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

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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) using the same formulation as in Healey and Mahé, 2010 adding 2010 data as for the 2011 assessment (Healey 2011). 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 summary of the model and objective function calculation is given in Mahé (2010) and a full description with the software on the NOAA website:

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

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.

Formulation

Input parameters are summarized in tables 1-4. Model parameters are summarised in table 5 and were chosen following a set of exploratory runs. Deviations from 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.

Indexes used were the same as in the XSA 2011 formulation plus the Spanish 3NO survey for ages 2 to 13 (table 4), age 1 from the Spanish 3NO survey was removed as it showed a lack of consistency with other ages

Index qs were not allowed to vary from year to year. 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 2003-2010 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 (1-54) 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 54 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 54 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, 2011) 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 2010 from the ASAP model and from the XSA 2011 updated run (using same formulation as in Healey and Mahé, 2010 adding 2010 data) are given in figure 5. The relative proportions at age are very similar but estimates are overall higher for the XSA at older ages. This is partly explained by the use of 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 especially for the period from the mid 90's to mid 2000's.

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.

Assuming error in the catch leads to significant revision upward of the estimated catch from 1999 to 2001 and a significant downward revision for the period 2003 – 2005. From the exploratory runs, one was done assuming no error in the catch. The results are given in figure 8 and are very close to the results from the XSA run. Figure 9 shows the residuals from this run and a comparison with residuals from the same run but assuming error in the catch (Fig. 10) illustrate that the model tries to remove the trends in the residuals by adjusting the total catch figures. The level of discrepancy between the observed and predicted catch (up to 60 % in some year) needed to slightly improve the residual pattern illustrate the level of inconsistencies in the available data.

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 especially if catch figures were assumed exact. The level of discrepancy between the observed and predicted catch when catch levels are estimated is a cause of concern and should be investigated.

References

Healey, B.P., J.-C. Mahé and M.J.. Morgan. 2010. An Assessment of Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 + Divisions 3KLMNO. NAFO SCR Doc. 10/040, Ser. No. N5799.

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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
2010	0	0	0	146	825	5077	11202	6171	2134	520	214	64	22	21

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
2010	0.000	0.000	0.000	0.250	0.347	0.567	0.844	1.212	1.650	2.101	2.605	3.305	4.181	5.217

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
2010	0.000	0.000	0.000	0.000	0.347	0.567	0.844	1.212	1.650	2.101	2.605	3.305	4.181	5.217

Table 4. Survey data (mean numbers per tow) used to calibrate ASAP 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
	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
	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
	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
	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
	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
	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
	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
	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
	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
	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
	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
	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
	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

EU 3M (0-700m)		1	2	3	4	5	6	7	8	9	10	11	12
	1995	12.407	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	10.996	12.334	11.297	7.84	2.621	0.746	0.195	0.034	0.007
	1999	1.059	0.7	3.008	10.468	13.413	12.583	5.554	1.823	0.348	0.102	0.008	0.003
	2000	3.748	0.292	0.595	2.165	7.092	14.096	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

EU 3M (0-1400m)		5	6	7	8	9	10	11	12	13
	2004	6.803	9.156	4.949	1.462	0.727	0.368	0.261	0.163	0.147
	2005	5.284	6.790	3.416	0.985	0.260	0.408	0.230	0.131	0.060
	2006	5.848	8.559	4.680	1.388	0.417	0.359	0.302	0.147	0.049
	2007	3.839	9.090	8.568	2.883	0.719	0.588	0.302	0.172	0.065
	2008	2.026	9.000	12.529	3.177	1.143	0.866	0.441	0.245	0.131
	2009	1.127	6.803	11.426	3.545	0.931	1.029	0.359	0.278	0.253
	2010	1.999	6.008	7.830	2.502	0.980	0.832	0.313	0.174	0.123

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
	2010	0.77	0.656	0.519	0.396	0.844	1.077	0.354	0.143

3NO Spain		2	3	4	5	6	7	8	9	10	11	12	13
	1997	5.523	3.489	3.806	2.242	1.966	1.223	0.601	0.073	0.051	0.049	0.017	0.008
	1998	5.242	9.085	8.468	5.058	2.768	1.097	0.660	0.208	0.084	0.034	0.032	0.019
	1999	4.805	7.207	9.307	6.286	2.923	0.775	0.490	0.232	0.087	0.030	0.046	0.030
	2000	0.489	0.800	1.389	3.842	4.423	2.562	0.706	0.284	0.078	0.058	0.036	0.045
	2001	5.901	1.183	1.070	2.838	3.959	1.559	0.220	0.059	0.046	0.040	0.050	0.049
	2002	0.641	1.023	0.695	1.139	0.922	0.440	0.227	0.016	0.011	0.019	0.019	0.006
	2003	2.399	1.685	1.910	1.578	0.903	0.776	0.264	0.061	0.036	0.013	0.069	0.008
	2004	6.957	2.086	2.060	1.238	0.849	0.514	0.210	0.047	0.026	0.011	0.025	0.019
	2005	0.968	1.810	1.038	1.319	1.441	0.681	0.189	0.076	0.058	0.025	0.032	0.023
	2006	1.118	0.408	1.553	1.383	0.815	0.520	0.225	0.049	0.025	0.017	0.019	0.005
	2007	0.645	0.509	0.324	1.481	1.397	1.021	0.286	0.100	0.091	0.034	0.029	
	2008	0.986	0.899	0.693	0.935	2.702	2.503	0.736	0.402	0.153	0.099	0.033	0.024
	2009	3.216	2.212	2.614	2.725	4.940	5.667	0.847	0.354	0.190	0.138	0.029	0.022
	2010	2.207	0.935	0.729	3.419	5.582	5.159	1.235	0.390	0.260	0.239	0.043	0.024

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		1	0.2		
Catchability in 1st Year	1			0.0001	
mF in 1st year	1	1	1	0.5	
S/R steepness	2			1	
Deviation from initial steepness		1	0.2		
Recruitment deviation	3	1	1		
N in 1st year	4	1	0.9		
mF deviations	4	1	1		
Catch in Wt		1	0.03		
Index fit (34)		1			
Indexes q		0	1		
Indexes q deviations		0	1		
Block 4 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		9824.44
Catch_Fleet_Total	1	1005.89
	0	0
Index_Fit_Total	54	7460.57
Catch_Age_Comps		751.209
Sel_Param_43 (ascending A50)	1	2.60981
Sel_Param_44 (ascending slope)	1	0.0465767
Sel_Param_45 (descending A50)	1	2.60945
Sel_Param_46 (descending slope)	1	3.71866
Sel_Params_Total	4	8.98449
Fmult_year1_fleet_1	2	0.0639145
Fmult_year1_fleet_Total	2	0.0639145
Fmult_devs_fleet_1	1	3.17991
Fmult_devs_fleet_Total	1	3.17991
N_year_1	1	133.128
Recruit_devs	1	448.069
SRR_steepness	2	-0.698228
SRR_unexpl_stock	2	14.0473

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

Component	Nb resids	RMSE
Catch_Fleet_Total	36	6.36632
_Index_1	9	4.51583
_Index_2	9	5.90735
_Index_3	9	5.7972
_Index_4	9	4.44671
_Index_5	9	3.15848
_Index_6	9	2.53229
_Index_7	9	3.40726
_Index_8	9	5.24745
_Index_9	9	5.66071
_Index_10	9	5.12183
_Index_11	9	6.60521
_Index_12	7	7.14826
_Index_13	14	2.75547
_Index_14	14	2.62528
_Index_15	14	3.34597
_Index_16	14	2.98018
_Index_17	14	2.0152
_Index_18	14	3.4111
_Index_19	14	4.98487
_Index_20	14	4.75927
_Index_21	14	5.22567
_Index_22	14	3.63107
_Index_23	14	4.58498
_Index_24	13	4.95472
_Index_25	12	5.6396
_Index_26	14	5.08906
_Index_27	14	5.43816
_Index_28	14	5.44052
_Index_29	14	4.57544
_Index_30	14	3.67737
_Index_31	14	5.49104
_Index_32	14	8.44939
_Index_33	14	11.4309
_Index_34	7	4.30406
_Index_35	7	2.15908
_Index_36	7	2.98475
_Index_37	7	1.58343
_Index_38	7	3.63383
_Index_39	7	3.02477

_Index_40	7	5.25047
_Index_41	7	3.83989
_Index_42	7	4.48646
_Index_43	14	7.89999
_Index_44	14	6.26749
_Index_45	14	6.07838
_Index_46	14	4.48422
_Index_47	14	6.37446
_Index_48	14	7.19397
_Index_49	14	4.1755
_Index_50	14	5.29004
_Index_51	14	4.32219
_Index_52	14	4.43512
_Index_53	14	5.73635
_Index_54	13	7.11229
Index_Total	627	5.24523
Nyear1	13	0.297425
Fmult_Year1	1	0.206783
_Fmult_devs_Fleet_1	35	0.368497
Fmult_devs_Total	35	0.368497
Recruit_devs	36	0.381779
Fleet_Sel_params	4	0.267373
SRR_steepness	1	0.0649381
SRR_unexpl_S	1	1.60552

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	292
1976	100	28
1977	100	86
1978	100	73
1979	100	39
1980	100	29
1981	100	556
1982	100	342
1983	100	107
1984	100	148
1985	100	56
1986	100	89
1987	100	74
1988	100	41
1989	100	63
1990	100	67
1991	100	127
1992	100	129
1993	100	25
1994	100	10
1995	100	25
1996	100	85
1997	100	16
1998	100	39
1999	100	15
2000	100	9
2001	100	12
2002	100	15
2003	100	177
2004	100	272
2005	100	49
2006	100	226
2007	100	39
2008	100	62
2009	100	118
2010	100	45

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	0.002	0.003
5	0.014	0.012	0.016	0.020	0.017	0.018	0.019	0.016	0.017	0.020	0.013	0.010	0.016	0.008	0.007	0.014	0.019	0.024
6	0.087	0.075	0.098	0.124	0.103	0.113	0.119	0.100	0.104	0.123	0.091	0.070	0.106	0.054	0.045	0.096	0.133	0.167
7	0.330	0.288	0.375	0.474	0.392	0.431	0.453	0.383	0.397	0.469	0.341	0.265	0.400	0.204	0.170	0.359	0.499	0.627
8	0.547	0.477	0.621	0.785	0.649	0.714	0.751	0.634	0.657	0.777	0.499	0.388	0.586	0.299	0.249	0.527	0.732	0.919
9	0.594	0.518	0.675	0.853	0.704	0.775	0.815	0.689	0.714	0.844	0.500	0.388	0.587	0.299	0.249	0.527	0.732	0.919
10	0.591	0.515	0.671	0.848	0.701	0.771	0.811	0.685	0.710	0.839	0.468	0.364	0.550	0.280	0.234	0.494	0.686	0.861
11	0.579	0.505	0.657	0.831	0.686	0.755	0.794	0.671	0.695	0.822	0.434	0.337	0.509	0.259	0.216	0.458	0.635	0.798
12	0.557	0.486	0.633	0.800	0.661	0.727	0.764	0.646	0.669	0.792	0.400	0.311	0.469	0.239	0.199	0.422	0.586	0.736
13	0.486	0.424	0.552	0.697	0.576	0.634	0.667	0.563	0.584	0.690	0.367	0.286	0.431	0.220	0.183	0.388	0.538	0.676
14	0.269	0.235	0.306	0.387	0.320	0.352	0.370	0.312	0.324	0.383	0.336	0.261	0.395	0.201	0.168	0.355	0.493	0.619

F	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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	0.002	0.003	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
4	0.015	0.021	0.010	0.010	0.009	0.009	0.010	0.018	0.024	0.016	0.009	0.008	0.007	0.006	0.005	0.005	0.005	0.006
5	0.103	0.149	0.070	0.072	0.066	0.066	0.071	0.126	0.166	0.112	0.058	0.047	0.043	0.038	0.033	0.032	0.031	0.037
6	0.513	0.742	0.350	0.359	0.327	0.328	0.354	0.630	0.829	0.558	0.304	0.251	0.227	0.200	0.177	0.169	0.165	0.196
7	1.005	1.453	0.685	0.702	0.640	0.643	0.692	1.233	1.623	1.092	0.948	0.782	0.707	0.622	0.550	0.527	0.515	0.609
8	1.016	1.468	0.692	0.709	0.647	0.649	0.699	1.246	1.639	1.103	1.280	1.056	0.954	0.840	0.743	0.711	0.696	0.823
9	0.883	1.276	0.602	0.617	0.562	0.564	0.608	1.083	1.425	0.959	1.050	0.866	0.782	0.689	0.609	0.583	0.571	0.675
10	0.747	1.080	0.509	0.522	0.476	0.478	0.515	0.917	1.206	0.812	0.680	0.561	0.507	0.446	0.395	0.378	0.370	0.437
11	0.626	0.905	0.426	0.437	0.399	0.400	0.431	0.768	1.010	0.680	0.378	0.312	0.282	0.248	0.220	0.210	0.206	0.243
12	0.521	0.753	0.355	0.364	0.332	0.333	0.359	0.639	0.841	0.566	0.191	0.157	0.142	0.125	0.111	0.106	0.104	0.122
13	0.431	0.623	0.294	0.301	0.274	0.275	0.297	0.529	0.695	0.468	0.091	0.075	0.068	0.060	0.053	0.050	0.049	0.058
14	0.355	0.513	0.242	0.248	0.226	0.227	0.244	0.435	0.573	0.386	0.042	0.035	0.031	0.028	0.024	0.023	0.023	0.027

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	101245	101613	98934	73130	89445	126447	129245	126517	153506	171987	147091	149359	182807	154097	81976	77448	79545	105520
2	126784	82892	83194	81000	59874	73232	103526	105817	103583	125680	140811	120428	122285	149670	126164	67117	63409	65126
3	106313	103802	67866	68113	66317	49021	59957	84760	86635	84807	102898	115287	98598	100118	122539	103294	54950	51915
4	62782	87016	84964	55546	55743	54277	40119	49069	69372	70906	69405	84229	94374	80706	81960	100317	84553	44976
5	46125	51295	71114	69398	45341	45526	44318	32753	40077	56655	57882	56727	68870	77113	66010	67046	81985	69054
6	29792	37236	41484	57300	55682	36508	36595	35590	26382	32262	45467	46764	45967	55513	62635	53687	54129	65830
7	24625	22369	28270	30785	41432	41142	26699	26607	26357	19467	23358	33999	35682	33836	43052	49015	39946	38806
8	15486	14488	13730	15904	15685	22925	21888	13892	14850	14509	9967	13603	21359	19584	22596	29741	28013	19855
9	9790	7336	7361	6038	5936	6711	9192	8459	6030	6301	5460	4953	7554	9731	11895	14422	14378	11036
10	3952	4426	3578	3070	2107	2403	2532	3332	3478	2419	2219	2712	2750	3440	5909	7591	6970	5661
11	1642	1792	2165	1498	1076	856	910	922	1375	1400	855	1137	1543	1299	2129	3830	3792	2873
12	608	754	886	918	534	444	329	337	386	562	504	454	665	759	821	1404	1984	1644
13	470	285	380	385	338	226	176	126	145	162	208	277	272	340	489	550	754	904
14	636	634	564	519	445	420	340	266	218	195	175	221	309	315	435	635	670	696

N	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	125312	188681	265280	231695	126535	77360	77113	116692	118962	125241	123749	78652	75192	75211	73452	70402	99543	138306	
2	86393	102597	154479	217193	189696	103598	63337	63135	95539	97398	102539	101313	64393	61560	61576	60137	57639	81498	113233
3	53321	70711	83962	126450	177785	155279	84802	51845	51671	78183	79716	83932	82932	52711	50394	50407	49229	47185	66715
4	42489	43571	57732	68652	103389	145379	126975	69338	42347	42173	63877	65169	68633	67824	43114	41223	41236	40273	38595
5	36709	34282	34927	46798	55637	83863	117919	102917	55760	33862	33984	51808	52943	55799	55188	35106	33575	33589	32774
6	55171	27114	24186	26658	35657	42660	64288	89934	74261	38662	24789	26268	40449	41526	43992	43699	27838	26642	26501
7	45619	27030	10568	13957	15250	21051	25155	36957	39219	26545	18119	14970	16730	26395	27845	30184	30211	19316	17936
8	16978	13667	5174	4362	5664	6582	9064	10306	8815	6338	7290	5749	5606	6757	11603	13148	14593	14773	8598
9	6488	5034	2578	2121	1757	2429	2816	3688	2427	1401	1721	1660	1637	1768	2389	4518	5286	5957	5312
10	3604	2197	1150	1157	937	820	1131	1255	1022	478	440	493	572	613	727	1063	2065	2446	2484
11	1959	1398	611	566	562	477	416	553	411	251	174	182	230	282	321	401	597	1168	1293
12	1059	857	463	326	299	309	262	222	210	122	104	97	109	142	180	211	266	398	750
13	645	515	331	266	186	176	181	150	96	74	57	70	68	78	103	132	155	196	288
14	683	736	587	579	531	463	411	374	270	164	129	144	167	185	207	245	299	360	439

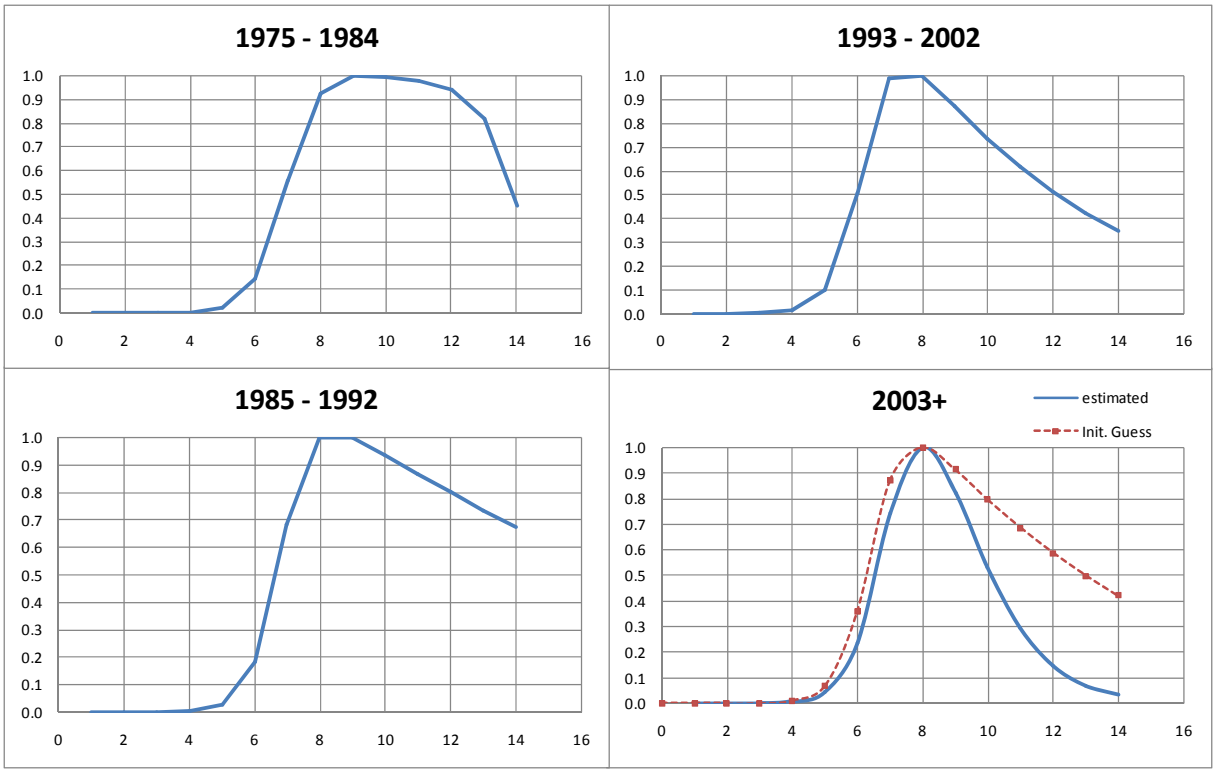


Figure 1 : Greenland Halibut in SA 2+3 - Selectivity blocks from the ASAP formulation. Selectivity is fixed for 1975 to 1992 in 3 blocks and estimated for the period 2003 on.

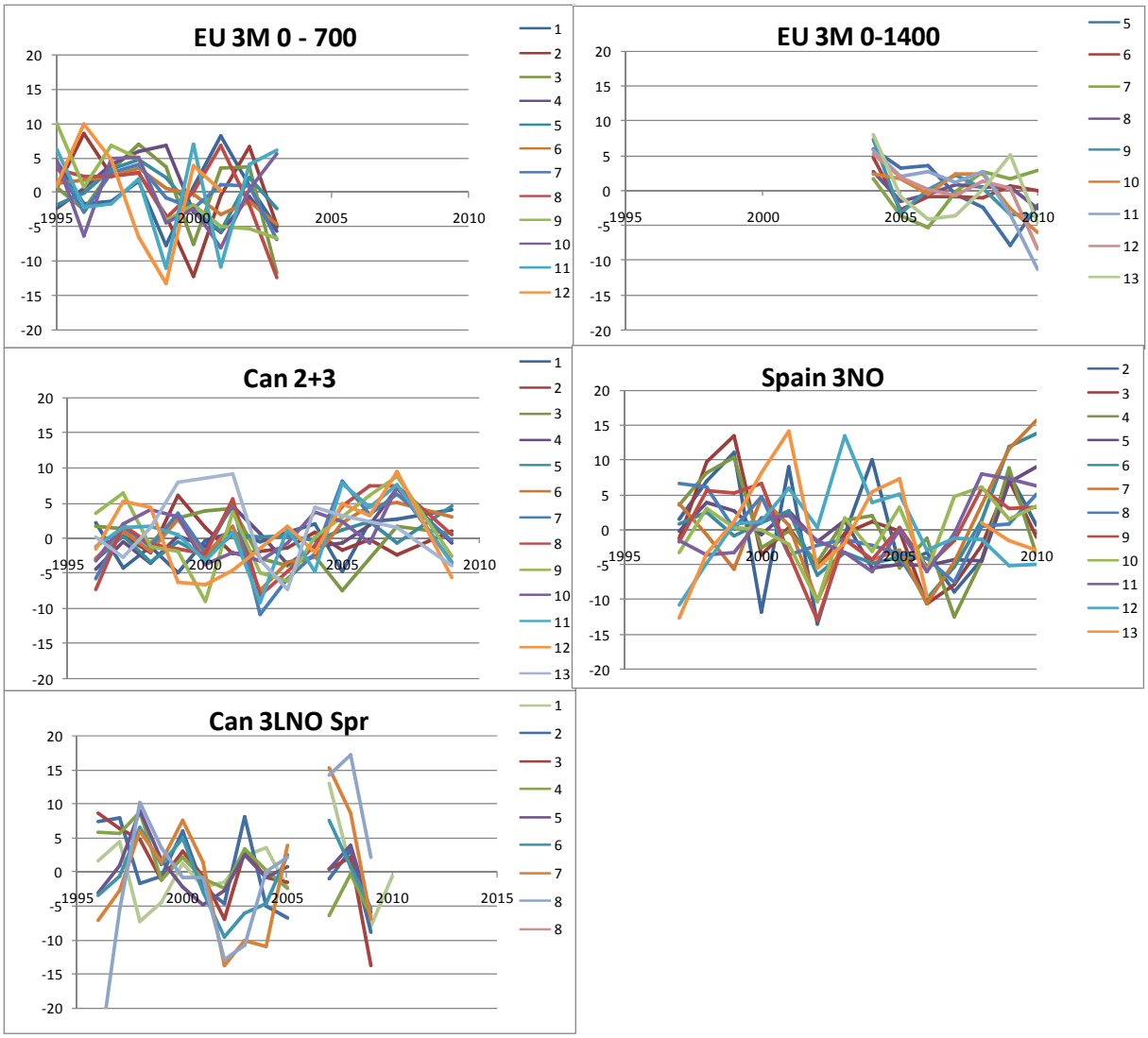
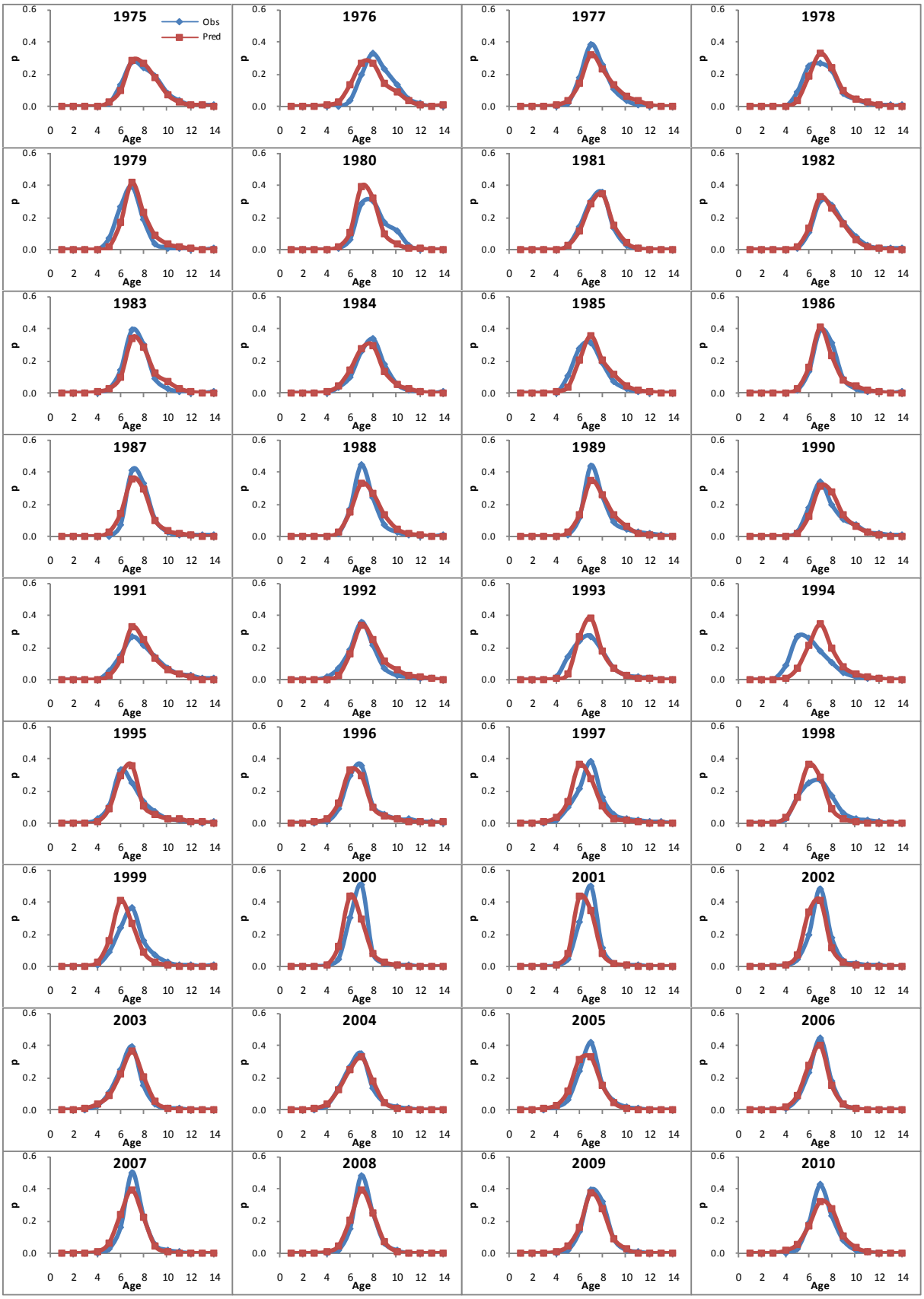


Figure 2 : Greenland Halibut in SA 2+3 – standardized residuals from ASAP formulation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0.6
0 2 4 6 8 10 12 14

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

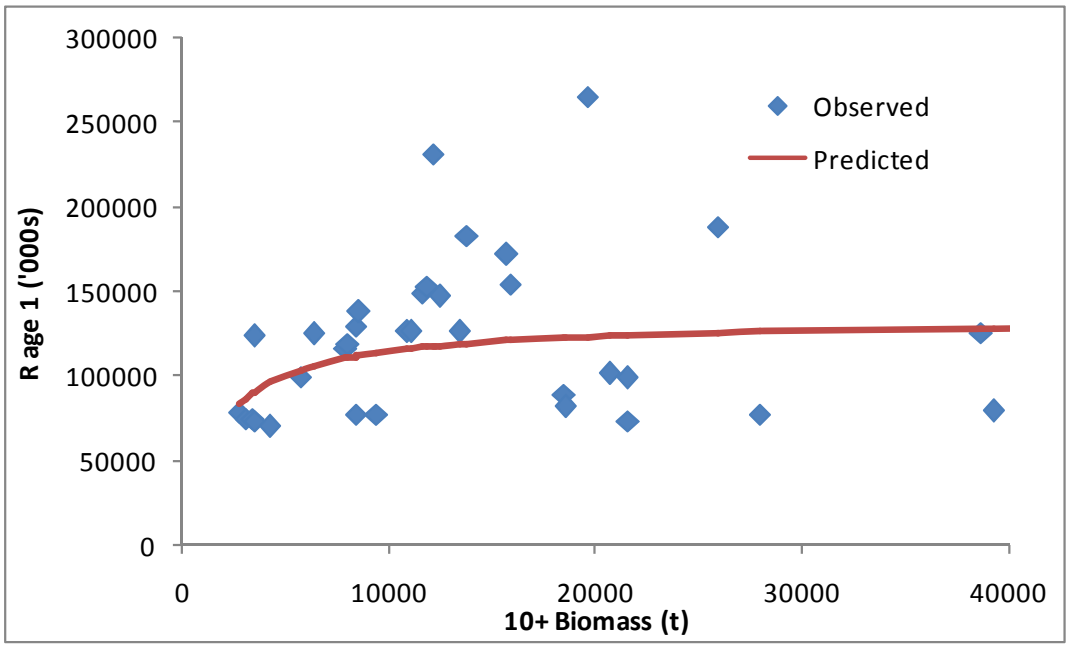

Figure 4: Greenland Halibut in SA 2+3 - Beverton & Holt Stock Recruitment relation fitted to the 10+ biomass as a proxy for SSB and used in the ASAP formulation.

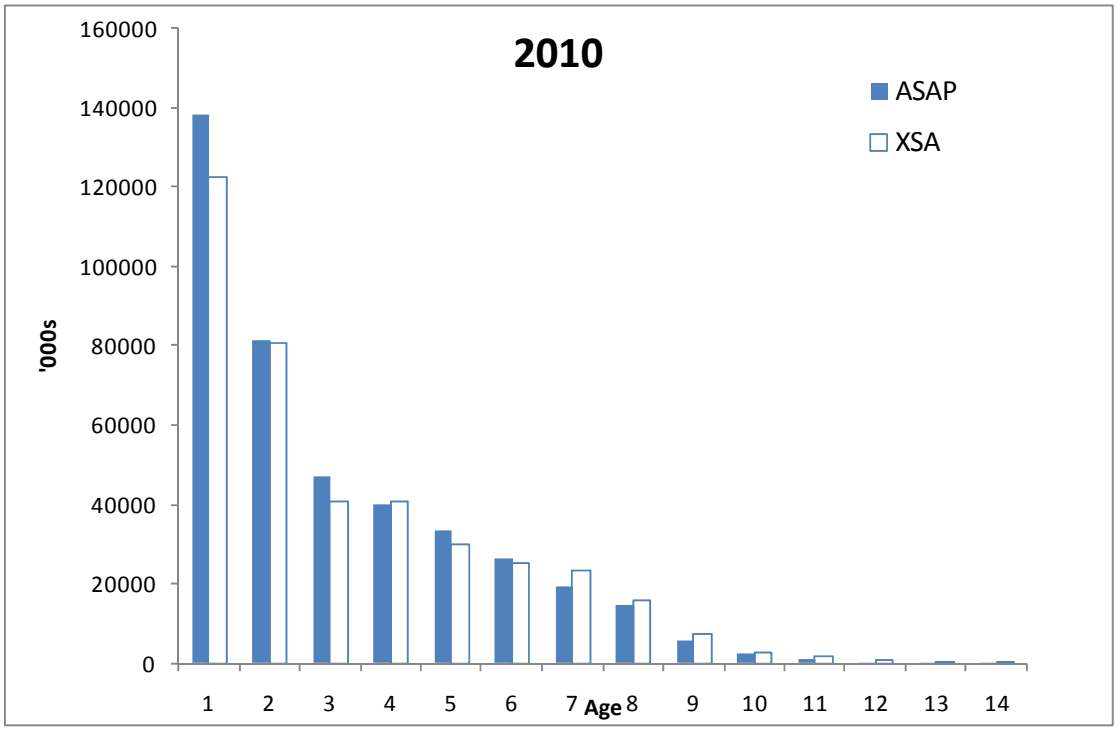

Figure 5: Greenland Halibut in SA 2+3 - Estimates of numbers at age in 2010 from ASAP and XSA.

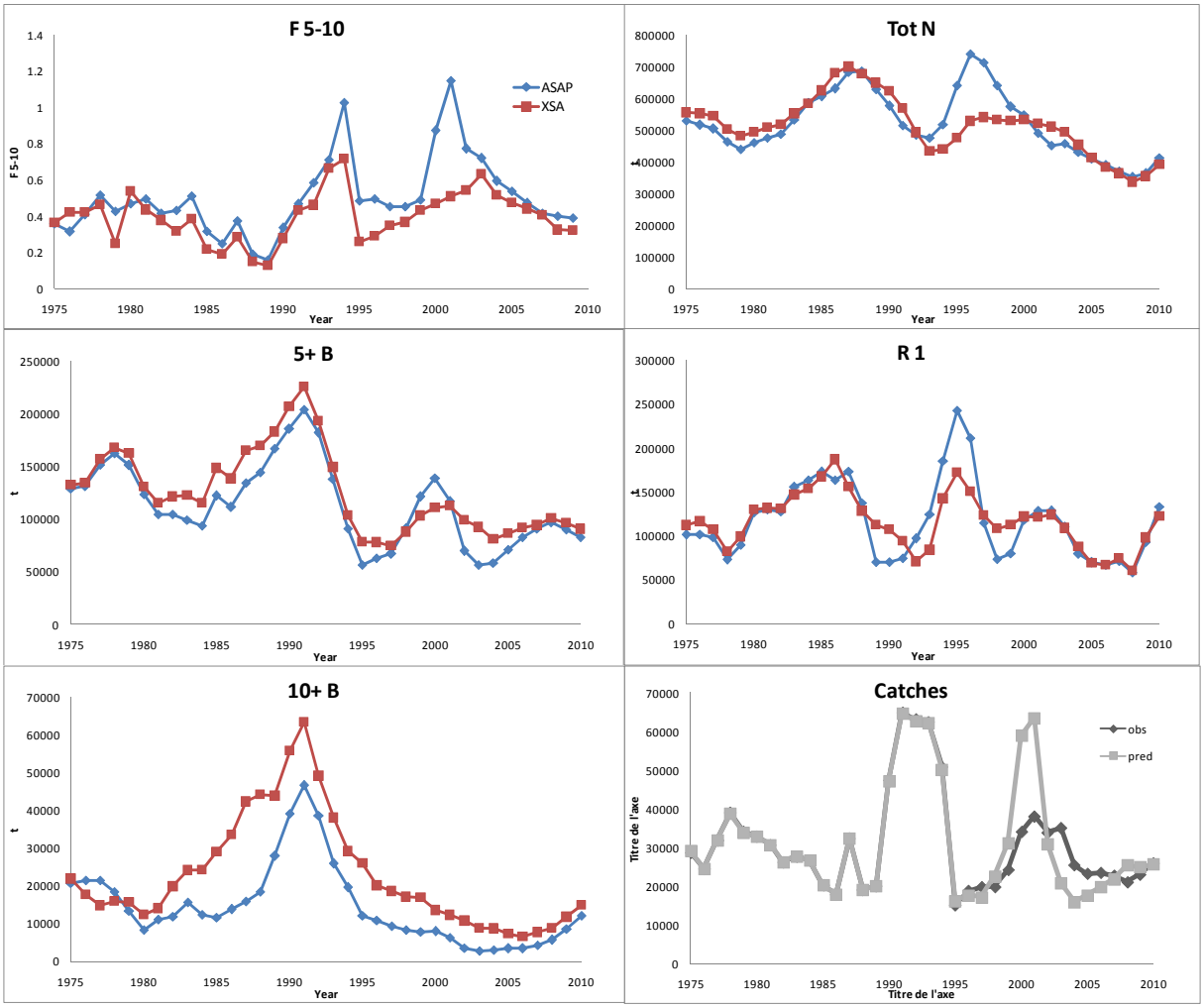

Figure 6 : Greenland Halibut in SA 2+3 - Estimates of trends in average fishing mortality, exploitable (5+B) and SSB proxy (10+B), Total abundance and recruitment (age 1) from ASAP and XSA. Observed and predicted total catch from ASAP is also presented.

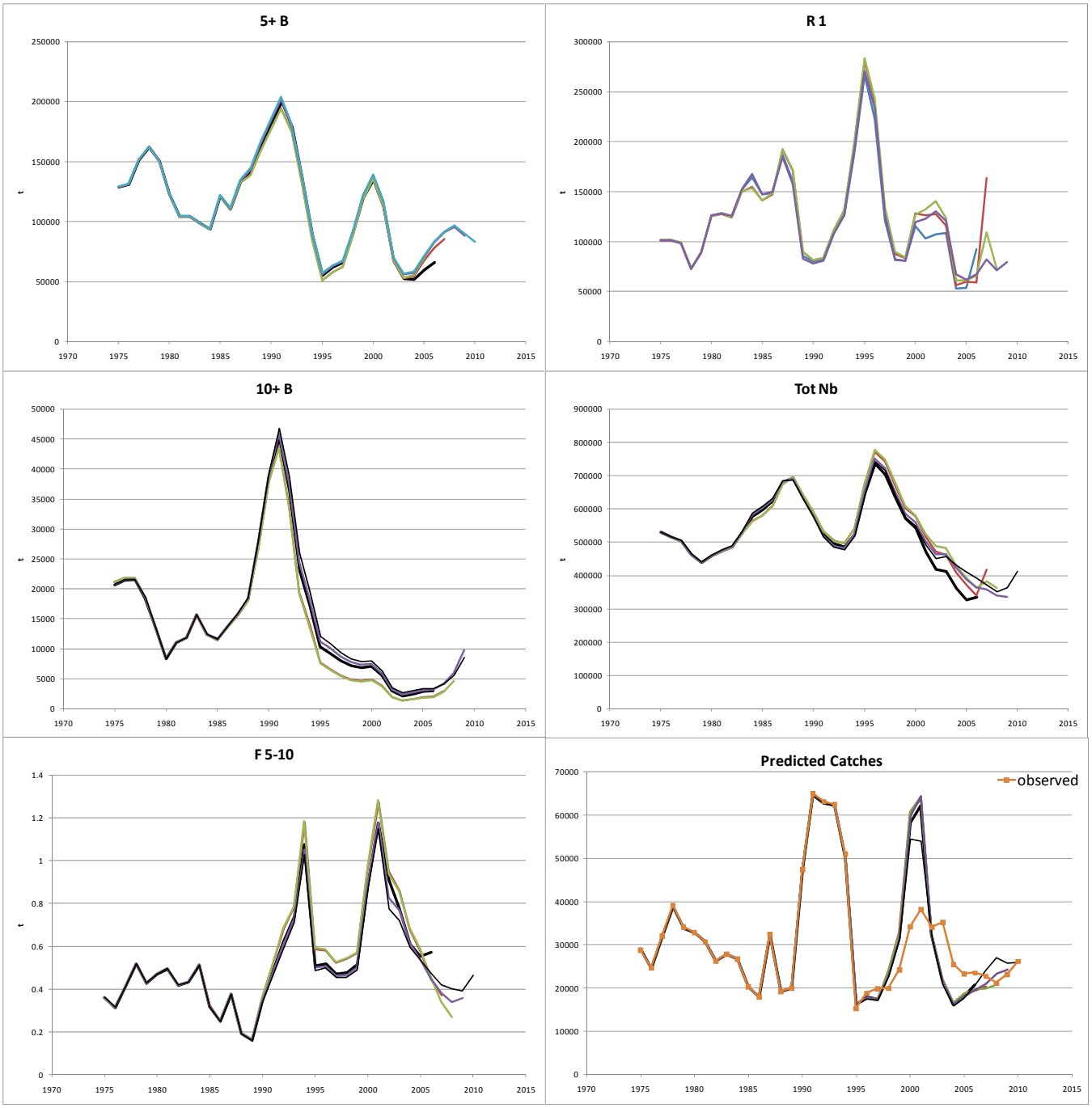

Figure 7: Greenland Halibut in SA 2+3 - ASAP formulation – Retrospective analysis.

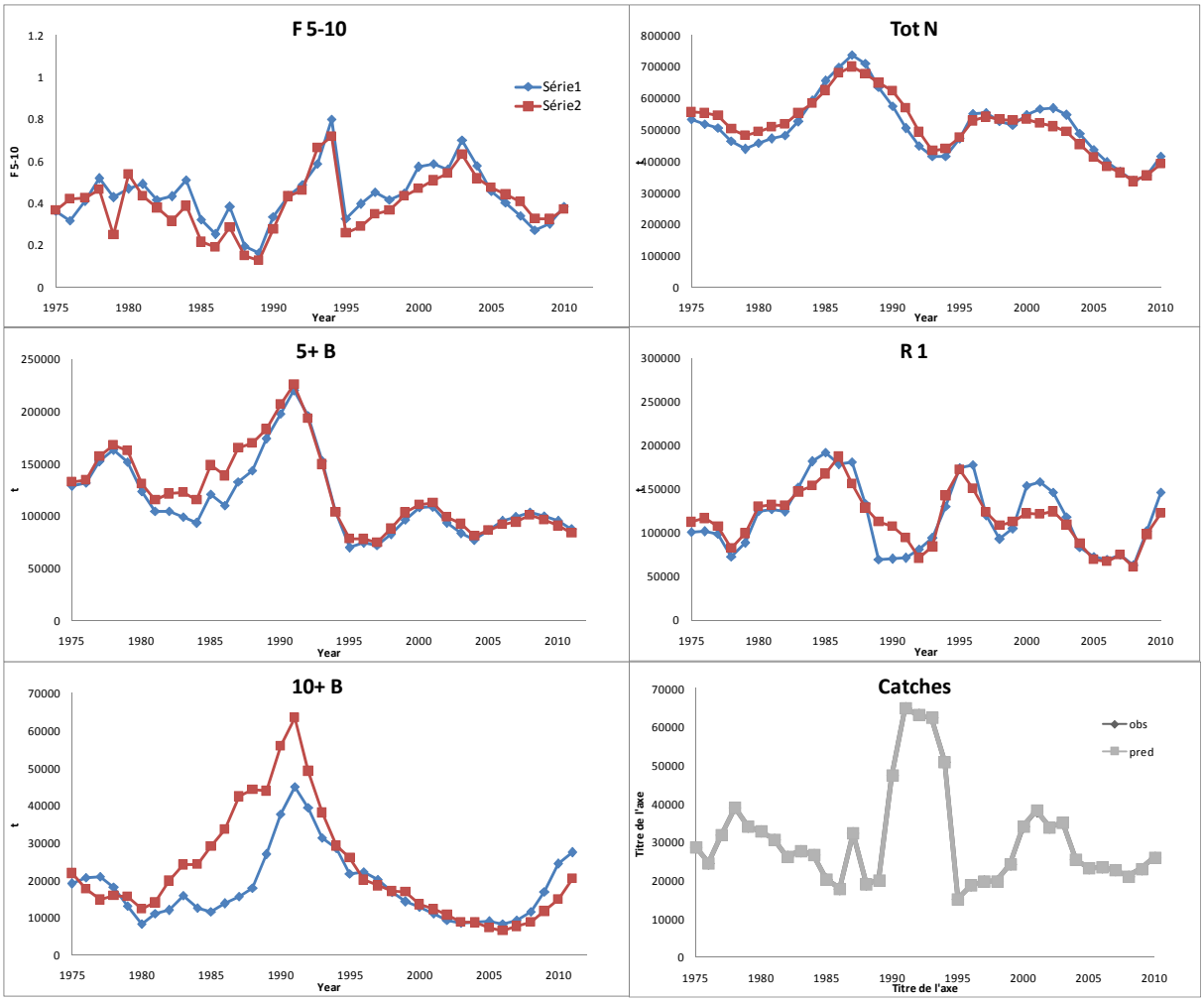

Figure 8 : Greenland Halibut in SA 2+3 - Estimates of trends in average fishing mortality, exploitable (5+B) and SSB proxy (10+B), Total abundance and recruitment (age 1) from XSA and ASAP assuming no error in the catch.

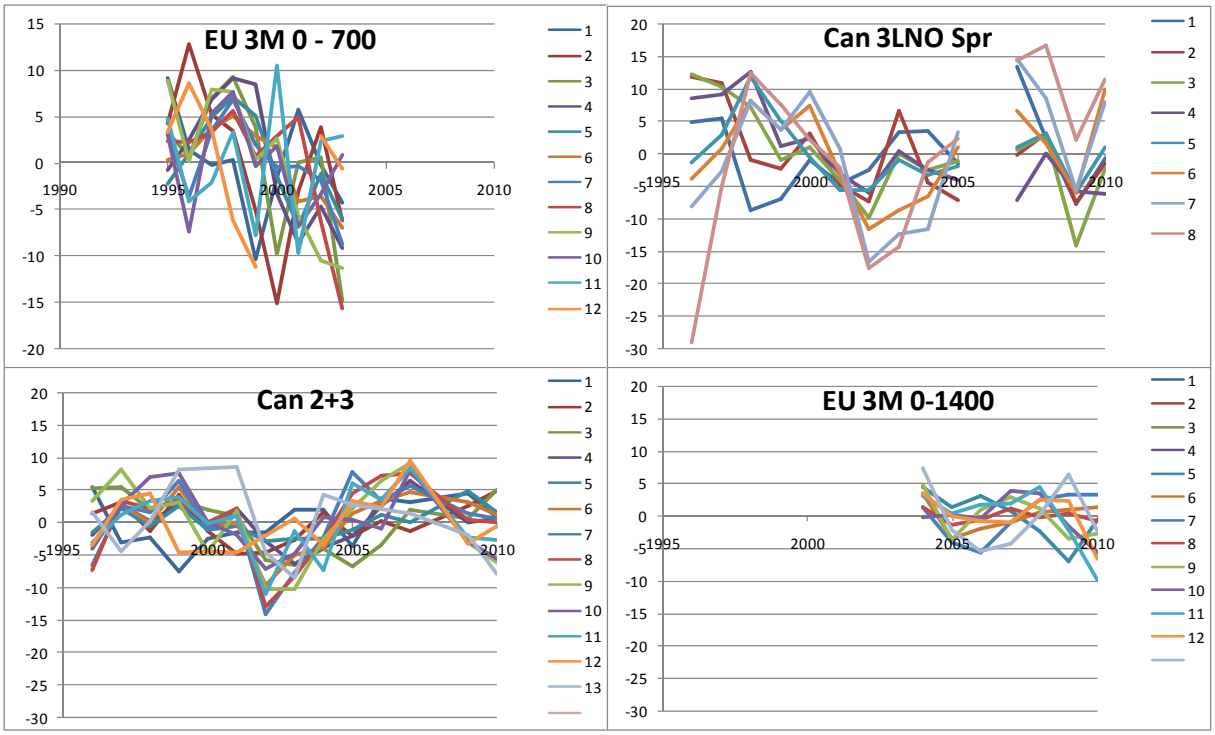

Figure 9 : Greenland Halibut in SA 2+3 – standardized residuals from an ASAP formulation assuming no error in the catch.

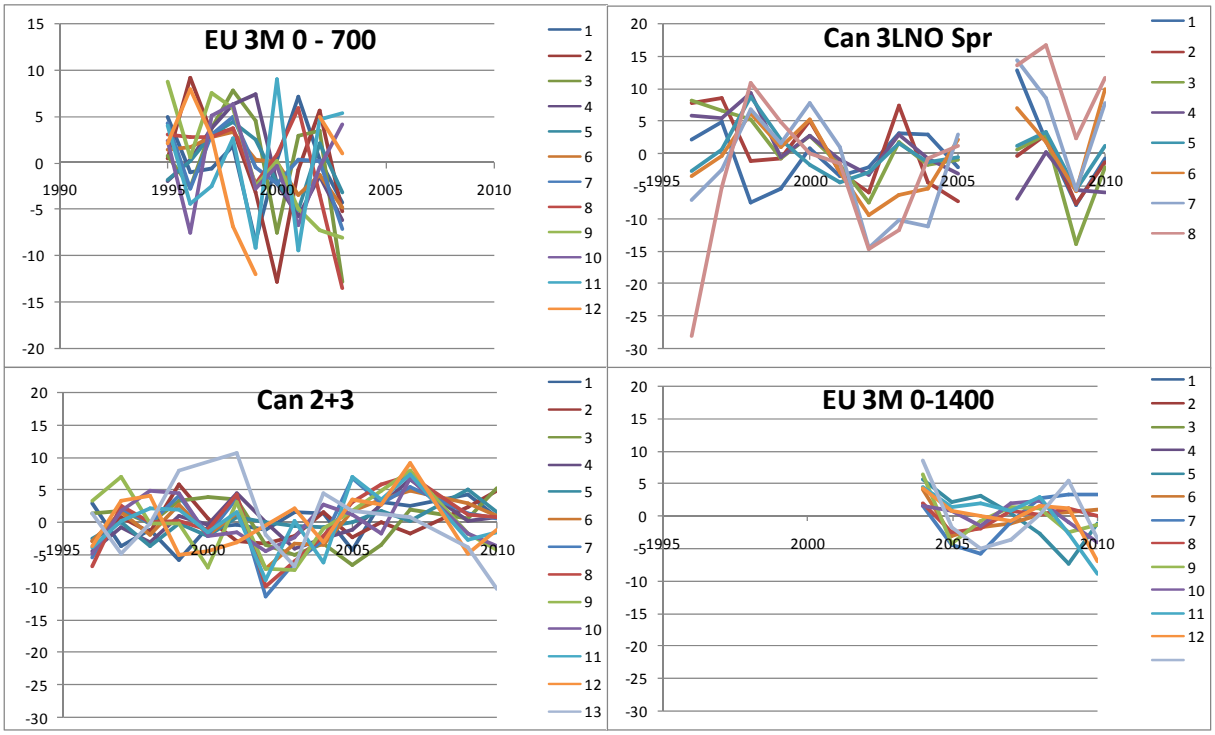

Figure10: Greenland Halibut in SA 2+3 – standardized residuals from an ASAP formulation assuming error in the catch.