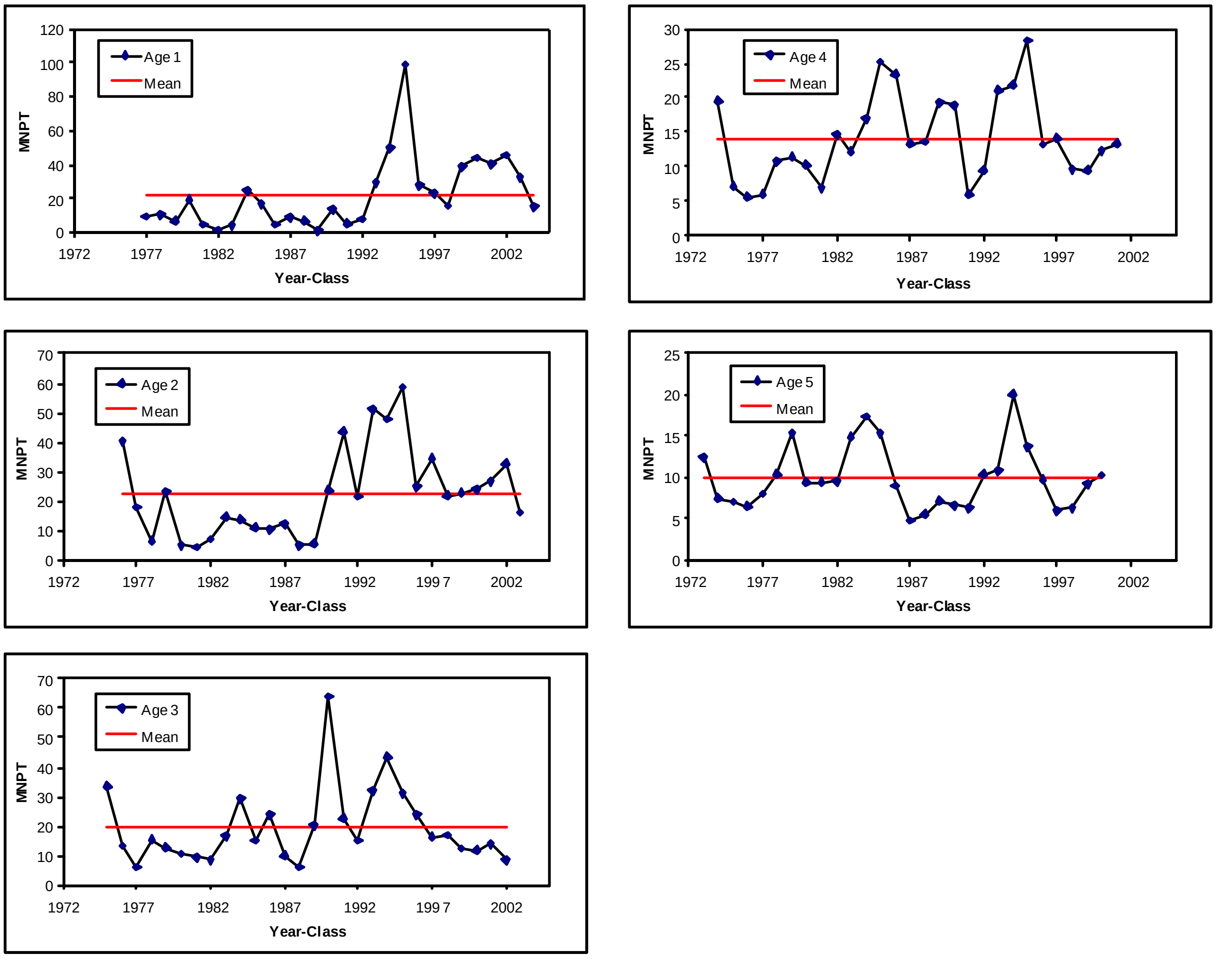

Fig. 2b. Canadian Div. 2J+3K data (Autumn; 1978-2005) at ages 1-5, by cohort.

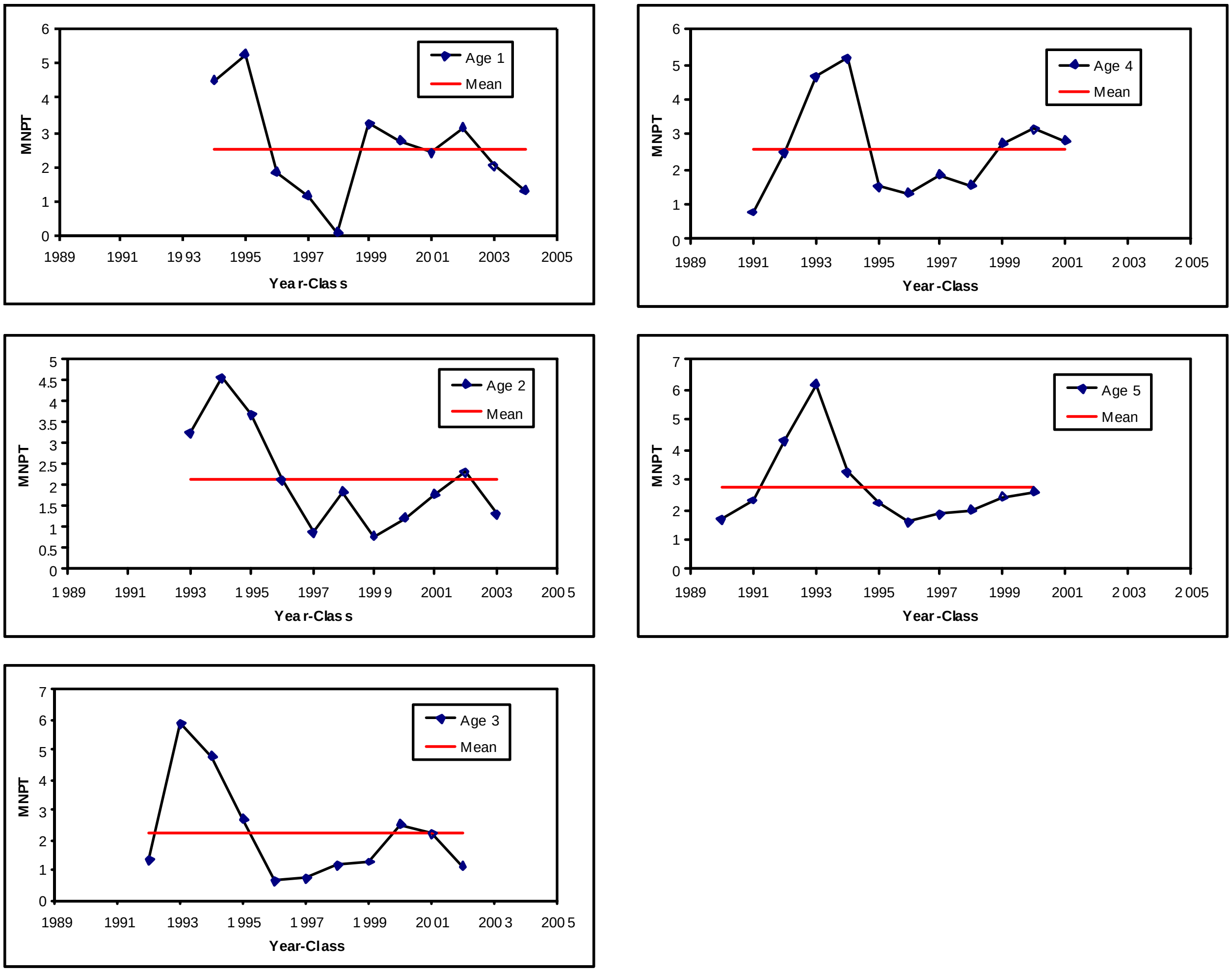

Fig. 2c. Canadian Div. 3L data (Autumn; 1996-2005) at ages 1-5, by cohort. The 2004 survey (hollow symbols) was incomplete (Brodie, 2005).

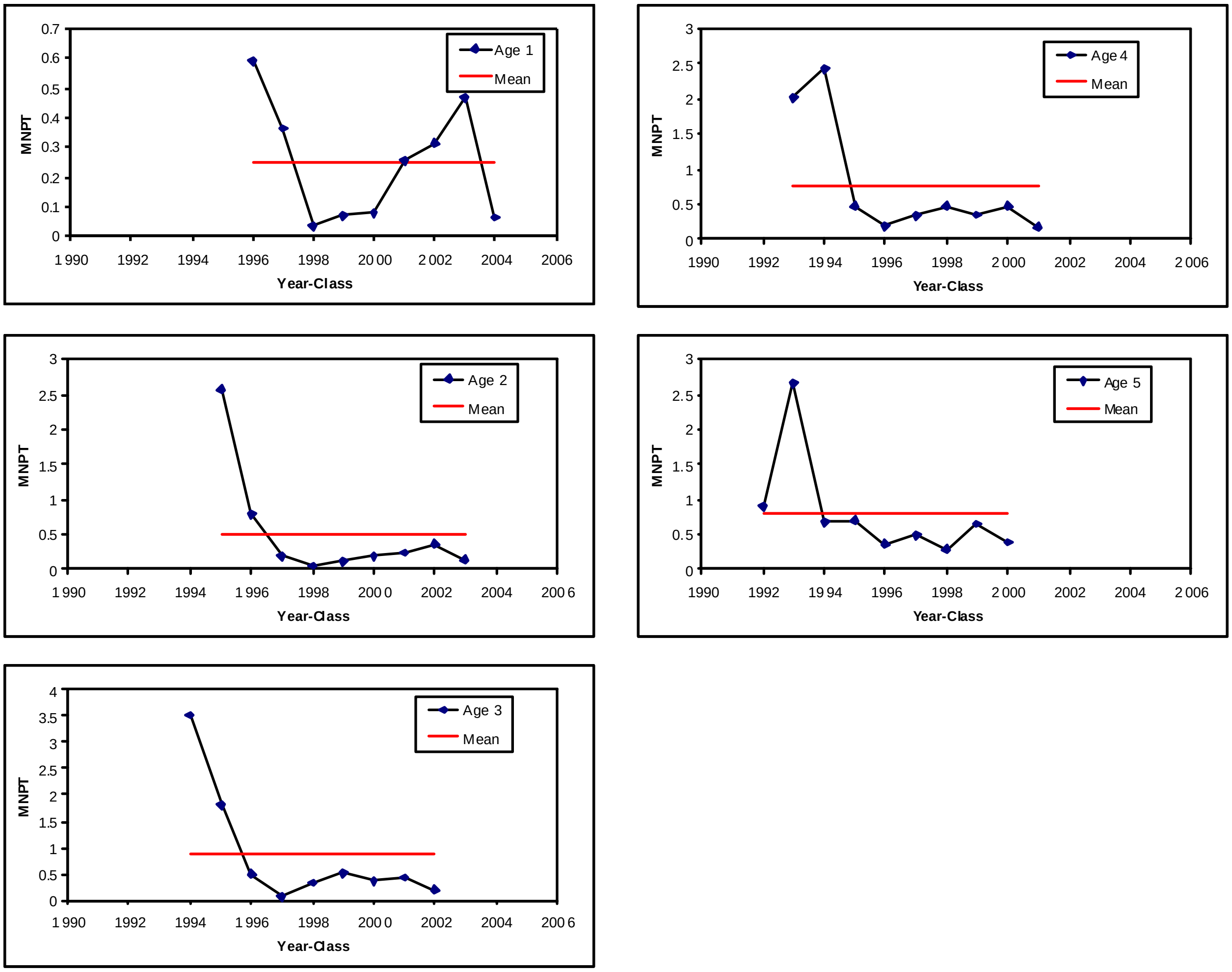

Fig. 2d. Canadian Div. 3NO data (Autumn; 1996-2005) at ages 1-5, by cohort. Note that the depth coverage of this survey has varied over time (Healey et. *al*., 2006).

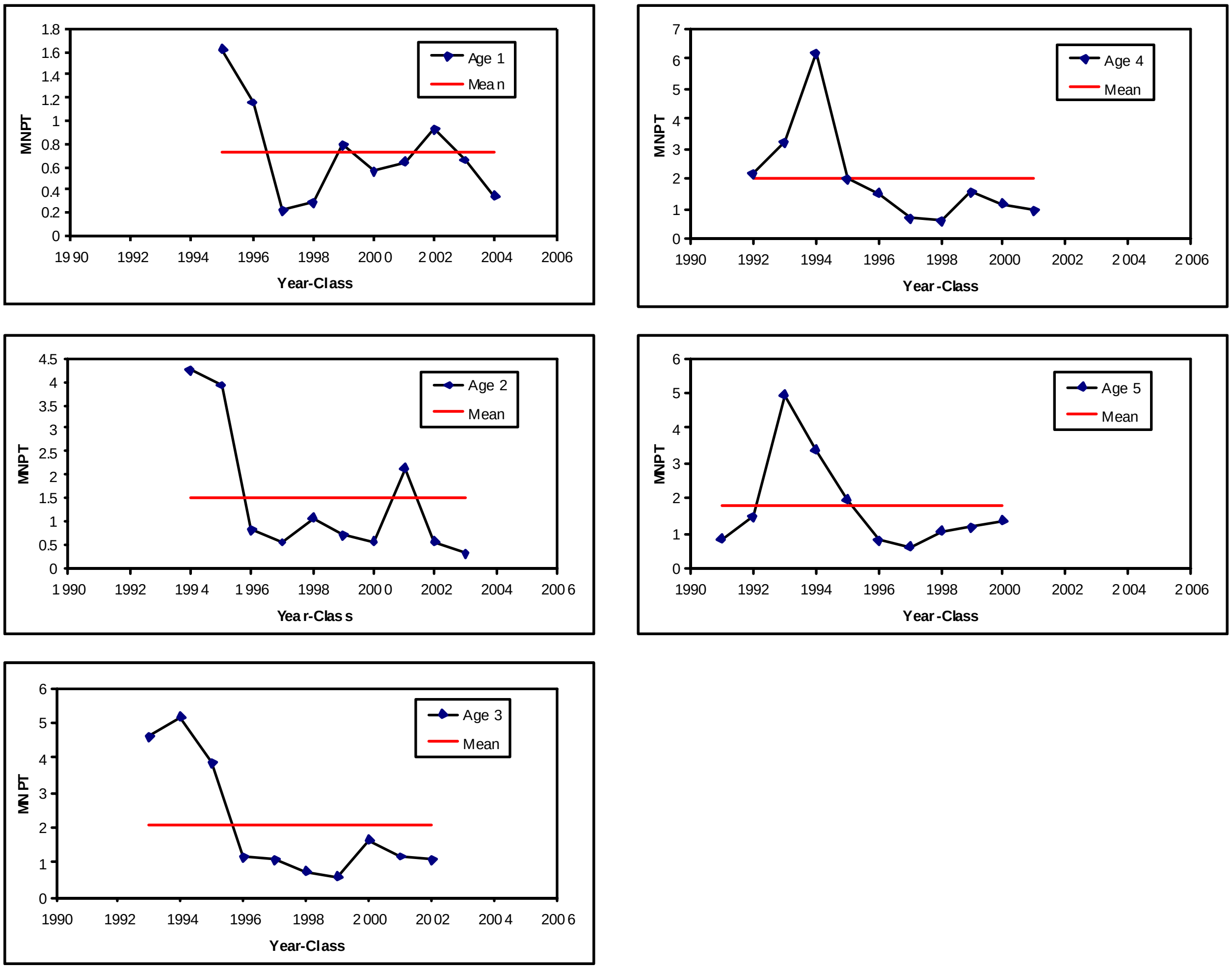

Fig. 2e. Canadian Div. 3LNO data (Spring; 1996-2005) at ages 1-5, by cohort.

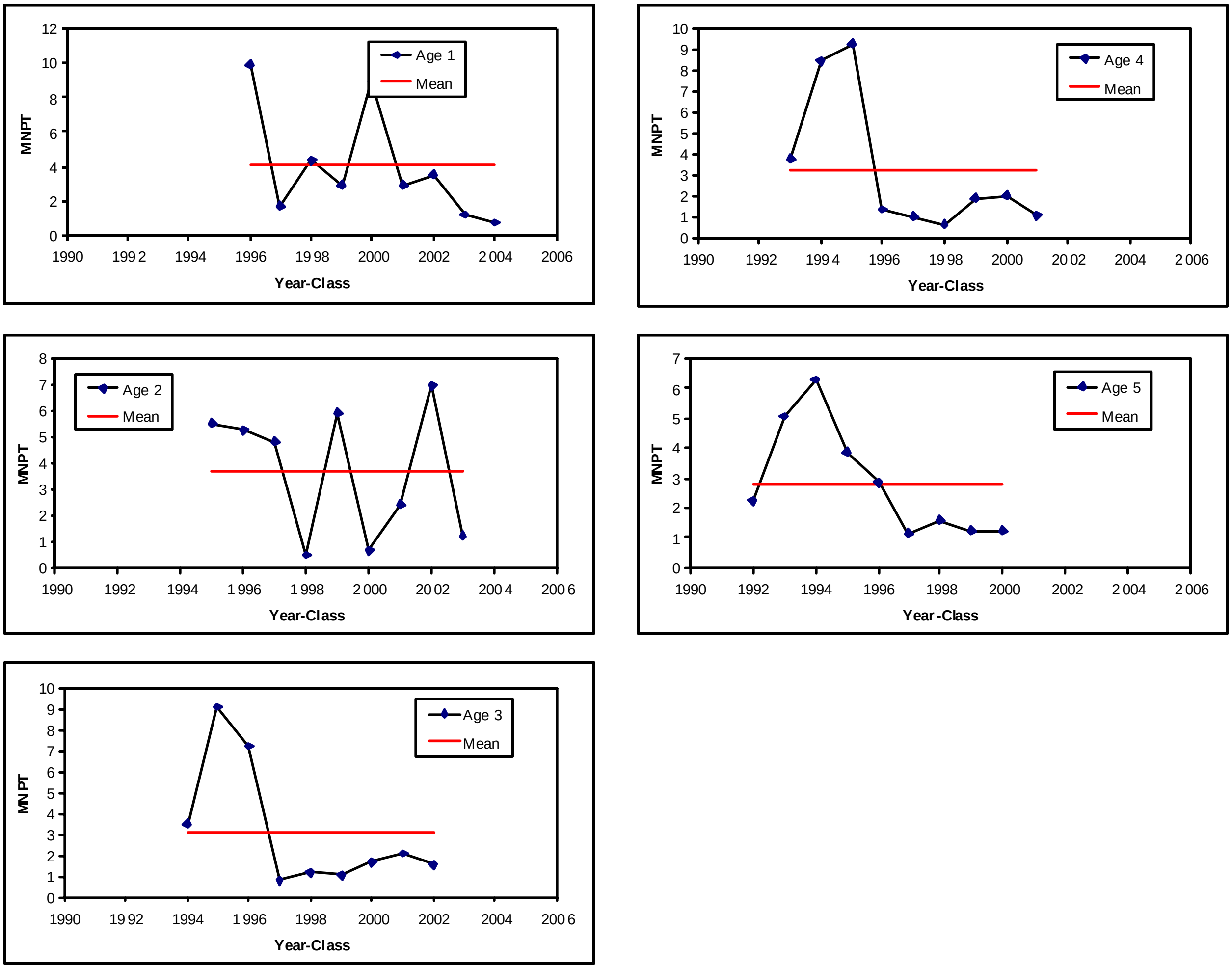

Fig. 2f. EU-Spain Div. 3NO data (Summer; 1997-2005) at ages 1-5, by cohort.

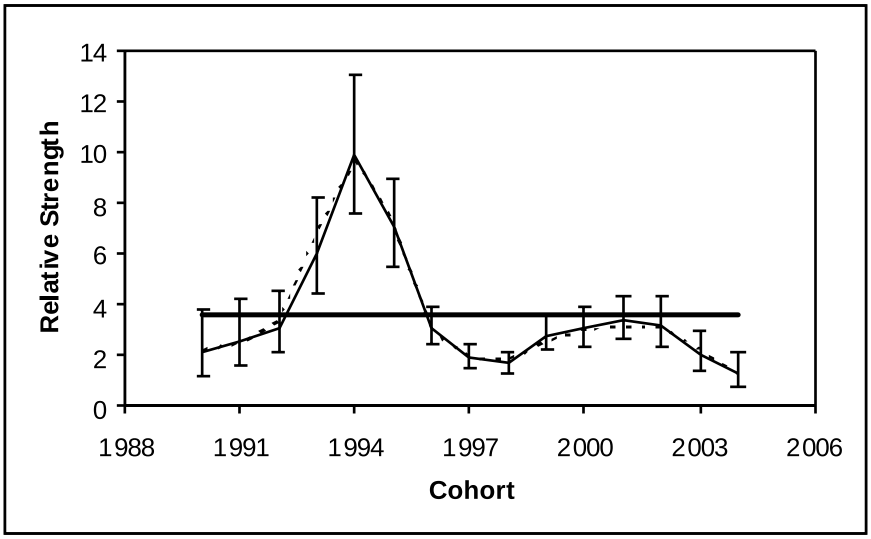

Fig. 3. Estimated year-class strength using age 1-4 MNPT data (+/- 2 SE's) with a single variance parameter estimated. The converted 2J+3K data are excluded from analysis. The dashed line indicates the model fit using 16 variance parameters. The solid line is the mean estimate of year-class strength from the single variance parameter model.

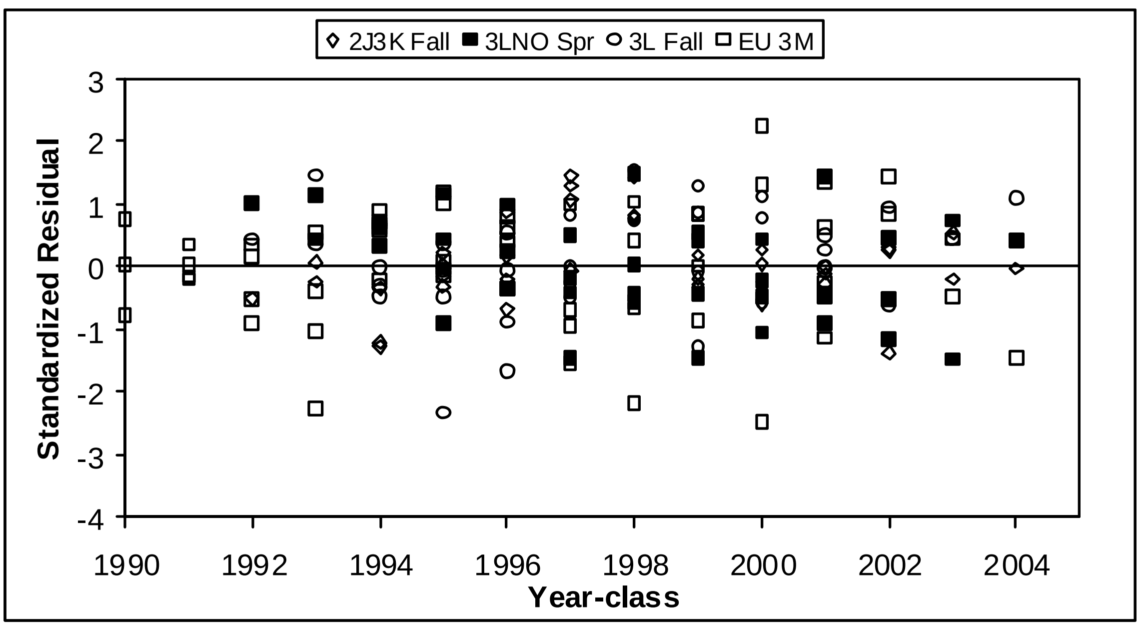

Fig. 4. Standardized residuals of model fit.

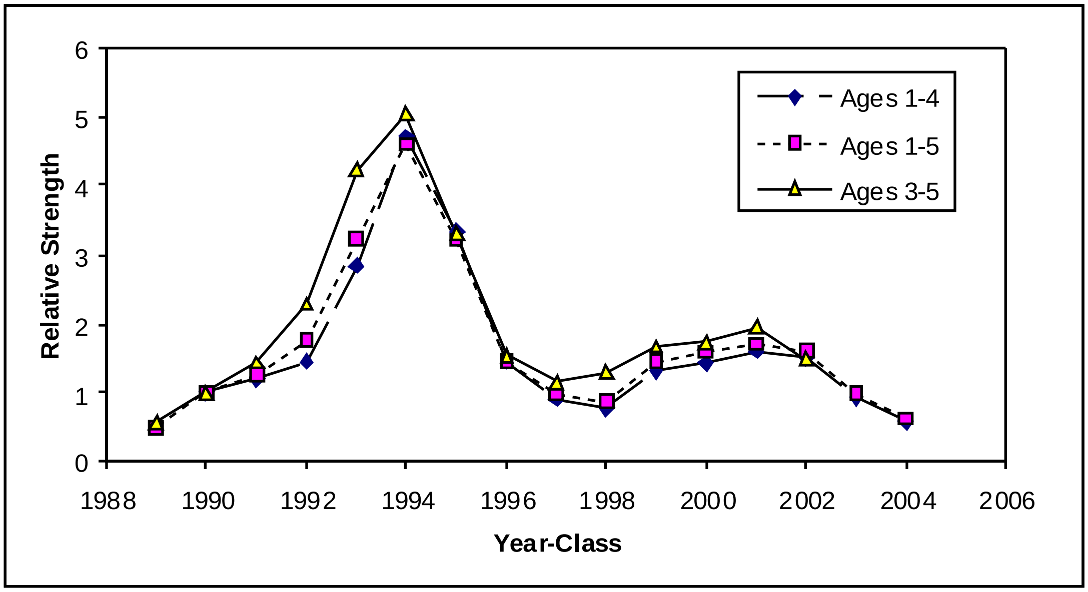

Fig. 5. Comparison of estimated year-class strength for varying age ranges in the input data set.

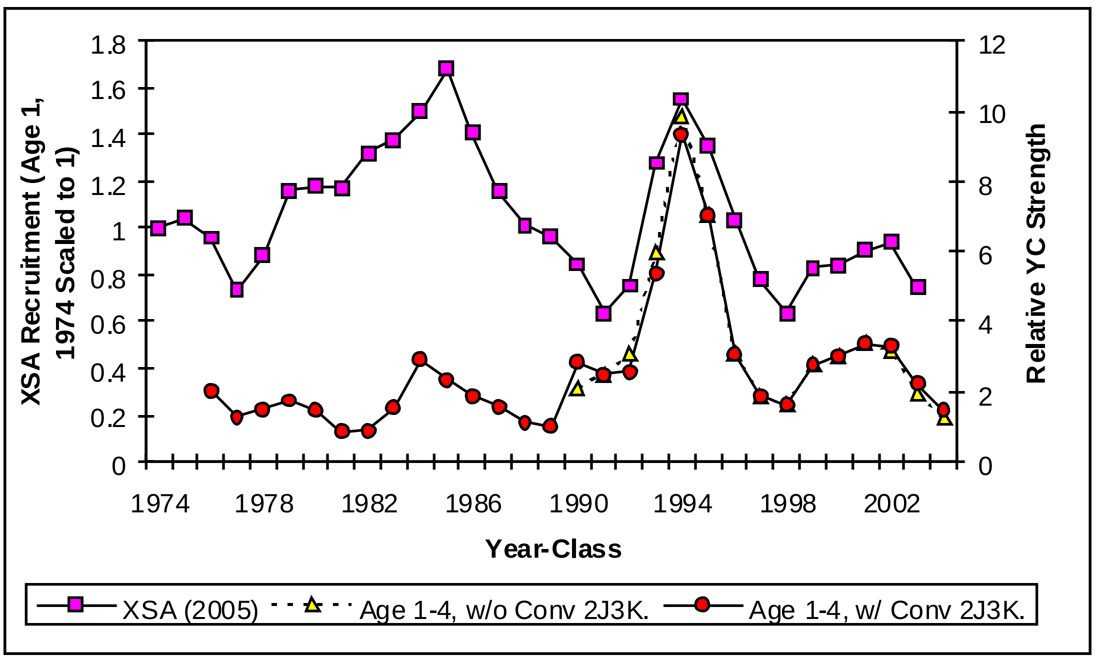

Fig. 6. Relative year-class strength estimated with and without the Campelen converted data in the Div. 2J+3K. The XSA (Healey and Mahé, 2005) estimates of recruitment at age 1 (2005 assessment) are plotted for comparison.