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Greenland Halibut in NAFO Sub-area 2 & Divisions 3KLMNO - A Statistical Catch at Age Formulation to assess the Resource

by

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Abstract

Estimates of stock size using a statistical catch at age formulation are presented and compared to the XSA estimates from an XSA (Shepherd, 1999) formulation using the same settings as for the 2008 assessment (Healey & Mahé, 2008). Statistical catch at age analysis are conducted with NOAA Fisheries Toolbox ASAP v2.0 (http://nft.nefsc.noaa.gov). Diagnostics showed a poor fit and a similar pattern of conflicting trends in the survey index as for the XSA. This was also reflected in the large differences in the observed versus predicted total catch and proportions at age in the mid 1990s to the mid 2000s. Retrospective analysis showed a better stability with no pattern. Results for population estimates were overall similar in terms of trends but magnitudes of inter-annual variations are higher for the statistical catch at age model.

Material and Methods

A statistical catch at age model was fit to the Greenland Halibut in SA 2+3 data using the NOAA NFT software ASAP (Age Structured Assessment Program).

Model

A full description of the model and objective function calculation is available with the software on the NOAA website :

http://nft.nefsc.noaa.gov/ASAP.html

The program is coded with ADMB and can be run directly from command line or through a GUI interface.

Estimated parameters :

Recruitment

N in 1st year
Selectivity (in blocks, age by age or parametric)
F multipliers
Index qs at age
S/R relation parameters

The Beverton and Holt stock recruitment relationship is used to calculate the expected recruitment. For Greenland Halibut the 10+ biomass was used as a proxy for SSB.

Selectivity is defined by blocks for each fleet (only one for Greenland halibut). Each selectivity block can be either fixed or estimated. Within each selectivity block, there are three options for estimating selectivity:
- estimate parameters for each age (one parameter for each age)
- logistic function (2 parameters)
- double logistic function (4 parameters)

Fishing mortality (F) is assumed to be separable, meaning it is the product of a year effect (Fmult) and selectivity at age. The Fmult for a fleet and year is determined by two sets of parameters, log_Fmult1ifleet, the parameter for first year for that fleet, and log_Fmultdevifleet,t, where t=2 to the number of years, the deviation of the parameter from the value in the first year for that fleet.

The objective function (from ASAP technical manual)

The objective function in ASAP is the sum of a number of model fits and two penalties. There are two types of error distributions in the calculation of the objective function: lognormal and multinomial. Both are converted to negative log likelihoods for use in the minimization conducted by ADMB. Both error distributions contain constant terms that do not change for any value of the parameters. These constants can be either included or excluded from the objective function. Note that since the weights for different components of the objective function multiply the constants, different solutions may result when the constants are included or not.

The lognormal model fits all contain a lambda value that allows emphasis of that particular part of the objective function along with an input coefficient of variation (CV) that is used to measure how strong a particular deviation is. The CV is converted to a variance (σ^2) and associated standard deviation (σ) using the equation

$$\sigma^2 = \ln(CV^2 + 1) \qquad (1)$$

The lognormal distribution has a negative log likelihood, -ln(L), defined by

$$-\ln(L) = 0.5\ln(2\pi) + \sum \ln(obs_i) + \ln(\sigma) + 0.5 \sum \frac{(\ln(obs_i) - \ln(pred_i))^2}{\sigma^2} \qquad (2)\#$$

The first two terms on the right side of equation (2) are the constants that are optionally kept or set to zero. The objective function is calculated as

$$Obj\ fxn = \lambda * (-\ln(L)) \qquad (3)\#$$

So that any component of the objective function can be turned off by setting λ for that component to zero. Standardized residuals for each component are calculated as

$$std\ resid_i = \frac{\ln(obs_i) - \ln(pred_i)}{\sigma} \qquad (4)$$

In a perfectly fit model, the standardized residuals would have mean zero and standard deviation one.

The multinomial distribution fits employ an input effective sample size to multiply the negative log likelihood when calculating the objective function. This distribution is made up of k bins each containing pi proportion of the total

(sum of pi=1). The input effective sample size (ESS) is used to create the number of fish in each bin (n_i) as n_i=ESS*p_i. The multinomial distribution then has a negative log likelihood defined by

$$-\ln(L) = -\ln(ESS!) + \sum_{i=1}^{k} \ln(n_i!) - ESS \sum_{i=1}^{k} p_i \ln(predp_i) \quad (5)$$

where p_i denotes an observed proportion and $predp_i$ denotes the associated predicted proportion. The first two terms on the right side of equation (5) are the constants that are optionally kept or set to zero. The objective function is simply the negative log likelihood for the multinomial distribution because the effective sample size is an integral part of the calculation of the likelihood.

The lognormal error distribution is assumed for

- Total catch in weight
- Indices
- Stock recruitment relationship
- Selectivity parameters (relative to initial guesses)
- The two stock recruitment parameters (relative to their initial guesses)
- Fmult in year 1 by fleet (relative to initial guesses)
- Fmult deviations
- Catchability in year 1 by fleet (relative to initial guesses)
- Catchability deviations
- Numbers at age in year 1 (relative to a population in equilibrium)

Multinomial distribution is assumed for catch at age

The two penalties are formed from estimated total fishing mortality rates. The first is a penalty associated with any total F greater than an input maximum value, calculated as 1000*(F-Fmax)² for F>Fmax. The second penalty is for F different than M in the early phases, calculated as $100*10^{-phase}$ (ln(avg(F)-ln(M))². The second penalty is always set to zero in the final estimation phase, regardless of the number of phase

Formulation

It is to be noted that input data can be age aggregated or disaggregated, catch data can also be separated in different components (Fleets) as well as tuning indices.

However, as a first approach and for exploratory purpose, the input data was identical to the data used in the XSA formulation to assess the stock in 2008 (Healey& Mahé, 2008) but updated to include up to 2009 data. All inputs are given in Tables 1-4.

Input parameters are summarized in table 5 and were chosen following a set of exploratory runs. Deviations from the default values were chosen as a first approach in order to reduce the total objective function, reduce the difference between observed and predicted total catch. Stock Recruitment steepness was also kept close to 1 and recruitment allowed to vary substantially from estimated values.

Index qs were not allowed to vary from year to year in this first formulation. Selectivity parameters were first estimated for all blocks and following results from sensitivity runs, selectivity was fixed for three blocks covering the period 1975-2002 and estimated for the period 2003-2009 on the basis of a double logistic function (4 parameters) (Fig. 1). Periods were chosen based on available data from the historical fishery and availability of index data (only from the period 1995 on).

The index were treated by age therefore each index (1-34) is a time series of abundance for one age*survey.

Results and discussion

Model fit

Table 6 gives a summary of the different components comprising the total objective function. With 34 ages the index fit comprise the most of the objective function followed by total catch and catch at age compositions. The value is quite high for the index fit although it is summed over 34 values. The detailed values by index of the RMSE are given in table 7. Optimal values should be around 1 indicating a poor fit of the survey index (Index 1 to 34). The standardized residuals are plotted on figure and the usual pattern is similar to the one seen in the XSA assessment (Healey and Mahé, 2008) with conflicting trends in recent years.

The results presented in table 8 are the estimated and input sample size for the catch at age data. Optimal fit would show better similarity between input and estimated values. The observed and expected proportion at age is given in figure 3. These figures show misfit for some years especially from 1993 to 2002 indicating inconsistencies in the catch at age data for this period.

Figure 4 shows the Beverton & Holt Stock-Recruitment relation fitted to generate recruitment estimates.

Trends in population size and fishing mortality

Estimated population size at age in 2009 from the ASAP model and from the XSA updated run are given if figure 5. The relative proportions at age show some similarity but estimates are overall higher For the XSA especially for ages 1 to 3. This is explained by the differences seen in the numbers at age of younger individuals from the different surveys and the fact that XSA uses inverse variance weighting for estimates of survivors in XSA, such weighting not implemented in ASAP. Figure shows estimates from XSA and ASAP of trends in fishing mortality, total abundance, recruitment (at age 1), biomass (5+ and 10+) as well as observed vs predicted total catch from ASAP. Results from both models are overall similar in terms of trends but magnitudes of inter-annual variations are higher for the statistical catch at age model.

The pattern in the observed and predicted catches is a consequence of the conflicting trends in the index data (fig. 2) and the year to year pattern in the relative proportion at age in the catch (fig. 3). Since there is no index data prior to 1995, the model fits the recruitment and selectivity to the catch only therefore showing limited discrepancies.

Retrospective analysis of the ASAP model (fig. 7) shows a relative good stability with no pattern.

Conclusion

The ASAP statistical catch at age model as it is formulated and applied to the Greenland Halibut stock in Sub-area 2 & Divisions 3KLMNO is a potential alternative model to asses the resource. Using the same data and a formulation tending to mimic the selectivity pattern observed in the XSA results lead to overall similar trends in population estimates but with higher inter-annual variations. The quality of the fit was poor but given the wider range of possibilities in data handling (separation by gear for the catch data, use of biomass tuning indexes) and parameterisation (possible variation in catchability, use of prior weighting…), there is scope for improvement in the formulation of the model.

References

Healey, B.P. and J.-C. Mahé. 2008. An Assessment of Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 + Divisions 3KLMNO. NAFO SCR Doc. 08/48, Ser. No. N5550.

Shepherd, J.G. 1999. Extended survivors analysis: An improved method for the analysis of catch-at-age data and abundance indices ICES Journal of Marine Science Vol. 56, No. 5, October 1999, pp. 584-591.

Table 1. Catch at age matrix (‘000s) for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

	Ages													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1975	0	0	0	0	334	2819	5750	4956	3961	1688	702	135	279	288
1976	0	0	0	0	17	610	3231	5413	3769	2205	829	260	101	53
1977	0	0	0	0	534	5012	10798	7346	2933	1013	220	130	116	84
1978	0	0	0	0	2982	8415	8970	7576	2865	1438	723	367	222	258
1979	0	0	0	0	2386	8727	12824	6136	1169	481	287	149	143	284
1980	0	0	0	0	209	2086	9150	9679	5398	3828	1013	128	53	27
1981	0	0	0	0	863	4517	9806	11451	4307	890	256	142	43	69
1982	0	0	0	0	269	2299	6319	5763	3542	1684	596	256	163	191
1983	0	0	0	0	701	3557	9800	7514	2295	692	209	76	106	175
1984	0	0	0	0	902	2324	5844	7682	4087	1259	407	143	106	183
1985	0	0	0	0	1983	5309	5913	3500	1380	512	159	99	87	86
1986	0	0	0	0	280	2240	6411	5091	1469	471	244	140	70	117
1987	0	0	0	0	137	1902	11004	8935	2835	853	384	281	225	349
1988	0	0	0	0	296	3186	8136	4380	1288	465	201	105	107	129
1989	0	0	0	0	181	1988	7480	4273	1482	767	438	267	145	71
1990	0	0	0	95	1102	6758	12632	7557	4072	2692	1204	885	434	318
1991	0	0	0	220	2862	7756	13152	10796	7145	3721	1865	1216	558	422
1992	0	0	0	1064	4180	10922	20639	12205	4332	1762	1012	738	395	335
1993	0	0	0	1010	9570	15928	17716	11918	4642	1836	1055	964	401	182
1994	0	0	0	5395	16500	15815	11142	6739	3081	1103	811	422	320	215
1995	0	0	0	323	1352	2342	3201	2130	1183	540	345	273	251	201
1996	0	0	0	190	1659	5197	6387	1914	956	504	436	233	143	89
1997	0	0	0	335	1903	4169	7544	3215	1139	606	420	246	137	89
1998	0	0	0	552	3575	5407	5787	3653	1435	541	377	161	92	51
1999	0	0	0	297	2149	5625	8611	3793	1659	623	343	306	145	151
2000	0	0	0	271	2029	12583	21175	3299	973	528	368	203	129	104
2001	0	0	0	448	2239	12163	22122	5154	1010	495	439	203	156	75
2002	0	0	0	479	1662	7239	17581	6607	1244	659	360	224	126	81
2003	0	0	0	1279	4491	10723	16764	6385	1614	516	290	144	76	85
2004	0	0	0	897	4062	8236	10542	4126	1307	529	289	184	87	75
2005	0	0	0	534	1652	5999	10313	3996	1410	444	244	114	64	46
2006	0	0	0	216	1869	6450	12144	4902	1089	372	136	47	32	40
2007	0	0	0	88	570	3732	11912	5414	1230	472	163	80	41	29
2008	0	0	0	29	448	3312	10697	5558	1453	393	115	46	26	15
2009	0	0	0	61	476	3121	8801	7276	1949	508	206	67	31	34

Table 2. Catch weights-at-age (kg) matrix for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

	Ages													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1975	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.764
1976	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.144
1977	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.992
1978	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.894
1979	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	6.077
1980	0.000	0.000	0.126	0.244	0.514	0.659	0.869	1.050	1.150	1.260	1.570	2.710	3.120	5.053
1981	0.000	0.000	0.126	0.244	0.392	0.598	0.789	0.985	1.240	1.700	2.460	3.510	4.790	7.426
1982	0.000	0.000	0.126	0.244	0.525	0.684	0.891	1.130	1.400	1.790	2.380	3.470	4.510	7.359
1983	0.000	0.000	0.126	0.244	0.412	0.629	0.861	1.180	1.650	2.230	3.010	3.960	5.060	7.061
1984	0.000	0.000	0.126	0.244	0.377	0.583	0.826	1.100	1.460	1.940	2.630	3.490	4.490	7.016
1985	0.000	0.000	0.126	0.244	0.568	0.749	0.941	1.240	1.690	2.240	2.950	3.710	4.850	7.010
1986	0.000	0.000	0.126	0.244	0.350	0.584	0.811	1.100	1.580	2.120	2.890	3.890	4.950	7.345
1987	0.000	0.000	0.126	0.244	0.364	0.589	0.836	1.160	1.590	2.130	2.820	3.600	4.630	6.454
1988	0.000	0.000	0.126	0.244	0.363	0.569	0.805	1.163	1.661	2.216	3.007	3.925	5.091	7.164
1989	0.000	0.000	0.126	0.244	0.400	0.561	0.767	1.082	1.657	2.237	2.997	3.862	4.919	6.370
1990	0.000	0.000	0.090	0.181	0.338	0.546	0.766	1.119	1.608	2.173	2.854	3.731	4.691	6.391
1991	0.000	0.000	0.126	0.244	0.383	0.592	0.831	1.228	1.811	2.461	3.309	4.142	5.333	7.081
1992	0.000	0.000	0.175	0.289	0.430	0.577	0.793	1.234	1.816	2.462	3.122	3.972	5.099	6.648
1993	0.000	0.000	0.134	0.232	0.368	0.547	0.809	1.207	1.728	2.309	2.999	3.965	4.816	6.489
1994	0.000	0.000	0.080	0.196	0.330	0.514	0.788	1.179	1.701	2.268	2.990	3.766	4.882	6.348
1995	0.000	0.000	0.080	0.288	0.363	0.531	0.808	1.202	1.759	2.446	3.122	3.813	4.893	6.790
1996	0.000	0.000	0.161	0.242	0.360	0.541	0.832	1.272	1.801	2.478	3.148	3.856	4.953	6.312
1997	0.000	0.000	0.120	0.206	0.336	0.489	0.771	1.159	1.727	2.355	3.053	3.953	5.108	6.317
1998	0.000	0.000	0.119	0.228	0.373	0.543	0.810	1.203	1.754	2.351	3.095	4.010	5.132	6.124
1999	0.000	0.000	0.176	0.253	0.358	0.533	0.825	1.253	1.675	2.287	2.888	3.509	4.456	5.789
2000	0.000	0.000	0.000	0.254	0.346	0.524	0.787	1.192	1.774	2.279	2.895	3.645	4.486	5.531
2001	0.000	0.000	0.000	0.249	0.376	0.570	0.830	1.168	1.794	2.367	2.950	3.715	4.585	5.458
2002	0.000	0.000	0.217	0.251	0.369	0.557	0.841	1.193	1.760	2.277	2.896	3.579	4.407	5.477
2003	0.000	0.000	0.188	0.247	0.389	0.564	0.822	1.199	1.651	2.166	2.700	3.404	4.377	5.409
2004	0.000	0.000	0.180	0.249	0.376	0.535	0.808	1.196	1.629	2.146	2.732	3.538	4.381	5.698
2005	0.000	0.000	0.252	0.301	0.396	0.564	0.849	1.247	1.691	2.177	2.705	3.464	4.264	5.224
2006	0.000	0.000	0.129	0.267	0.405	0.605	0.815	1.092	1.495	1.874	2.396	3.139	3.747	4.701
2007	0.000	0.000	0.000	0.276	0.389	0.581	0.833	1.137	1.500	1.948	2.607	3.057	3.869	4.954
2008	0.000	0.000	0.000	0.278	0.404	0.617	0.891	1.195	1.605	2.038	2.804	3.247	4.232	4.721
2009	0.000	0.000	0.000	0.279	0.390	0.599	0.862	1.158	1.611	2.099	2.549	3.118	3.432	4.431

Table 3. Stock weights-at-age (kg) matrix for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

	Ages													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1975	0.000	0.000	0.000	0.000	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.764
1976	0.000	0.000	0.000	0.000	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.144
1977	0.000	0.000	0.000	0.000	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.992
1978	0.000	0.000	0.000	0.000	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	5.894
1979	0.000	0.000	0.000	0.000	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	6.077
1980	0.000	0.000	0.000	0.000	0.514	0.659	0.869	1.050	1.150	1.260	1.570	2.710	3.120	5.053
1981	0.000	0.000	0.000	0.000	0.392	0.598	0.789	0.985	1.240	1.700	2.460	3.510	4.790	7.426
1982	0.000	0.000	0.000	0.000	0.525	0.684	0.891	1.130	1.400	1.790	2.380	3.470	4.510	7.359
1983	0.000	0.000	0.000	0.000	0.412	0.629	0.861	1.180	1.650	2.230	3.010	3.960	5.060	7.061
1984	0.000	0.000	0.000	0.000	0.377	0.583	0.826	1.100	1.460	1.940	2.630	3.490	4.490	7.016
1985	0.000	0.000	0.000	0.000	0.568	0.749	0.941	1.240	1.690	2.240	2.950	3.710	4.850	7.010
1986	0.000	0.000	0.000	0.000	0.350	0.584	0.811	1.100	1.580	2.120	2.890	3.890	4.950	7.345
1987	0.000	0.000	0.000	0.000	0.364	0.589	0.836	1.160	1.590	2.130	2.820	3.600	4.630	6.454
1988	0.000	0.000	0.000	0.000	0.363	0.569	0.805	1.163	1.661	2.216	3.007	3.925	5.091	7.164
1989	0.000	0.000	0.000	0.000	0.400	0.561	0.767	1.082	1.657	2.237	2.997	3.862	4.919	6.370
1990	0.000	0.000	0.000	0.000	0.338	0.546	0.766	1.119	1.608	2.173	2.854	3.731	4.691	6.391
1991	0.000	0.000	0.000	0.000	0.383	0.592	0.831	1.228	1.811	2.461	3.309	4.142	5.333	7.081
1992	0.000	0.000	0.000	0.000	0.430	0.577	0.793	1.234	1.816	2.462	3.122	3.972	5.099	6.648
1993	0.000	0.000	0.000	0.000	0.368	0.547	0.809	1.207	1.728	2.309	2.999	3.965	4.816	6.489
1994	0.000	0.000	0.000	0.000	0.330	0.514	0.788	1.179	1.701	2.268	2.990	3.766	4.882	6.348
1995	0.000	0.000	0.000	0.000	0.363	0.531	0.808	1.202	1.759	2.446	3.122	3.813	4.893	6.790
1996	0.000	0.000	0.000	0.000	0.360	0.541	0.832	1.272	1.801	2.478	3.148	3.856	4.953	6.312
1997	0.000	0.000	0.000	0.000	0.336	0.489	0.771	1.159	1.727	2.355	3.053	3.953	5.108	6.317
1998	0.000	0.000	0.000	0.000	0.373	0.543	0.810	1.203	1.754	2.351	3.095	4.010	5.132	6.124
1999	0.000	0.000	0.000	0.000	0.358	0.533	0.825	1.253	1.675	2.287	2.888	3.509	4.456	5.789
2000	0.000	0.000	0.000	0.000	0.346	0.524	0.787	1.192	1.774	2.279	2.895	3.645	4.486	5.531
2001	0.000	0.000	0.000	0.000	0.376	0.570	0.830	1.168	1.794	2.367	2.950	3.715	4.585	5.458
2002	0.000	0.000	0.000	0.000	0.369	0.557	0.841	1.193	1.760	2.277	2.896	3.579	4.407	5.477
2003	0.000	0.000	0.000	0.000	0.389	0.564	0.822	1.199	1.651	2.166	2.700	3.404	4.377	5.409
2004	0.000	0.000	0.000	0.000	0.376	0.535	0.808	1.196	1.629	2.146	2.732	3.538	4.381	5.698
2005	0.000	0.000	0.000	0.000	0.396	0.564	0.849	1.247	1.691	2.177	2.705	3.464	4.264	5.224
2006	0.000	0.000	0.000	0.000	0.405	0.605	0.815	1.092	1.495	1.874	2.396	3.139	3.747	4.701
2007	0.000	0.000	0.000	0.000	0.389	0.581	0.833	1.137	1.500	1.948	2.607	3.057	3.869	4.954
2008	0.000	0.000	0.000	0.000	0.404	0.617	0.891	1.195	1.605	2.038	2.804	3.247	4.232	4.721
2009	0.000	0.000	0.000	0.000	0.390	0.599	0.862	1.158	1.611	2.099	2.549	3.118	3.432	4.431

Table 4. Survey data (mean numbers per tow) used to calibrate XSA assessment of Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

		Ages													
2J3K Fall		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	1996	98.68	47.82	32.01	9.539	6.283	2.466	0.836	0.191	0.179	0.039	0.024	0.012	0.017	0.006
	1997	28.05	58.62	43.61	21.13	10.37	5.007	1.998	0.641	0.203	0.055	0.032	0.022	0.009	0.003
	1998	23.35	25.07	31.19	21.87	10.86	4.452	2.066	0.565	0.132	0.059	0.028	0.021	0.013	0.002
	1999	15.99	34.42	24.07	28.28	20.04	10.53	3.811	0.703	0.139	0.072	0.021	0.006	0.025	0.002
	2000	38.57	21.94	16.43	13.2	13.76	7.207	2.161	0.502	0.063	0.03	0.015	0.004	0	0.007
	2001	43.9	22.72	17	14.07	9.765	7.591	3.403	0.692	0.112	0.023	0.014	0.004	0.011	0.001
	2002	40.67	24.08	12.5	9.679	6.027	1.974	0.719	0.19	0.039	0.013	0.004	0	0.003	0
	2003	45.7	26.67	11.69	9.49	6.389	2.271	0.893	0.268	0.04	0.017	0.01	0.006	0.002	0
	2004	32.49	32.93	13.89	12.31	9.209	2.684	1.198	0.358	0.083	0.032	0.006	0.004	0.008	0
	2005	16.06	16.15	8.557	13.84	10.98	6.848	3.96	0.662	0.116	0.034	0.027	0.009	0.007	0.002
	2006	32.34	17.98	8.502	17.6	13.03	9.113	4.177	1.151	0.18	0.028	0.024	0.01	0	0.002
	2007	32.61	14.51	12.81	18.77	9.573	10.35	6.171	2.14	0.338	0.076	0.039	0.024	0.009	0.005
	2008	**Not used, survey partially completed**													
	2009	50.62	19.15	11.4	8.421	9.889	5.395	3.591	1.393	0.25	0.077	0.024	0.008	0.008	0.004

EU 3M (0-700m)		1	2	3	4	5	6	7	8	9	10	11	12
	1995	12.41	2.543	2.23	1.909	2.656	5.098	3.766	2.122	1.308	0.26	0.066	0.022
	1996	5.843	7.969	2.415	3.036	4.203	5.82	2.488	1.616	0.424	0.086	0.026	0.038
	1997	3.325	3.775	5.996	6.497	7.105	8.455	4.992	2.152	0.657	0.22	0.028	0.021
	1998	2.735	2.134	7.685	11	12.33	11.3	7.84	2.621	0.746	0.195	0.034	0.007
	1999	1.059	0.7	3.008	10.47	13.41	12.58	5.554	1.823	0.348	0.102	0.008	0.003
	2000	3.748	0.292	0.595	2.165	7.092	14.1	5.404	2.32	0.449	0.114	0.054	0
	2001	8.031	1.433	1.811	0.993	2.788	7.787	6.625	3.213	0.183	0.045	0.006	0
	2002	4.081	2.939	2.795	1.668	3.786	5.593	5.732	1.275	0.129	0.06	0.019	0.007
	2003	2.198	1	0.608	1.514	2.476	2.937	1.93	0.466	0.131	0.099	0.019	0.005
	2004	2.192	3.288	4.373	1.971	6.965	7.797	2.537	0.644	0.29	0.134	0.079	0.047
	2005	0.544	0.811	3.176	2.496	6.885	7.592	2.916	0.61	0.111	0.12	0.055	0.019
	2006	0.68	0.4	0.65	1.17	5.98	7.46	3.31	0.77	0.22	0.18	0.13	0.06
	2007	0.418	0.092	0.567	0.342	3.438	7.371	5.76	1.513	0.307	0.205	0.077	0.047
	2008	0.195	0.097	0.15	0.193	1.499	5.701	6.156	1.13	0.352	0.261	0.124	0.053
	2009	0.076	0.009	0.037	0.101	0.754	3.612	4.048	0.887	0.19	0.267	0.077	0.058

3LNO Spr		1	2	3	4	5	6	7	8
	1996	1.621	4.241	4.599	2.183	0.827	0.284	0.057	0.001
	1997	1.162	3.924	5.16	3.227	1.461	0.507	0.099	0.013
	1998	0.22	0.814	3.847	6.186	4.955	1.238	0.326	0.072
	1999	0.292	0.552	1.149	1.982	3.388	1.09	0.242	0.05
	2000	0.793	1.069	1.068	1.506	1.954	2.037	0.556	0.031
	2001	0.565	0.714	0.739	0.676	0.796	0.716	0.279	0.023
	2002	0.642	0.572	0.603	0.581	0.608	0.208	0.049	0.006
	2003	0.926	2.137	1.663	1.569	1.055	0.206	0.051	0.008
	2004	0.662	0.572	1.181	1.184	1.161	0.259	0.041	0.02
	2005	0.353	0.306	1.09	0.946	1.372	0.823	0.206	0.025
	2006	**Survey not completed**							
	2007	1.595	0.516	0.802	0.399	1.405	1.491	1.121	0.183
	2008	0.443	0.772	0.963	0.713	1.254	0.754	0.637	0.284
	2009	0.266	0.22	0.192	0.385	0.45	0.26	0.134	0.07

Table 5. Greenland Halibut in SA 2+3 - ASAP formulation - parameters estimated and components of the objective function.

Parameter	Phase	lambda	CV	Initial guess	Rational
Unexploited Stock Size	1			700000	
Deviation from unexploited Stock Size		2	0.2		
Catchability in 1st Year	1			0.0001	
mF in 1st year	1	2	1	0.5	
S/R steepness	2			1	
Deviation from initial steepness		2	0.2		
Recruitment deviation	3	1	1		
N in 1st year	4	1	0.9		
mF deviations	4	1	1		
Catch in Wt		1	0.05		
Index fit (34)		1			
Indexes q		0	1		
Indexes q deviations		0	1		
Block 3 selectivity parameters (4)	2	1	1		

Table 6. Greenland Halibut in SA 2+3 - ASAP formulation fit– Components of the objective function

Component	Lambda	obj_fun
Objective function Total		9189.83
Catch_Fleet_Total	1	796.962
	0	0
Index_Fit_Total	34	7023.57
Catch_Age_Comps		765.123
Sel_Param_43 (ascending A50)	1	2.62235
Sel_Param_44 (ascending slope)	1	0.04862
Sel_Param_45 (descending A50)	1	2.34522
Sel_Param_46 (descending slope)	1	3.98095
Sel_Params_Total	4	8.99715
Fmult_year1_fleet_1	2	0.14676
Fmult_year1_fleet_Total	2	0.14676
Fmult_devs_fleet_1	1	2.94224
Fmult_devs_fleet_Total	1	2.94224
N_year_1	1	132.242
Recruit_devs	1	435.333
SRR_steepness	2	-1.35747
SRR_unexpl_stock	2	25.8703

Table 7. Greenland Halibut in SA 2+3 - ASAP formulation fit– Root Mean Square Error computed from Standardized Residuals

Component	Nb of resids	RMSE
Catch_Fleet_Total	35	5.40
Index1 (EU3M age1)	15	6.74
Index2 (EU3M age2)	15	9.86
Index3 (EU3M age3)	15	8.72
Index4 (EU3M age4)	15	7.16
Index5 (EU3M age5)	15	3.35
Index6 (EU3M age6)	15	2.23
Index7 (EU3M age7)	15	3.21
Index8 (EU3M age8)	15	5.77
Index9 (EU3M age9)	15	6.06
Index10 (EU3M age10)	15	3.80
Index11 (EU3M age11)	15	7.21
Index12 (EU3M age12)	13	8.07
Index13 (Can2J3K age1)	13	6.49
Index14 (Can2J3K age2)	13	5.39
Index15 (Can2J3K age3)	13	4.56
Index16 (Can2J3K age4)	13	4.71
Index17 (Can2J3K age5)	13	3.62
Index18 (Can2J3K age6)	13	3.42
Index19 (Can2J3K age7)	13	4.68
Index20 (Can2J3K age8)	13	4.59
Index21 (Can2J3K age9)	13	4.50
Index22 (Can2J3K age10)	13	2.96
Index23 (Can2J3K age11)	13	4.12
Index24 (Can2J3K age12)	12	4.78
Index25 (Can2J3K age13)	11	6.20
Index26 (Can2J3K age14)	10	4.95
Index27 (CanS3LNOage1)	13	7.71
Index28 (CanS3LNOage2)	13	5.51
Index29 (CanS3LNOage3)	13	4.77
Index30 (CanS3LNOage4)	13	3.47
Index31 (CanS3LNOage5)	13	3.21
Index32 (CanS3LNOage6)	13	4.19
Index33 (CanS3LNOage7)	13	7.71
Index34 (CanS3LNOage8)	13	11.58
Index_Total	458	5.86
Nyear1	13	0.28
Fmult_Year1	1	0.25
Fmult_devs_Fleet_1	34	0.36
Fmult_devs_Total	34	0.36
Recruit_devs	35	0.70
Fleet_Sel_params	4	0.27
SRR_steepness	1	0.21
SRR_unexpl_S	1	0.59

Table 8. Greenland Halibut in SA 2+3 - ASAP formulation fit– Input and Estimated effective sample sizes for catch at age

Year	Input Sample size	Estimated Sample size
1975	100	252
1976	100	28
1977	100	89
1978	100	72
1979	100	39
1980	100	29
1981	100	518
1982	100	364
1983	100	103
1984	100	156
1985	100	54
1986	100	91
1987	100	75
1988	100	43
1989	100	74
1990	100	84
1991	100	91
1992	100	283
1993	100	22
1994	100	10
1995	100	23
1996	100	66
1997	100	14
1998	100	25
1999	100	11
2000	100	10
2001	100	13
2002	100	18
2003	100	366
2004	100	278
2005	100	57
2006	100	185
2007	100	45
2008	100	133
2009	100	58

Table 9. Greenland Halibut in SA 2+3 - ASAP formulation results – Fishing mortalities.

F	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.002	0.002	0.002	0.003	0.002	0.003	0.003	0.002	0.002	0.003	0.002	0.001	0.002	0.001	0.001	0.002	0.003	0.003
5	0.015	0.012	0.016	0.020	0.016	0.018	0.019	0.016	0.017	0.020	0.014	0.011	0.016	0.009	0.007	0.016	0.022	0.027
6	0.090	0.076	0.099	0.124	0.101	0.112	0.119	0.101	0.104	0.124	0.092	0.073	0.112	0.058	0.050	0.108	0.151	0.183
7	0.342	0.292	0.378	0.472	0.386	0.429	0.452	0.384	0.397	0.473	0.347	0.274	0.422	0.220	0.187	0.405	0.567	0.688
8	0.566	0.483	0.625	0.781	0.640	0.710	0.749	0.636	0.657	0.784	0.509	0.401	0.619	0.322	0.273	0.593	0.830	1.009
9	0.615	0.524	0.679	0.848	0.695	0.770	0.813	0.690	0.713	0.851	0.509	0.401	0.619	0.322	0.274	0.594	0.831	1.010
10	0.612	0.522	0.675	0.844	0.691	0.766	0.809	0.686	0.710	0.846	0.477	0.376	0.580	0.302	0.256	0.557	0.779	0.946
11	0.599	0.511	0.661	0.826	0.677	0.751	0.793	0.672	0.695	0.829	0.442	0.348	0.537	0.280	0.238	0.516	0.721	0.876
12	0.577	0.492	0.637	0.796	0.652	0.723	0.763	0.647	0.669	0.798	0.408	0.321	0.496	0.258	0.219	0.475	0.665	0.808
13	0.503	0.429	0.555	0.694	0.568	0.630	0.665	0.564	0.584	0.696	0.374	0.295	0.455	0.237	0.201	0.437	0.611	0.742
14	0.279	0.238	0.308	0.385	0.315	0.349	0.369	0.313	0.324	0.386	0.343	0.270	0.417	0.217	0.184	0.400	0.559	0.679

F	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.002	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
4	0.015	0.021	0.012	0.011	0.009	0.012	0.012	0.018	0.025	0.019	0.009	0.008	0.007	0.006	0.006	0.008	0.008
5	0.105	0.149	0.087	0.075	0.062	0.084	0.081	0.129	0.174	0.135	0.059	0.048	0.040	0.039	0.038	0.052	0.051
6	0.522	0.743	0.433	0.375	0.311	0.417	0.406	0.645	0.867	0.673	0.292	0.236	0.200	0.192	0.190	0.257	0.251
7	1.022	1.455	0.847	0.735	0.608	0.816	0.795	1.264	1.697	1.319	0.990	0.801	0.679	0.650	0.646	0.873	0.851
8	1.032	1.470	0.855	0.743	0.615	0.824	0.803	1.276	1.714	1.332	1.312	1.063	0.901	0.862	0.856	1.157	1.128
9	0.898	1.278	0.744	0.646	0.534	0.716	0.698	1.110	1.491	1.158	0.711	0.576	0.488	0.467	0.464	0.627	0.612
10	0.760	1.082	0.629	0.546	0.452	0.606	0.591	0.939	1.261	0.980	0.303	0.245	0.208	0.199	0.198	0.267	0.260
11	0.636	0.906	0.527	0.458	0.379	0.508	0.495	0.787	1.057	0.821	0.124	0.101	0.085	0.082	0.081	0.109	0.107
12	0.530	0.754	0.439	0.381	0.315	0.423	0.412	0.655	0.879	0.683	0.051	0.041	0.035	0.033	0.033	0.045	0.043
13	0.438	0.624	0.363	0.315	0.261	0.350	0.341	0.542	0.727	0.565	0.021	0.017	0.014	0.013	0.013	0.018	0.018
14	0.361	0.514	0.299	0.259	0.215	0.288	0.281	0.446	0.599	0.465	0.008	0.007	0.006	0.005	0.005	0.007	0.007

Table 10. Greenland Halibut in SA 2+3 - ASAP formulation results – Population numbers.

N	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	101320	101425	98263	72162	87541	122743	124064	120085	145319	142884	168844	171431	194918	155358	84242	78180	76527	104812
2	126959	82954	83040	80451	59081	71673	100494	101575	98317	118977	116984	138238	140356	159586	127197	68972	64008	62655
3	106299	103945	67917	67987	65868	48372	58681	82277	83162	80495	97410	95778	113179	114914	130658	104140	56469	52406
4	62804	87004	85081	55587	55640	53909	39588	48024	67340	68063	65876	79737	78404	92641	94071	106962	85242	46218
5	46338	51309	71102	69493	45376	45443	44018	32320	39224	54996	55560	53841	65194	64057	75765	76948	87396	69594
6	30076	37389	41489	57285	55764	36544	36533	35351	26032	31576	44128	44877	43614	52504	51997	61581	62012	69990
7	25035	22514	28360	30770	41449	41260	26743	26568	26175	19209	22838	32941	34163	31915	40545	40511	45269	43666
8	15807	14559	13770	15917	15717	23057	22007	13926	14818	14410	9797	13214	20516	18339	20974	27547	22123	21031
9	10009	7345	7354	6033	5966	6785	9285	8517	6038	6288	5388	4822	7245	9048	10880	13064	12458	7895
10	3697	4431	3560	3054	2115	2439	2571	3370	3498	2422	2199	2651	2643	3194	5366	6775	5906	4443
11	1510	1642	2154	1484	1076	868	928	937	1389	1408	851	1117	1490	1211	1933	3400	3179	2219
12	544	679	807	910	532	448	335	344	392	567	503	448	646	713	750	1248	1662	1265
13	410	250	340	349	336	227	178	128	147	164	209	274	266	322	451	493	635	700
14	510	519	468	441	389	388	323	258	214	194	175	220	304	302	407	579	579	553

N	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	150279	227415	280155	225142	107102	69648	73468	111276	123573	131918	102309	58318	41081	29456	29033	14209	22045	
2	85813	123038	186192	229371	184330	87688	57023	60151	91105	101173	108005	83762	47746	33634	24116	23770	11633	18049
3	51297	70236	100691	152402	187751	150889	71775	46675	49228	74552	82801	88413	68570	39087	27534	19743	19459	9523
4	42889	41917	57344	82305	124600	153538	123344	58675	38122	40174	60884	67704	72311	56090	31975	22524	16146	15914
5	37710	34596	33599	46374	66669	101115	124224	99824	47164	30450	32267	49376	55006	58818	45637	26017	18287	13111
6	55469	27806	24402	25223	35214	51285	76150	93750	71807	32453	21781	24906	38542	43250	46328	35955	20222	14233
7	47714	26946	10826	12964	14187	21129	27682	41537	40256	24708	13549	13320	16099	25827	29234	31354	22757	12882
8	17962	14059	5147	3800	5089	6320	7652	10233	9612	6038	5412	4124	4893	6682	11039	12548	10723	7955
9	6279	5238	2646	1791	1481	2253	2270	2806	2338	1417	1305	1193	1167	1628	2311	3839	3229	2841
10	2355	2095	1194	1030	769	710	901	924	757	431	364	525	549	586	835	1190	1679	1434
11	1412	902	582	521	488	401	317	409	296	176	132	220	336	365	393	561	746	1059
12	756	612	298	281	270	274	197	158	152	84	63	96	163	253	276	297	412	549
13	462	365	236	158	157	161	147	107	67	52	35	49	75	129	200	218	233	323
14	502	531	420	389	340	324	292	266	190	112	82	94	116	155	231	350	460	561

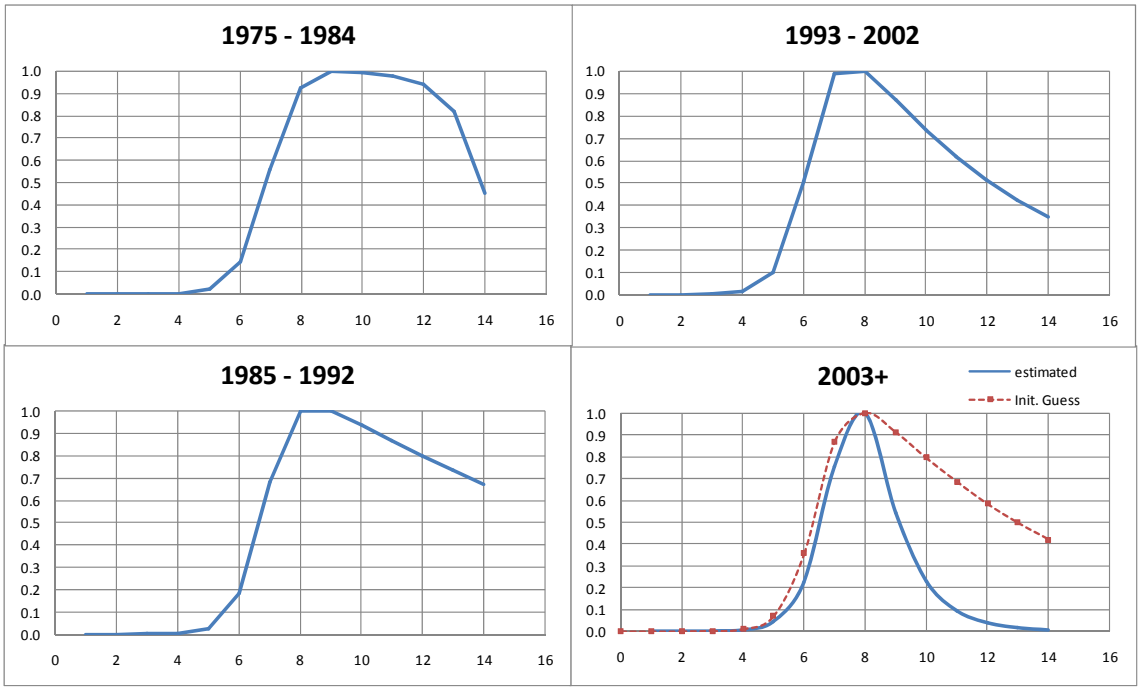

Figure 1 : Greenland Halibut in SA 2+3 - Selectivity blocks from the ASAP formulation. Selectivity is fixed for 1975 to 1992 in 3 blocks and estimated for the period 2003 on.

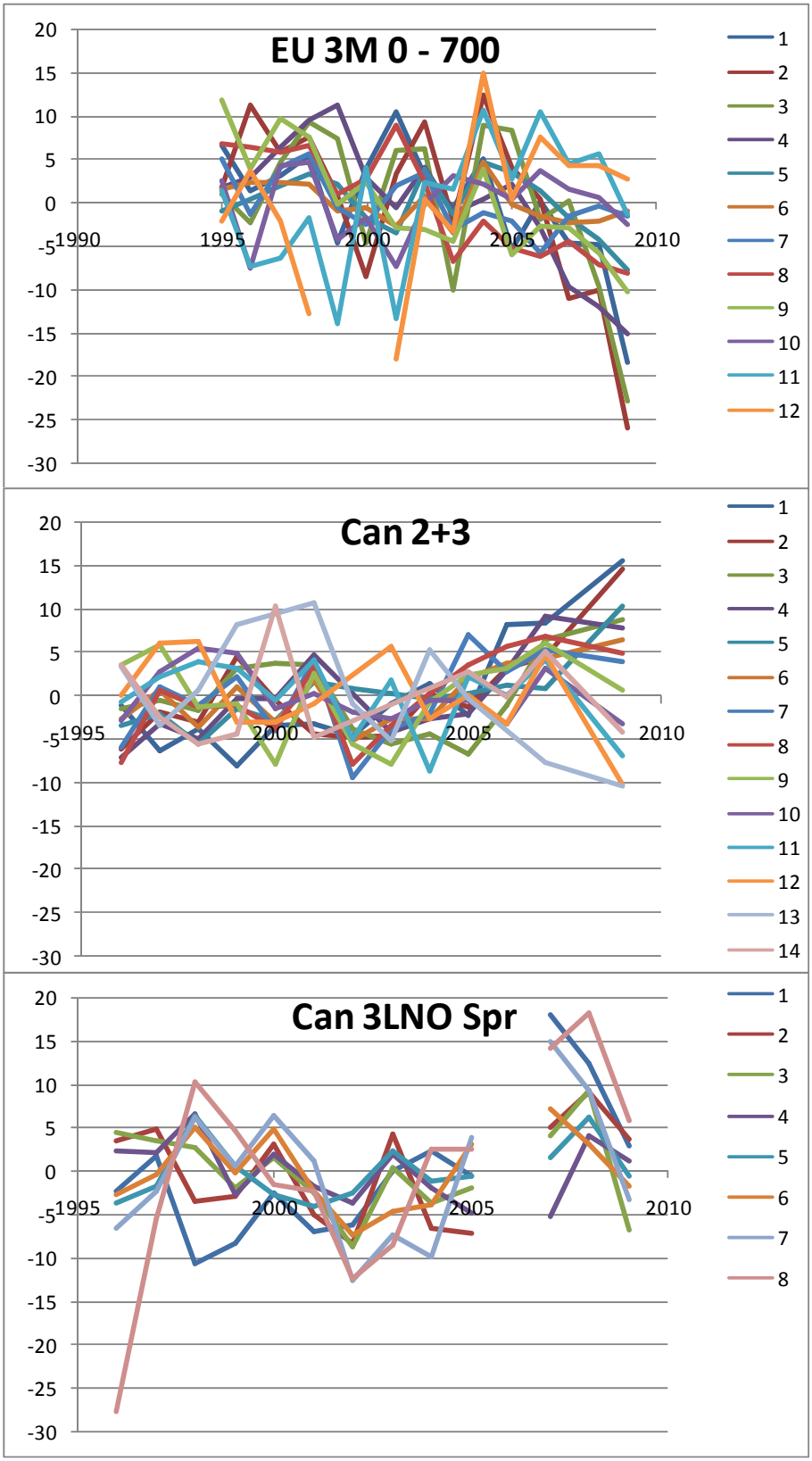

Figure 2 : Greenland Halibut in SA 2+3 – standardized residuals from ASAP formulation

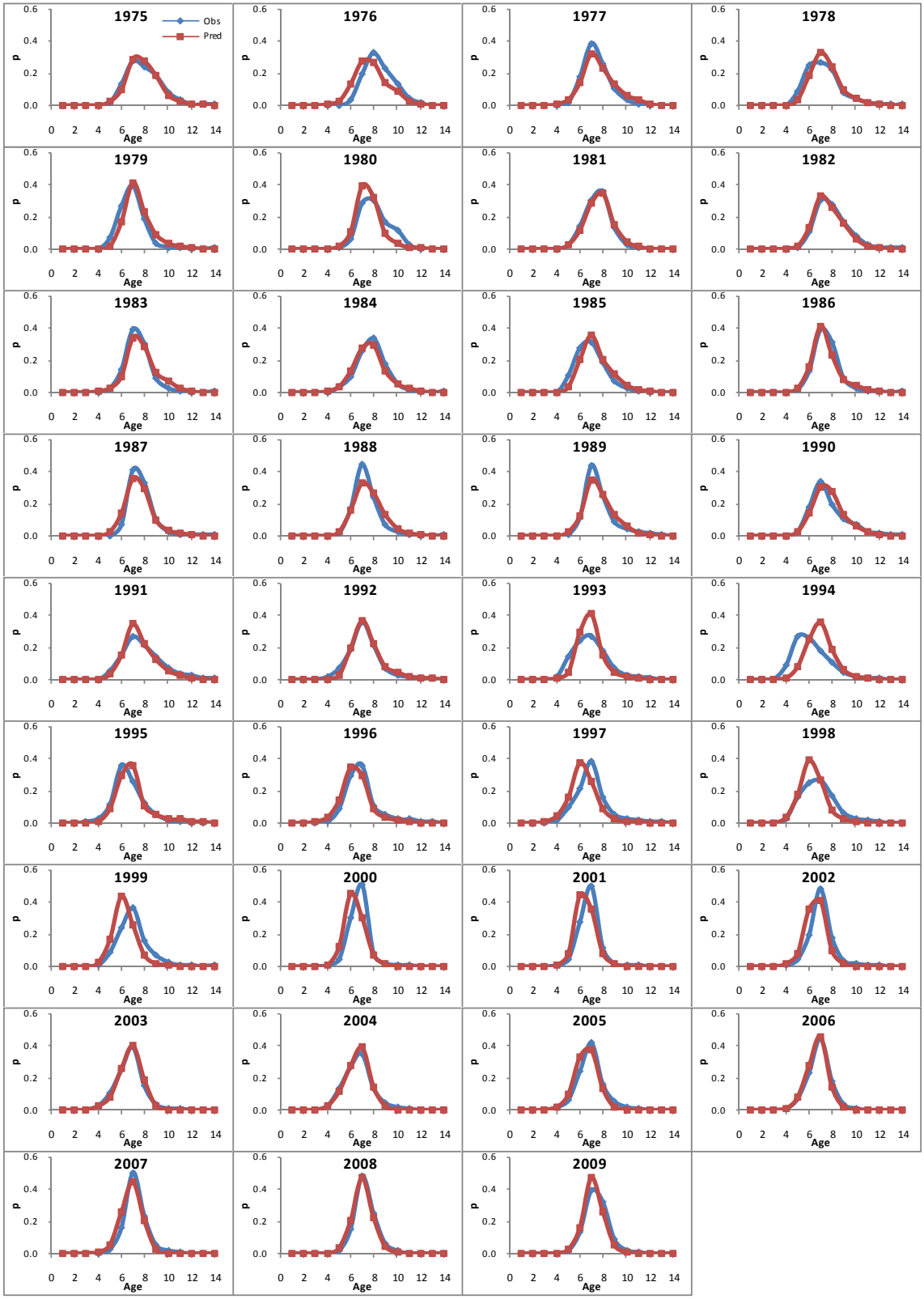

Figure 3: Greenland Halibut in SA 2+3 – Expected and observed proportions at age in the catch.

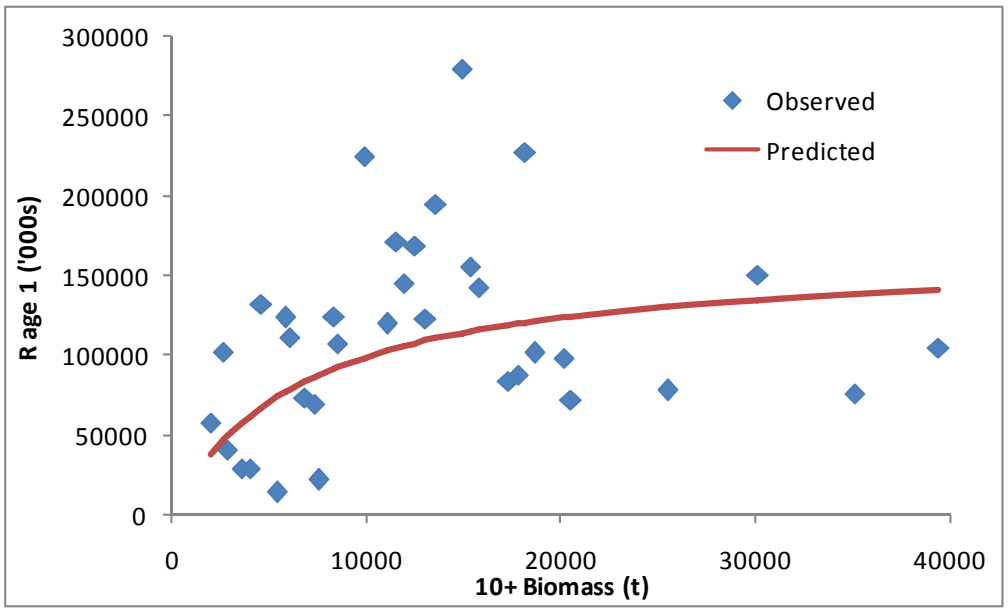

Figure 4: Greenland Halibut in SA 2+3 - Beverton & Holt Stock Recruitment relation fitted to the 10+ biomass as a proxy for SSB and used in the ASAP formulation.

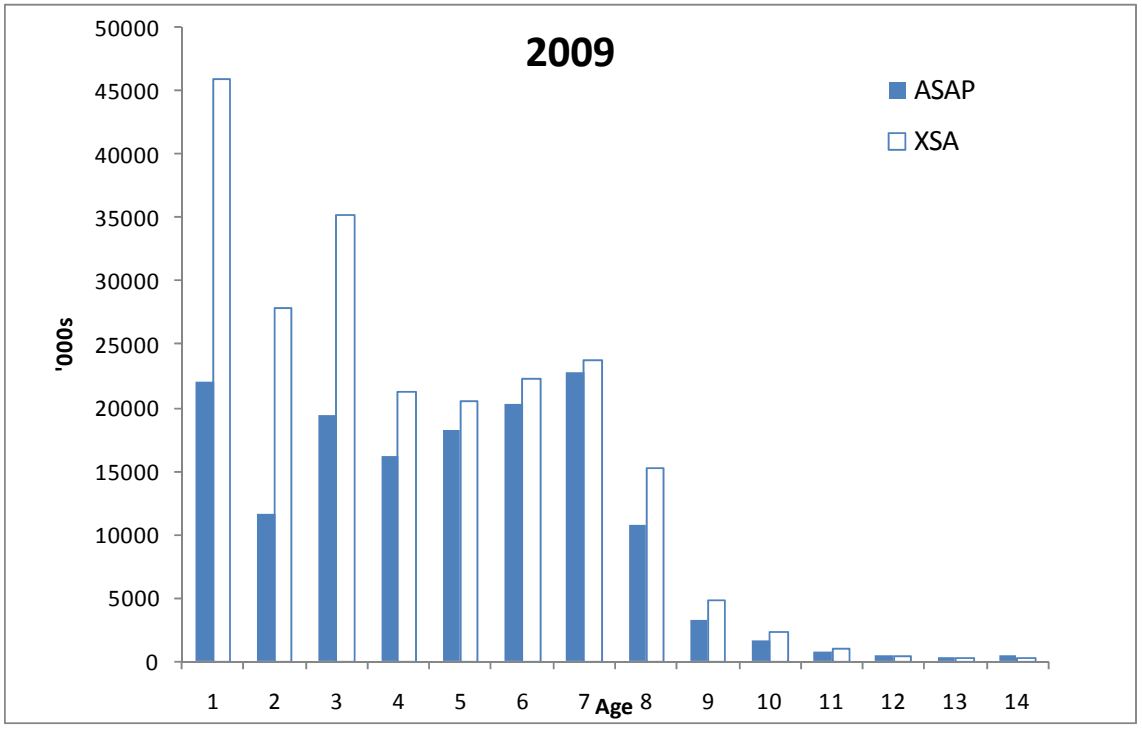

Figure 5: Greenland Halibut in SA 2+3 - Estimates of numbers at age in 2009 from ASAP and XSA.

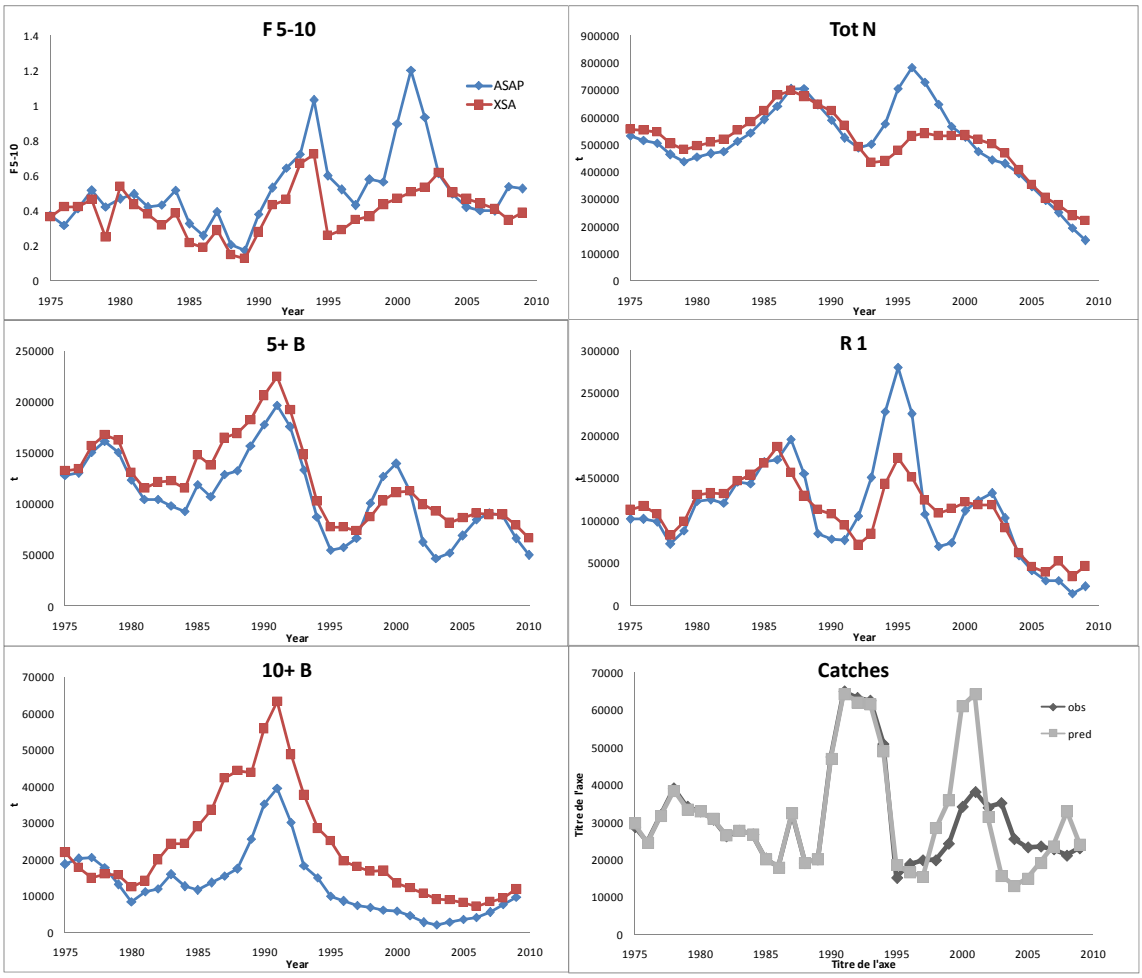

Figure 6 : Greenland Halibut in SA 2+3 - Estimates of trends in average fishing mortality, exploitable (5+B) and SSB proxy (10+B), Total abundance and recruitment (age 1) from ASAP and XSA. Observed and predicted total catch from ASAP is also presented.

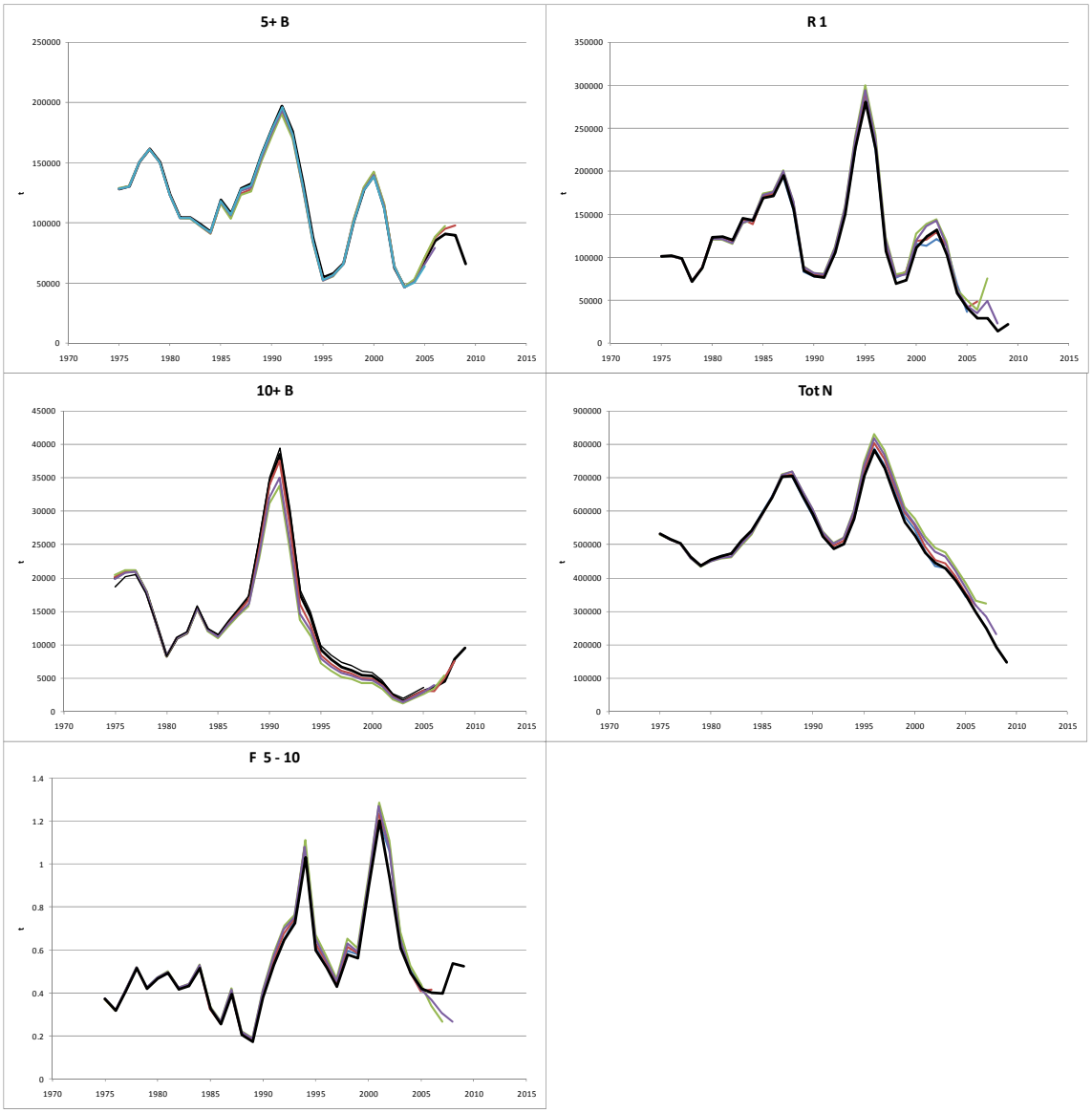

Figure 7: Greenland Halibut in SA 2+3 - ASAP formulation – Retrospective analysis.