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Coleraine Assessment of the Icelandic Cod Fishery

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1 EXECUTIVE SUMMARY

A stock assessment of the Icelandic cod is presented, where models are fitted to commercial catch data as well as data from three different annual research surveys. An important question in the modelling approach is whether to combine the eight different commercial fishing gears or to treat them seperately, with respect to their total landings and catch-at-age data. In this assessment both alternatives are explored using two different models: *Comb* uses combined commercial gear data from 1971 to 1999, whereas *Gear* uses segregated commercial gear data from 1991 to 1999. The objective of fitting the two different models was not to select one either of them as the better model, but to check for any major discrepancies. In short, the two model fits supported each other.

2 DATA OVERVIEW

The age-specific catch data contain information about two different aspects of the cod stock: the overall biomass of the catch and the age distribution. In this assessment these are extracted seperately, both from research survey data and commercial catch data. The annual biomass estimates are calculated by multiplying numbers-at-age with weight-at-age, while the age distribution is portrayed as the proportional frequency within each year.

2.1 Research survey data

Three surveys are conducted each year: spring trawl survey in March, net survey in April, and autumn trawl survey in October.

2.1.1 Survey biomass indices

Table 1. Biomass indices from the three surveys. For comparison purposes, the indicis are standardized so that the average index between 1996 and 1999 equals 1.0.

	Spring trawl	Autumn trawl	Nets
1985	1.750		
1986	1.263		
1987	1.470		
1988	1.663		
1989	1.628		
1990	0.953		
1991	0.893		
1992	0.626		
1993	0.685		
1994	0.558		
1995	0.701		
1996	0.896	0.975	0.713
1997	1.004	0.960	0.930
1998	1.206	1.266	1.788
1999	0.895	0.798	0.569
2000	0.822		

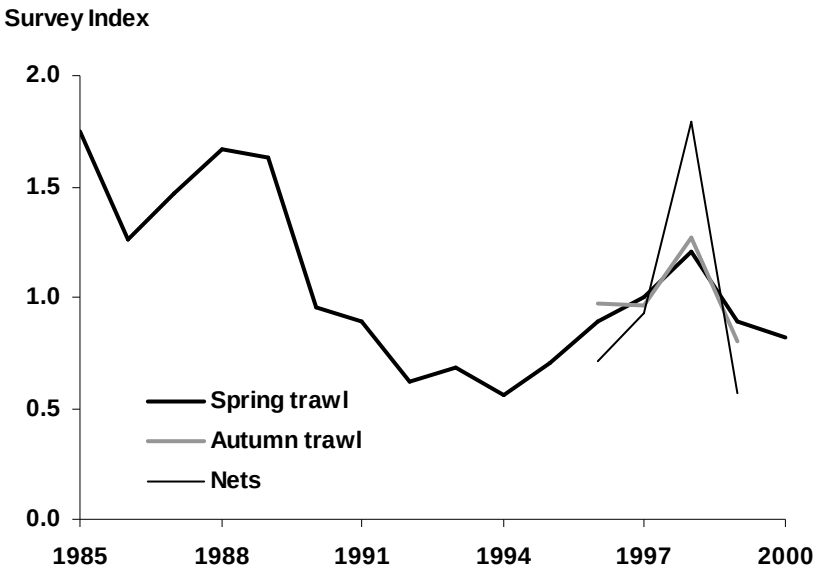

Figure 1. Biomass indices from the three surveys. For comparison purposes, the indicis are standardized so that the average index between 1996 and 1999 equals 1.0.

2.1.2 Survey catch-at-age

Table 2. Catch-at-age data from spring trawl survey. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1985	0.051	0.344	0.108	0.148	0.199	0.070	0.047	0.015	0.010	0.005	0.001	0.001	0.000	0.000
1986	0.059	0.239	0.375	0.088	0.084	0.108	0.028	0.011	0.004	0.003	0.001	0.000	0.000	0.000
1987	0.014	0.106	0.381	0.305	0.079	0.048	0.048	0.010	0.004	0.002	0.002	0.001	0.001	0.000
1988	0.012	0.027	0.257	0.371	0.251	0.030	0.023	0.025	0.002	0.001	0.000	0.000	0.000	0.000
1989	0.017	0.070	0.091	0.325	0.303	0.160	0.020	0.007	0.006	0.001	0.001	0.000	0.000	0.000
1990	0.039	0.085	0.188	0.101	0.197	0.249	0.118	0.012	0.004	0.003	0.001	0.000	0.000	0.000
1991	0.030	0.126	0.138	0.225	0.119	0.145	0.170	0.036	0.007	0.003	0.002	0.000	0.001	0.000
1992	0.007	0.175	0.298	0.175	0.153	0.064	0.058	0.053	0.014	0.002	0.000	0.000	0.000	0.000
1993	0.032	0.043	0.312	0.344	0.118	0.093	0.021	0.019	0.012	0.004	0.001	0.000	0.000	0.000
1994	0.141	0.158	0.083	0.265	0.230	0.060	0.042	0.008	0.006	0.004	0.001	0.000	0.000	0.000
1995	0.010	0.252	0.225	0.081	0.215	0.158	0.034	0.016	0.003	0.001	0.002	0.001	0.000	0.000
1996	0.030	0.044	0.332	0.222	0.101	0.121	0.112	0.027	0.008	0.001	0.000	0.001	0.000	0.000
1997	0.008	0.152	0.092	0.378	0.196	0.066	0.060	0.042	0.003	0.001	0.001	0.000	0.001	0.000
1998	0.049	0.035	0.182	0.096	0.370	0.170	0.039	0.033	0.020	0.005	0.001	0.000	0.000	0.000
1999	0.050	0.234	0.051	0.297	0.091	0.167	0.078	0.016	0.009	0.004	0.001	0.000	0.000	0.000
2000	0.113	0.175	0.341	0.044	0.190	0.052	0.052	0.027	0.003	0.002	0.000	0.000	0.000	0.000

Table 3. Catch-at-age data from autumn trawl survey. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1996	0.082	0.056	0.309	0.221	0.087	0.118	0.096	0.024	0.005	0.002	0.000	0.001	0.000	0.000
1997	0.013	0.198	0.086	0.363	0.194	0.057	0.050	0.032	0.004	0.002	0.000	0.000	0.000	0.000
1998	0.058	0.034	0.210	0.104	0.237	0.234	0.071	0.031	0.017	0.003	0.001	0.000	0.000	0.000
1999	0.115	0.218	0.073	0.280	0.090	0.144	0.062	0.009	0.005	0.005	0.000	0.000	0.000	0.000

Table 4. Catch-at-age data from net survey. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1996	0.000	0.001	0.020	0.081	0.118	0.293	0.352	0.091	0.035	0.006	0.001	0.000	0.000	0.000
1997	0.000	0.000	0.013	0.104	0.378	0.159	0.138	0.162	0.033	0.010	0.001	0.001	0.000	0.000
1998	0.000	0.000	0.003	0.017	0.107	0.408	0.172	0.136	0.124	0.020	0.011	0.001	0.000	0.000
1999	0.000	0.000	0.003	0.035	0.058	0.343	0.385	0.081	0.056	0.033	0.005	0.002	0.000	0.000

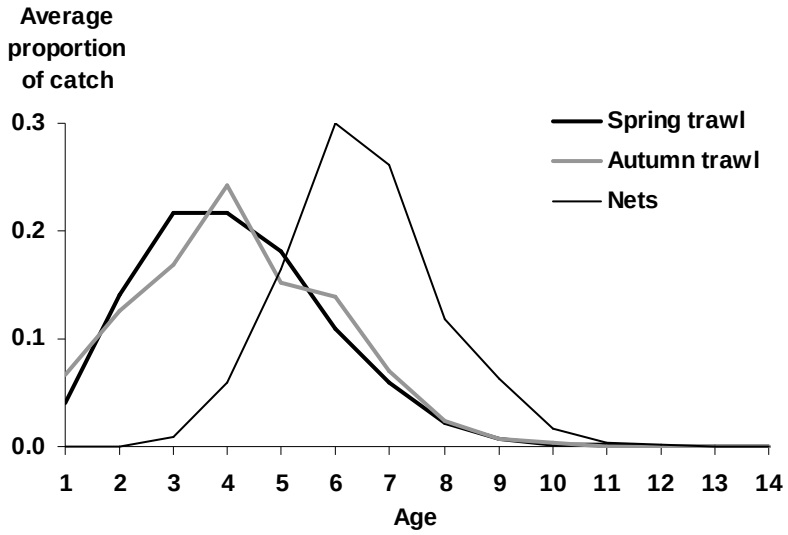

Figure 2. Catch-at-age from the three surveys. The Y-axis represents the average proportion of catch in numbers over all years: 1985–2000 for the spring trawl survey, 1996–1999 for the autumn survey and net survey.

2.2 Commercial catch data

The commercial catch data can either be viewed as a whole, or split by fishing gear. The latter option is especially advantageous if the proportional landings between the gears have been changing through time, which is the case with the Icelandic cod. On the other hand, gear-specific data was not available for the earlier years, so introducing a higher number of estimated parameters is likely to decrease the robustness and power of statistical inference.

Described below are both versions of the commercial catch data, combined-gear and gear-specific. In the latter version, the eight gears were categorized in five groups, based on their catch-at-age trends: Handlines, Bottom trawl & longlines, Danish seine, 6" net and 7-9" nets. Gear-specific landed catch data were available from 1982, but the model's behaviour proved to be considerably more robust when run from 1985 onwards (the year of first survey data points).

2.2.1 Combined commercial landings

Table 5. Landed catch from combined commercial gears. For purposes of model fitting, the year 2000 was assumed to be similar to the year 1999.

	Yield (t)		Yield (t)
1971	453 052	**1986**	368 633
1972	398 528	**1987**	392 257
1973	383 446	**1988**	378 076
1974	374 770	**1989**	355 954
1975	370 991	**1990**	335 390
1976	347 849	**1991**	308 560
1977	340 050	**1992**	267 718
1978	330 390	**1993**	251 979
1979	368 064	**1994**	178 808
1980	434 344	**1995**	169 404
1981	468 659	**1996**	181 656
1982	388 387	**1997**	203 366
1983	300 056	**1998**	242 566
1984	283 822	**1999**	260 404
1985	325 267	**2000**	260 404

2.2.2 Combined commercial catch-at-age

Table 6. Catch-at-age data from combined commercial gears. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1971	0.000	0.000	0.085	0.232	0.295	0.137	0.112	0.071	0.039	0.027	0.002	0.000	0.000	0.000
1972	0.000	0.000	0.070	0.229	0.240	0.177	0.086	0.076	0.082	0.031	0.010	0.001	0.000	0.000
1973	0.000	0.000	0.271	0.189	0.203	0.126	0.094	0.027	0.035	0.043	0.008	0.002	0.000	0.000
1974	0.000	0.000	0.110	0.460	0.162	0.107	0.067	0.046	0.012	0.019	0.013	0.002	0.000	0.000
1975	0.000	0.000	0.221	0.222	0.333	0.091	0.073	0.028	0.015	0.006	0.007	0.003	0.000	0.000
1976	0.000	0.000	0.193	0.325	0.172	0.199	0.047	0.044	0.011	0.005	0.002	0.001	0.001	0.000
1977	0.000	0.000	0.024	0.395	0.300	0.113	0.120	0.026	0.016	0.004	0.001	0.000	0.000	0.000
1978	0.000	0.000	0.061	0.166	0.447	0.179	0.089	0.042	0.010	0.004	0.001	0.000	0.000	0.000
1979	0.000	0.000	0.069	0.272	0.132	0.330	0.135	0.042	0.014	0.003	0.002	0.000	0.000	0.000
1980	0.000	0.000	0.037	0.240	0.274	0.127	0.228	0.066	0.019	0.005	0.002	0.001	0.000	0.000
1981	0.000	0.000	0.017	0.107	0.315	0.187	0.102	0.213	0.039	0.013	0.005	0.002	0.000	0.001
1982	0.000	0.000	0.029	0.185	0.217	0.252	0.125	0.068	0.102	0.017	0.003	0.001	0.000	0.000
1983	0.000	0.000	0.040	0.122	0.273	0.213	0.195	0.094	0.023	0.031	0.006	0.002	0.001	0.000
1984	0.000	0.000	0.073	0.341	0.210	0.166	0.087	0.079	0.029	0.006	0.006	0.002	0.001	0.000
1985	0.000	0.000	0.064	0.242	0.349	0.180	0.086	0.041	0.022	0.010	0.002	0.002	0.001	0.000
1986	0.000	0.000	0.176	0.173	0.227	0.262	0.097	0.038	0.015	0.007	0.003	0.001	0.001	0.000
1987	0.000	0.000	0.080	0.451	0.197	0.110	0.114	0.030	0.011	0.004	0.002	0.001	0.000	0.000
1988	0.000	0.000	0.050	0.291	0.413	0.138	0.047	0.043	0.010	0.003	0.002	0.001	0.001	0.000
1989	0.000	0.000	0.030	0.318	0.191	0.357	0.068	0.022	0.010	0.003	0.001	0.001	0.000	0.000
1990	0.000	0.000	0.052	0.111	0.246	0.403	0.154	0.023	0.006	0.003	0.001	0.000	0.000	0.000
1991	0.000	0.000	0.083	0.243	0.150	0.208	0.242	0.062	0.009	0.002	0.001	0.001	0.000	0.000
1992	0.000	0.000	0.132	0.234	0.286	0.123	0.109	0.090	0.022	0.003	0.000	0.000	0.000	0.000
1993	0.000	0.000	0.222	0.357	0.164	0.144	0.039	0.030	0.029	0.013	0.002	0.000	0.000	0.000
1994	0.000	0.000	0.096	0.377	0.307	0.109	0.069	0.020	0.009	0.008	0.004	0.001	0.000	0.000
1995	0.000	0.000	0.191	0.162	0.299	0.232	0.073	0.028	0.006	0.003	0.003	0.003	0.001	0.000
1996	0.000	0.000	0.102	0.282	0.140	0.233	0.179	0.041	0.016	0.004	0.001	0.001	0.001	0.000
1997	0.000	0.000	0.030	0.287	0.302	0.117	0.129	0.104	0.020	0.009	0.002	0.000	0.001	0.000
1998	0.000	0.000	0.049	0.110	0.362	0.287	0.084	0.055	0.042	0.007	0.003	0.001	0.000	0.000
1999	0.000	0.000	0.033	0.259	0.184	0.313	0.149	0.031	0.017	0.011	0.002	0.001	0.000	0.000

2.2.3 Gear-specific commercial landings

Table 7. Landed catch from five groups of commercial gears. For purposes of model fitting, the year 2000 was assumed to be similar to the year 1999.

	Handlines	Bottom trawl & longlines	Danish seine	6" net	7-9" nets
1985	16 671	208 427	8 228	14 078	74 562
1986	19 750	230 000	9 315	15 495	90 566
1987	20 838	254 157	6 816	19 153	86 867
1988	18 040	268 588	11 201	16 515	59 945
1989	16 946	239 029	11 382	15 846	69 981
1990	16 881	237 189	9 510	16 009	52 116
1991	17 673	219 827	6 780	7 958	52 790
1992	21 532	173 825	7 199	7 825	53 563
1993	17 656	159 850	8 390	7 812	49 563
1994	23 163	106 270	8 264	8 924	32 112
1995	21 624	106 193	9 798	4 626	27 505
1996	19 438	107 419	12 914	2 603	39 443
1997	25 477	116 689	14 510	2 327	44 947
1998	24 426	148 094	17 908	1 270	52 158
1999	17 590	178 579	15 912	1 282	47 289
2000	17 590	178 579	15 912	1 282	47 289

2.2.4 Gear-specific commercial catch-at-age

Table 8. Catch-at-age data from handlines. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	0.000	0.000	0.094	0.431	0.088	0.143	0.174	0.059	0.005	0.004	0.000	0.000	0.000	0.002
1992	0.000	0.000	0.066	0.392	0.366	0.087	0.053	0.033	0.002	0.002	0.000	0.000	0.000	0.000
1993	0.000	0.002	0.277	0.491	0.130	0.077	0.013	0.005	0.005	0.001	0.000	0.000	0.000	0.000
1994	0.000	0.000	0.150	0.439	0.295	0.076	0.029	0.003	0.005	0.002	0.000	0.000	0.000	0.000
1995	0.000	0.000	0.142	0.291	0.353	0.177	0.023	0.013	0.002	0.000	0.001	0.000	0.000	0.000
1996	0.000	0.052	0.132	0.481	0.130	0.112	0.080	0.011	0.001	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.000	0.007	0.259	0.401	0.114	0.120	0.076	0.019	0.005	0.000	0.000	0.000	0.000
1998	0.000	0.001	0.031	0.129	0.498	0.254	0.046	0.026	0.014	0.001	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.029	0.319	0.279	0.183	0.142	0.034	0.009	0.004	0.001	0.000	0.000	0.000

Table 9. Catch-at-age data from bottom trawl & longlines. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	0.000	0.006	0.093	0.260	0.158	0.209	0.226	0.040	0.006	0.001	0.001	0.000	0.000	0.000
1992	0.000	0.037	0.153	0.232	0.288	0.125	0.096	0.059	0.009	0.001	0.000	0.000	0.000	0.000
1993	0.000	0.014	0.214	0.378	0.180	0.143	0.030	0.019	0.014	0.006	0.001	0.000	0.000	0.000
1994	0.000	0.032	0.110	0.391	0.305	0.096	0.049	0.009	0.005	0.003	0.001	0.000	0.000	0.000
1995	0.000	0.022	0.224	0.148	0.292	0.229	0.062	0.017	0.003	0.001	0.000	0.001	0.000	0.000
1996	0.000	0.008	0.103	0.288	0.147	0.238	0.167	0.034	0.011	0.003	0.001	0.000	0.001	0.000
1997	0.000	0.008	0.041	0.344	0.305	0.113	0.096	0.074	0.011	0.006	0.002	0.000	0.001	0.000
1998	0.000	0.000	0.051	0.131	0.369	0.302	0.079	0.034	0.028	0.004	0.002	0.000	0.000	0.000
1999	0.000	0.010	0.038	0.278	0.184	0.324	0.131	0.021	0.008	0.005	0.001	0.000	0.000	0.000

Table 10. Catch-at-age data from Danish seine. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1991	0.000	0.005	0.005	0.286	0.197	0.188	0.163	0.136	0.016	0.003	0.001	0.000	0.000	0.000
1992	0.000	0.000	0.049	0.394	0.314	0.078	0.036	0.054	0.061	0.007	0.004	0.002	0.000	0.001
1993	0.000	0.016	0.280	0.347	0.130	0.152	0.020	0.033	0.013	0.008	0.001	0.000	0.000	0.000
1994	0.000	0.009	0.121	0.401	0.303	0.107	0.033	0.012	0.006	0.005	0.004	0.001	0.000	0.000
1995	0.000	0.000	0.101	0.134	0.337	0.228	0.080	0.048	0.014	0.009	0.018	0.021	0.006	0.003
1996	0.000	0.000	0.000	0.059	0.108	0.338	0.332	0.074	0.058	0.015	0.008	0.006	0.004	0.000
1997	0.000	0.000	0.000	0.120	0.298	0.138	0.226	0.179	0.021	0.016	0.000	0.001	0.000	0.000
1998	0.000	0.000	0.027	0.099	0.307	0.362	0.066	0.068	0.056	0.009	0.005	0.001	0.000	0.000
1999	0.000	0.000	0.008	0.194	0.181	0.373	0.180	0.035	0.019	0.009	0.000	0.000	0.000	0.000

Table 11. Catch-at-age data from 6" net. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1996	0.000	0.003	0.030	0.118	0.183	0.253	0.262	0.092	0.046	0.011	0.001	0.000	0.000	0.000
1997	0.000	0.000	0.000	0.129	0.556	0.150	0.091	0.064	0.004	0.002	0.000	0.003	0.000	0.000
1998	0.000	0.000	0.008	0.020	0.155	0.513	0.138	0.067	0.084	0.011	0.005	0.000	0.000	0.000
1999	0.000	0.000	0.001	0.039	0.055	0.443	0.334	0.055	0.044	0.022	0.006	0.000	0.000	0.000

Table 12. Catch-at-age data from 7–9" nets. The values represent proportion of total catch in numbers, adding up to one within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1996	0.000	0.001	0.017	0.069	0.096	0.306	0.381	0.091	0.032	0.004	0.001	0.000	0.000	0.000
1997	0.000	0.000	0.023	0.085	0.241	0.165	0.174	0.238	0.055	0.016	0.002	0.001	0.000	0.000
1998	0.000	0.000	0.001	0.015	0.076	0.339	0.194	0.182	0.151	0.026	0.016	0.002	0.000	0.000
1999	0.000	0.000	0.004	0.033	0.061	0.280	0.417	0.096	0.064	0.039	0.003	0.003	0.000	0.000

2.3 Biological data

2.3.1 Maturity-at-age

The maturity ogive was assumed to be constant between years, calculated as the average maturity-at-age from 1971 to 1999. This unrealistic assumption is addressed in the introduction of section 3.

Table 13. Maturity-at-age assumed for fitting the models, using averages from 1971 to 1999.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Proportion mature	0.00	0.00	0.03	0.11	0.32	0.56	0.79	0.91	0.95	0.97	0.99	0.98	0.99	1.00

2.3.2 Weight-at-age

Table 14. Weight-at-age in kg. The weights of 1 and 2 yr olds were not available, but were roughly estimated using the simple growth model $W=\alpha\times Age^{\beta}$. For the purposes of model fitting, the weight-at-age was assumed to be similar in 2000 as it was in 1999.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1971	0.20	0.60	1.26	1.78	2.58	3.62	4.90	6.30	7.68	9.35	10.92	12.77	14.52	17.24
1972	0.20	0.60	1.26	1.78	2.58	3.62	4.90	6.30	7.68	9.35	10.92	12.77	14.52	17.24
1973	0.20	0.60	1.03	1.42	2.47	3.60	4.90	6.11	6.67	6.75	7.43	7.95	10.17	17.00
1974	0.20	0.60	1.05	1.71	2.43	3.82	5.24	6.66	7.15	7.76	8.19	9.78	12.38	14.70
1975	0.20	0.60	1.10	1.77	2.78	3.76	5.45	6.69	7.57	8.58	8.81	9.78	10.09	11.00
1976	0.20	0.60	1.35	1.78	2.65	4.10	5.07	6.73	8.25	9.61	11.54	11.43	14.06	16.18
1977	0.20	0.60	1.26	1.91	2.86	4.07	5.78	6.64	7.69	9.73	11.70	14.39	17.46	24.12
1978	0.20	0.60	1.29	1.83	2.93	3.96	5.73	6.81	9.04	10.87	13.07	11.98	19.06	21.28
1979	0.20	0.60	1.41	1.96	2.64	4.00	5.55	6.75	8.30	9.31	13.13	13.42	13.54	20.07
1980	0.20	0.60	1.39	1.86	2.73	3.77	5.26	6.98	8.04	10.73	12.30	17.28	14.89	19.07
1981	0.20	0.60	1.18	1.65	2.26	3.29	4.48	5.82	7.74	9.42	11.37	12.78	12.51	19.07
1982	0.20	0.60	1.01	1.55	2.25	3.10	4.26	5.39	6.68	9.14	11.96	14.23	17.29	16.59
1983	0.20	0.60	1.10	1.60	2.28	3.02	4.10	5.48	7.05	8.13	11.01	13.97	15.88	18.50
1984	0.20	0.60	1.29	1.73	2.60	3.58	4.37	5.80	7.46	9.85	11.05	14.34	15.27	16.66
1985	0.20	0.60	1.41	1.97	2.58	3.65	4.98	6.37	8.21	10.32	12.20	14.68	16.18	19.05
1986	0.20	0.60	1.46	1.96	2.84	3.59	4.64	6.16	7.50	9.08	10.36	15.28	14.54	15.02
1987	0.20	0.60	1.32	1.96	2.69	3.89	4.72	6.26	7.37	9.24	10.70	10.62	15.89	12.59
1988	0.20	0.60	1.44	1.81	2.58	3.52	4.93	6.00	7.14	8.82	9.98	11.73	14.16	13.04
1989	0.20	0.60	1.19	1.81	2.59	3.92	5.21	6.89	8.04	9.83	11.99	10.00	12.61	16.05
1990	0.20	0.60	1.29	1.70	2.38	3.03	4.62	6.52	8.89	10.59	10.99	14.57	15.73	17.29
1991	0.20	0.60	1.31	1.90	2.48	3.16	3.79	5.68	7.24	9.80	9.75	14.34	14.17	20.20
1992	0.20	0.60	1.29	1.77	2.47	3.29	4.39	5.58	6.83	8.13	12.68	13.41	15.72	11.27
1993	0.20	0.60	1.39	1.89	2.77	3.76	4.93	6.05	7.45	8.64	10.90	12.52	14.74	16.87
1994	0.20	0.60	1.44	2.06	2.56	3.66	5.12	6.26	7.72	8.90	10.85	12.87	14.74	17.47
1995	0.20	0.60	1.35	1.96	2.92	3.63	5.18	6.42	7.92	10.27	11.02	11.41	13.10	15.18
1996	0.20	0.60	1.46	1.93	3.13	4.14	4.92	6.01	7.41	9.77	10.54	13.50	13.69	16.19
1997	0.20	0.60	1.48	1.88	2.88	4.03	5.40	6.39	7.34	8.54	10.80	11.53	10.43	12.79
1998	0.20	0.60	1.23	1.75	2.46	3.56	5.21	7.74	7.84	9.30	10.76	14.90	16.65	18.67
1999	0.20	0.60	1.34	1.75	2.49	3.50	4.92	6.45	8.75	9.64	10.36	11.43	15.01	15.05
2000	0.20	0.60	1.34	1.75	2.49	3.50	4.92	6.45	8.75	9.64	10.36	11.43	15.01	15.05

3 MODEL SPECIFICATIONS

The Coleraine models are specified using a Excel/Visual Basic user interface and then fitted with AD Model Builder. The output files can be viewed and diagnosed by a statistical package of choice. The Coleraine software and manual are available at www.fish.washington.edu/research/coleraine.

The stock-recruitment relationship used in this assessment is Beverton-Holt, and in Coleraine this relationship is dynamically estimated during the model fit, as opposed to after a model fit has been reached. The constant maturity-at-age assumption mentioned in section 2.3.1 is known to be unrealistic and is likely to bias the stock-recruitment estimation. This is taken care of by a low likelihood penalty for residuals from the Beverton-Holt curve, so recruitment estimates are allowed to deviate substantially from the deterministic stock-recruitment function.

The objective function is a product of likelihood components minus penalties, where the likelihood components are based on model residuals from observed biomass indices (lognormal likelihood) and catch-at-age (robust lognormal likelihood for proportions).

3.1 Comb: 3 surveys, 1 commercial gear group, 1971–2000

The data are listed in sections 2.1.1, 2.1.2, 2.2.1, 2.2.2, 2.3.1 and 2.3.2.
The word recruit is used for one year olds in this assessment.

Table 15. Parameters estimated in the Comb model.

Parameters	df	Meaning
R0	1	Asymptotic maximum of stock-recruitment curve
Rinit	1	Recruits in 1971 as a fraction of R0 (before allowing for RESinit, see below)
Uinit	1	Harvest rate in 1971
Qspring	1	Catchability coefficient of spring trawl survey
Qautumn	1	Catchability coefficient of autumn trawl survey
Qnet	1	Catchability coefficient of net survey
AFSspring	1	Age of full selectivity of spring survey bottom trawl
AFSautumn	1	Age of full selectivity of autumn survey bottom trawl
AFSnet	1	Age of full selectivity of survey nets
SELspring	2	Shape of left and right sides of spring survey selectivity curve
SELautumn	2	Shape of left and right sides of autumn survey selectivity curve
SELnet	2	Shape of left and right sides of net survey selectivity curve
AFScomb	1	Age of full selectivity of combined commercial gears
SELcomb	2	Shape of left and right sides of combined commercial gear selectivity curve
RESinit	12	Residuals between fitted age classes 2*–13** in 1971 and a deterministic decay model
RESrec	31	Residuals between fitted recruitment in 1971–1999 from Beverton-Holt model
TOTAL df	**61**	*: The residual for the 1st age class is the same as RESrec1971 **: The 14th age class is not estimated, but is calculated as all survivors

The overall likelihood is the product of seven likelihood components, based on the following residuals:

1. Commercial C@A
Fitted catch-at-age from Combined commercial gears (via fitted selectivity and biomass)
vs Catch-at-age data from Combined commercial gears

2. Spring survey biomass
Fitted vulnerable biomass (via the fitted Spring survey selectivity curve)
vs Spring survey biomass index (via the fitted Spring survey catchability coefficient)

3. Autumn survey biomass
Fitted vulnerable biomass (via the fitted Autumn survey selectivity curve)
vs Autumn survey biomass index (via the fitted Autumn survey catchability coefficient)

4. Net survey biomass
Fitted vulnerable biomass (via the fitted Net survey selectivity curve)
vs Net survey biomass index (via the fitted Net survey catchability coefficient)

5. Spring survey C@A
Fitted catch-at-age from Spring survey (via the fitted selectivity and biomass)
vs Catch-at-age data from Spring survey

6. Autumn survey C@A
Fitted catch-at-age from Autumn survey (via the fitted selectivity and biomass)
vs Catch-at-age data from Autumn survey

7. Net survey C@A
Fitted catch-at-age from Net survey (via the fitted selectivity and biomass)
vs Catch-at-age data from Net survey

3.2 Gear: 3 surveys, 5 commercial gear groups, 1985–2000

The data sources are from sections 2.1.1, 2.1.2, 2.2.3, 2.2.4, 2.3.1 and 2.3.2.
The word recruit is used for one year olds in this assessment.
The initial year 1985 was chosen after considerable exploration of other starting points for the gear-specific model. It is the first year when both catch-at-age data and survey data are available.

Table 16. Parameters estimated in the Gear model.

Parameters	df	Meaning
R0	1	Asymptotic maximum of stock-recruitment curve
Rinit	1	Recruits in 1971 as a fraction of R0 (before allowing for RESinit, see below)
Uinit	1	Harvest rate in 1971
Qspring	1	Catchability coefficient of spring trawl survey
Qautumn	1	Catchability coefficient of autumn trawl survey
Qnet	1	Catchability coefficient of net survey
AFSspring	1	Age of full selectivity of spring survey bottom trawl
AFSautumn	1	Age of full selectivity of autumn survey bottom trawl
AFSnet	1	Age of full selectivity of survey nets
SELspring	2	Shape of left and right sides of spring survey selectivity curve
SELautumn	2	Shape of left and right sides of autumn survey selectivity curve
SELnet	2	Shape of left and right sides of net survey selectivity curve
AFShand	1	Age of full selectivity of handlines commercial gears
AFStralo	1	Age of full selectivity of trawl & longline commercial gears
AFSdnsh	1	Age of full selectivity of Danish seine commercial gears
AFS6in	1	Age of full selectivity of 6" net commercial gears
AFS7to9	1	Age of full selectivity of 7–9" commercial gears
SELhand	2	Shape of left and right sides of handlines commercial gear selectivity curve
SELtrali	2	Shape of left and right sides of trawl & longline commercial gear selectivity curve
SELdnsh	2	Shape of left and right sides of Danish seine commercial gear selectivity curve
SEL6in	2	Shape of left and right sides of 6" net commercial gear selectivity curve
SEL7to9	2	Shape of left and right sides of 7–9" nets commercial gear selectivity curve
RESinit	14	Residuals between fitted age classes in 1985 and a deterministic decay model
RESrec	14	Residuals between fitted recruitment in 1986*–1999 from Beverton-Holt model
TOTAL df	**58**	*: (RESrec1985 = RESinit1)

The likelihood components used in fitting in this model are analogous to those listed in section 3.1, except the commercial catch-at-age components are five instead of one, bringing the total number of likelihood components to eleven.

4 MODEL OUTPUT AND DIAGNOSTICS

The Comb and Gear models were close to each other in parameter estimates, resulting in comparable portrays of the fishery. Hence, to avoid repetition this section is based on the Comb model except where otherwise noted. First, the basic output of the model is described, then fishery indicators, followed by a closer look at the fit, retrospective analysis and MCMC (Markov Chain Monte Carlo) runs.

4.1 Basic output

4.1.1 Parameter estimates

Table 17. Maximum likelihood point estimates of parameters in the Comb model.

Parameters	Estimate
R0	620 087
Rinit	0.53
Uinit	0.37
Qspring	1.2e–6
Qautumn	1.3e–6
Qnet	3.7e–6
AFSspring	4.3
AFSautumn	4.7
AFSnet	7.4
SELspring	1.5 and 15
SELautumn	1.9 and 15
SELnet	1.0 and 1.4
AFScomb	5.8
SELcomb	1.2 and 15
RESinit	Stdev of 0.22
RESrec	Stdev of 0.57

Component	–log Likelihood
C@Acomb	–654
SurvBspring	6
SurvBautumn	1
SurvBnet	1
SurvC@Aspring	–378
SurvC@Aautumn	–93
SurvC@Anet	–102
TOTAL –log L	**–1213**

4.1.2 Numbers-at-age matrix

Table 18. Numbers-at-age output from Comb model fit.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1971	498521	171001	173832	136591	108768	46555	36490	27043	8933	4151	1855	1005	535	668
1972	263587	407905	138955	135059	90222	52833	19688	15432	11437	3778	1756	785	425	508
1973	435143	215668	331335	107664	88116	42286	21273	7927	6213	4605	1521	707	316	376
1974	648947	355987	174885	253594	66393	34667	13243	6662	2483	1946	1442	476	221	217
1975	213253	530874	288504	133300	153355	24452	9821	3752	1887	703	551	409	135	124
1976	351339	174466	430664	221476	83363	63146	8191	3290	1257	632	236	185	137	87
1977	384481	287466	141712	333614	144361	38964	25328	3285	1320	504	254	95	74	90
1978	213432	314633	233949	111293	230963	79779	19576	12726	1651	663	253	127	47	82
1979	214889	174678	256414	185536	80301	141845	45916	11267	7324	950	382	146	73	75
1980	183513	175869	142342	203210	133480	48961	80892	26185	6425	4177	542	218	83	84
1981	337186	150182	143215	112270	143296	77378	26174	43244	13998	3435	2233	290	116	90
1982	208019	275909	122110	111741	75553	73353	35130	11883	19633	6355	1560	1014	131	93
1983	190007	170208	224217	94914	73950	36901	31255	14968	5063	8365	2708	664	432	96
1984	552824	155472	138336	174429	63052	36508	15954	13513	6472	2189	3617	1171	287	228
1985	538131	452355	126395	107840	116935	31935	16340	7141	6048	2897	980	1619	524	231
1986	280584	440311	367543	98127	70985	56238	13323	6817	2979	2523	1208	409	675	315
1987	109365	229552	357207	282216	61431	29328	18931	4485	2295	1003	849	407	138	333
1988	188754	89469	186109	273027	172930	23663	8898	5744	1361	696	304	258	123	143
1989	149272	154436	72650	143845	176160	78425	9101	3422	2209	523	268	117	99	102
1990	277872	122146	125591	56757	97350	91592	36355	4219	1586	1024	243	124	54	93
1991	235830	227361	99247	97515	37381	46894	38296	15200	1764	663	428	101	52	62
1992	104902	192936	184435	76164	60891	15317	15597	12737	5056	587	221	142	34	38
1993	249878	85814	156325	140339	45682	21793	4150	4226	3451	1370	159	60	39	19
1994	293199	204405	69511	118703	83335	15775	5579	1062	1082	883	351	41	15	15
1995	85812	239902	166085	53972	78185	40152	6598	2333	444	452	370	147	17	13
1996	208783	70222	195201	130252	37141	42525	19757	3246	1148	219	223	182	72	15
1997	44790	170856	57161	153529	90753	20873	21838	10146	1667	590	112	114	93	45
1998	284085	36655	139117	45047	107879	52131	11028	11538	5360	881	311	59	60	73
1999	268361	232470	29822	109032	30913	58241	25401	5373	5622	2612	429	152	29	65
2000	425162	219580	188900	23166	71957	14979	24548	10706	2265	2370	1101	181	64	40
2001	216994	347861	178306	146038	14963	32741	5788	9485	4137	875	916	425	70	40

4.2 Fishery indicators

4.2.1 Biomass and yield

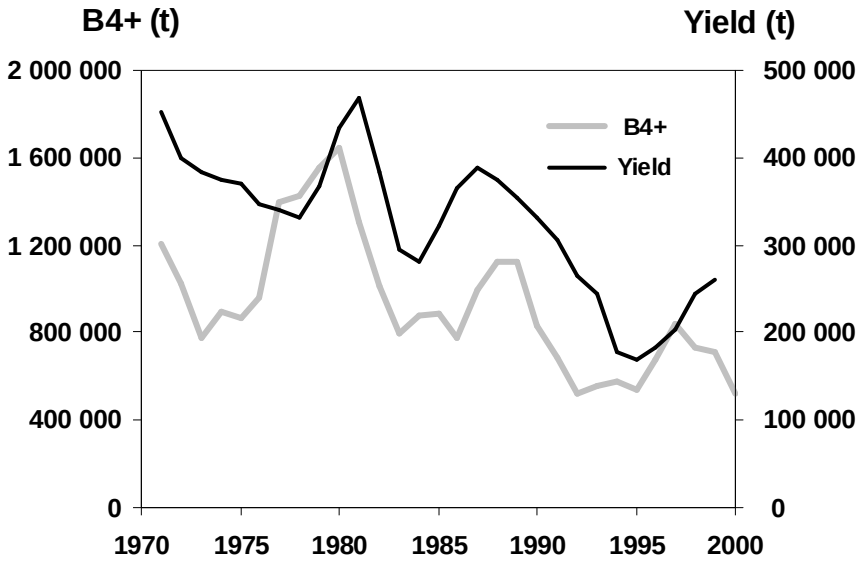

Figure 3. Biomass of cod age 4 and older from the Comb model fit, graphed with observed yield as time series.

4.2.2 Fishing mortality rate

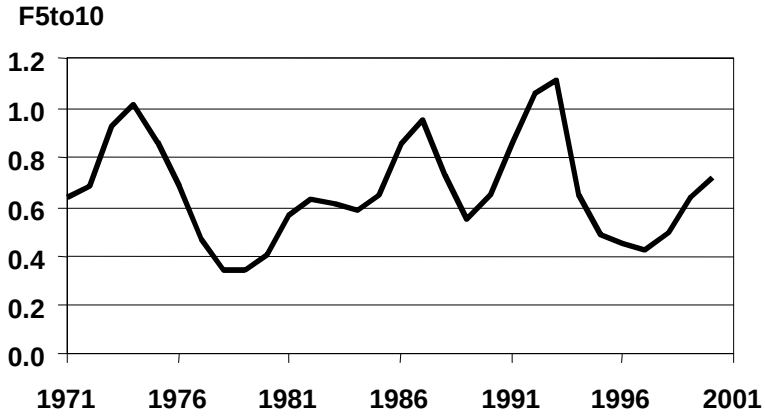

Figure 4. Average fishing mortality of 5 to 10 year olds from the Comb model fit.

4.2.3 Fraction of B4+ harvested

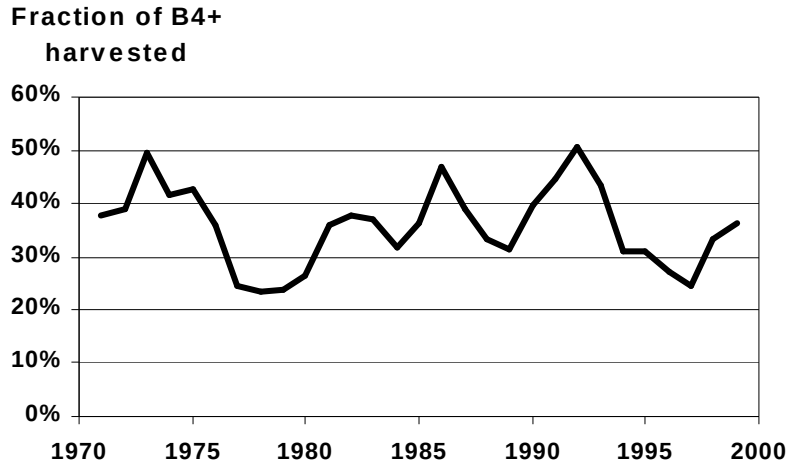

Figure 5. Annual harvest as a fraction of the biomass of age groups 4 yrs and older from the Comb model fit.

4.2.4 Gear selectivity

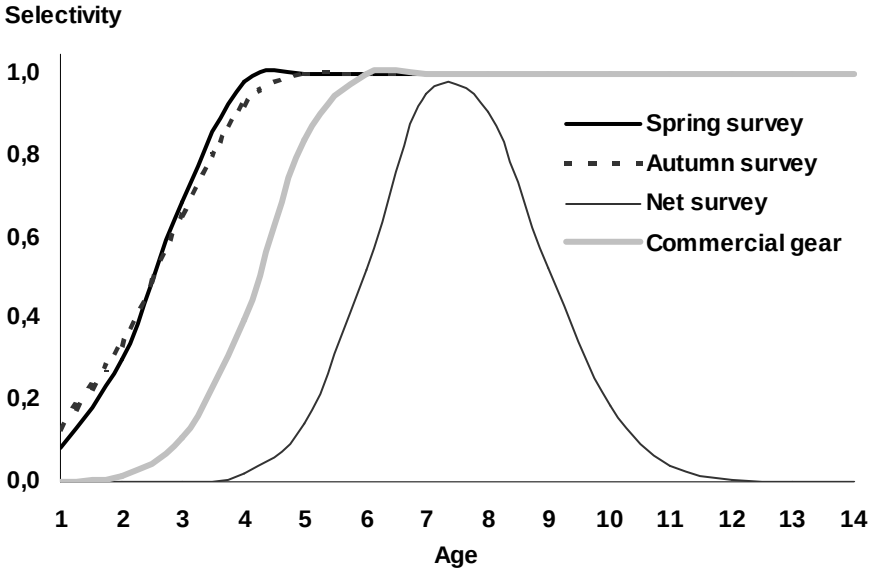

Figure 6. Survey and commercial gear selectivity curves from the Comb model fit.

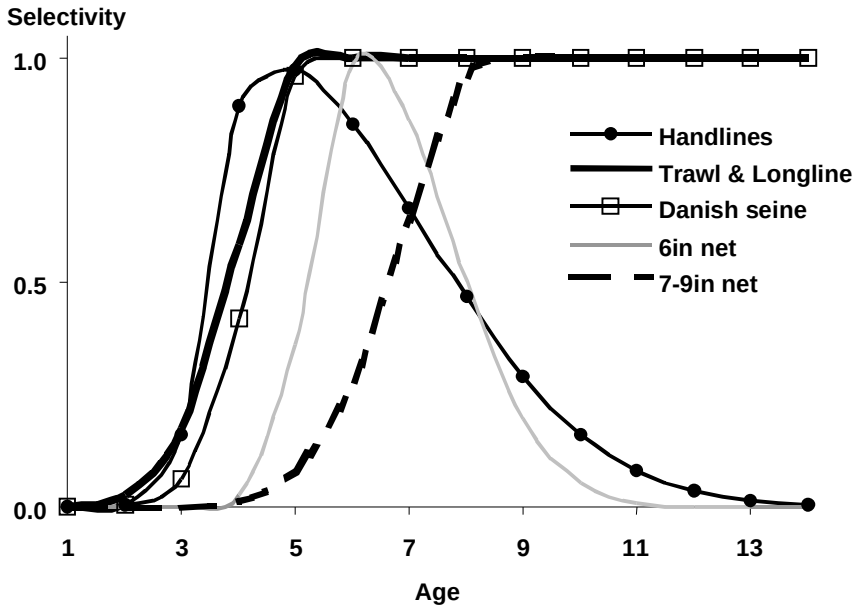

Figure 7. Commercial gear selectivity curves from the Gear model fit.

4.2.5 Spawners and recruits

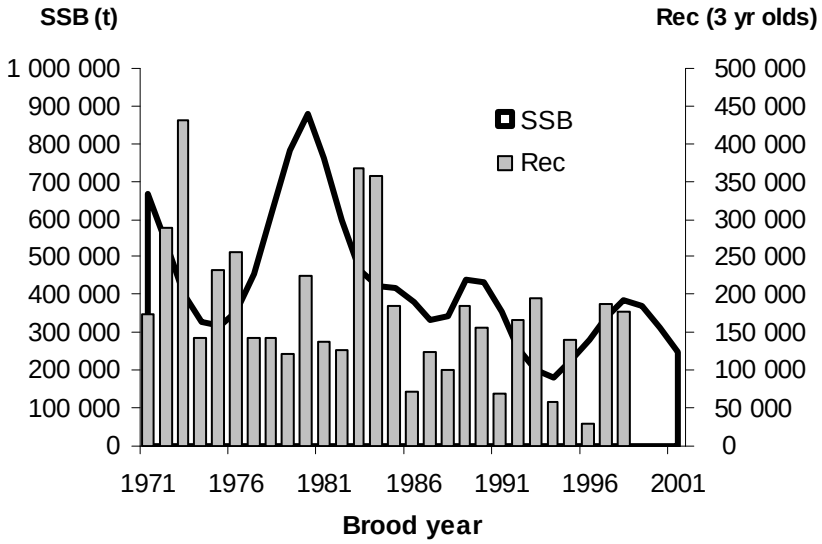

Figure 8. Spawning stock biomass (SSB) and 3 year old recruits from the Comb model fit, graphed as time series on brood year.

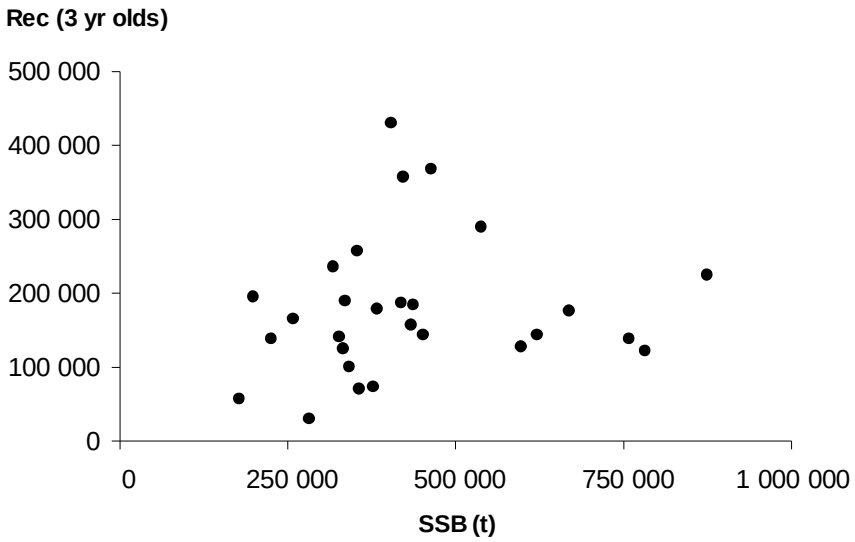

Figure 9. Spawning stock biomass (SSB) and 3 year old recruits from the Comb model fit, graphed as a scatterplot.

4.2.6 Cohort biomass

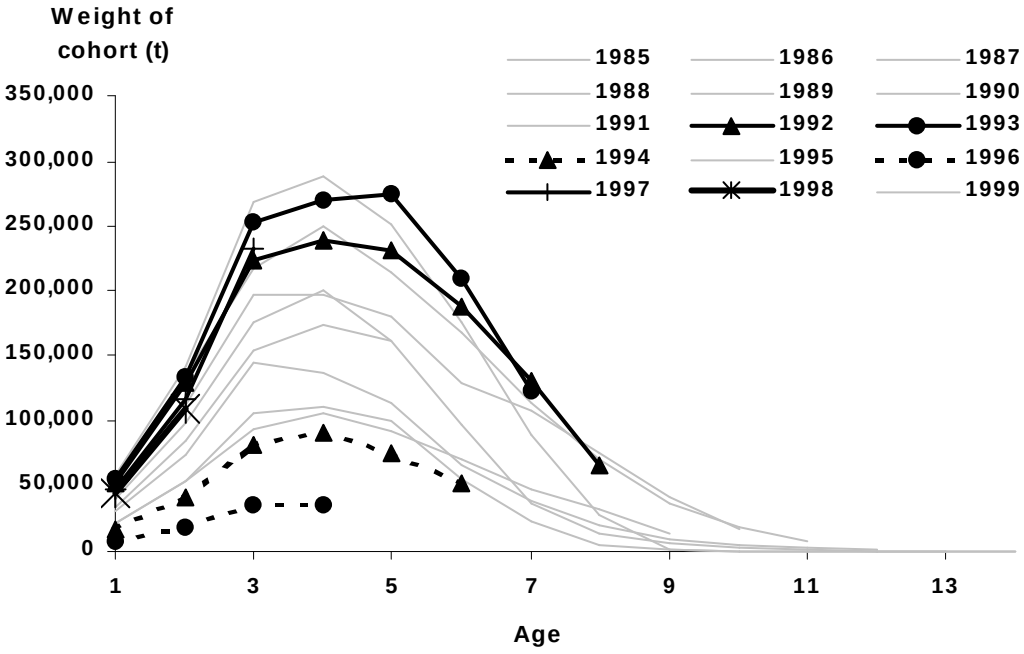

Figure 10. Cohort biomass from the Comb model fit.

4.3 Model fit

4.3.1 Fitted biomass indices

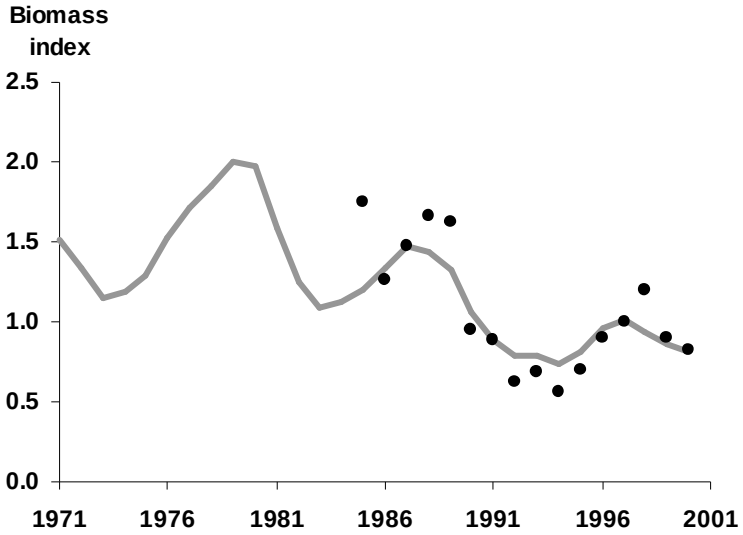

Figure 11. Observed spring trawl survey biomass index (solid circles) and the Comb model fit.

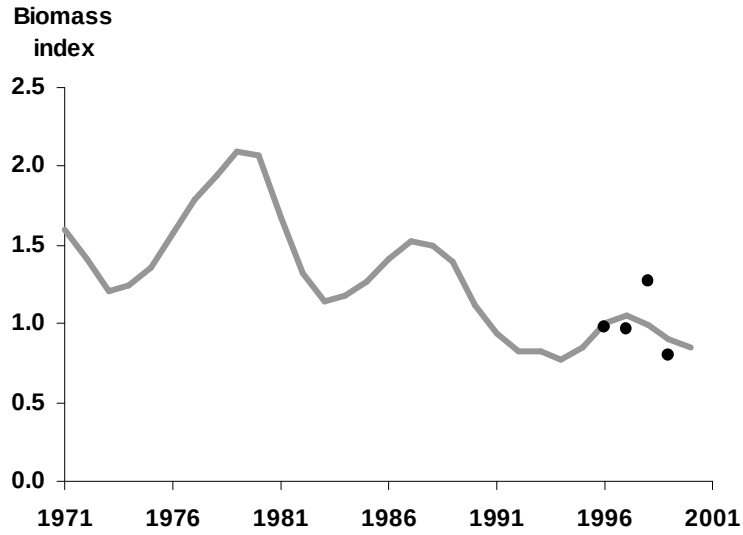

Figure 12. Observed autumn trawl survey biomass index (solid circles) and the Comb model fit.

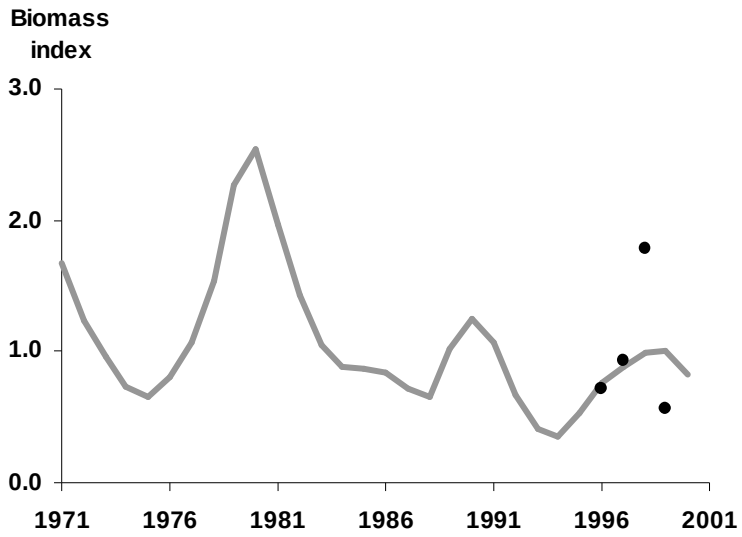

Figure 13. Observed net trawl survey biomass index (solid circles) and the Comb model fit.

4.3.2 Fitted catch-at-age

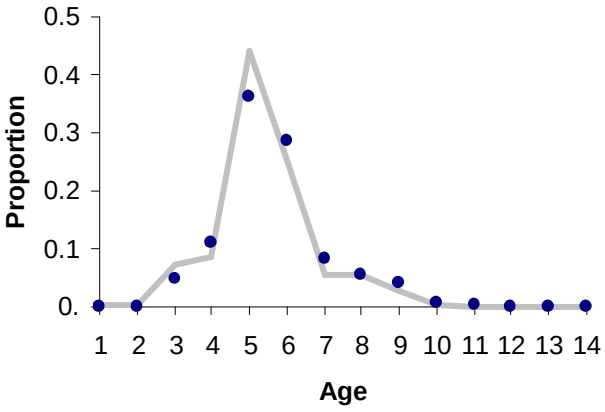

Figure 14. Commercial catch-at-age from 1998 (solid circles) and the Comb model fit.

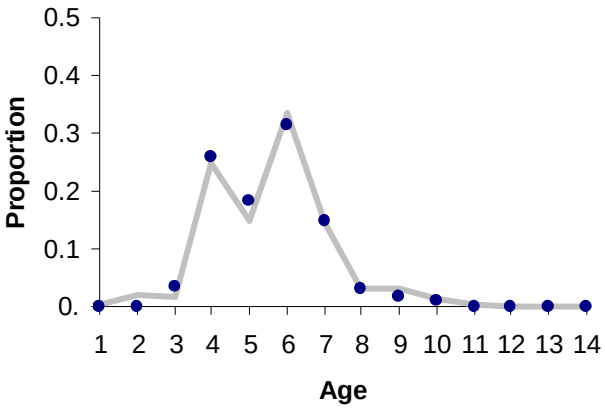

Figure 15. Commercial catch-at-age from 1999 (solid circles) and the Comb model fit.

Figures 14 and 15 are displayed here as a glimpse of the catch-at-age fits, which in total consist of 53 graphs: 29 commercial catch-at-age graphs (1971–1999), 16 spring survey catch-at-age graphs (1985–2000), 4 autumn survey catch-at-age graphs (1996–1999) and 4 net survey catch-at-age graphs (1996–1999).

4.4 Retrospective analysis

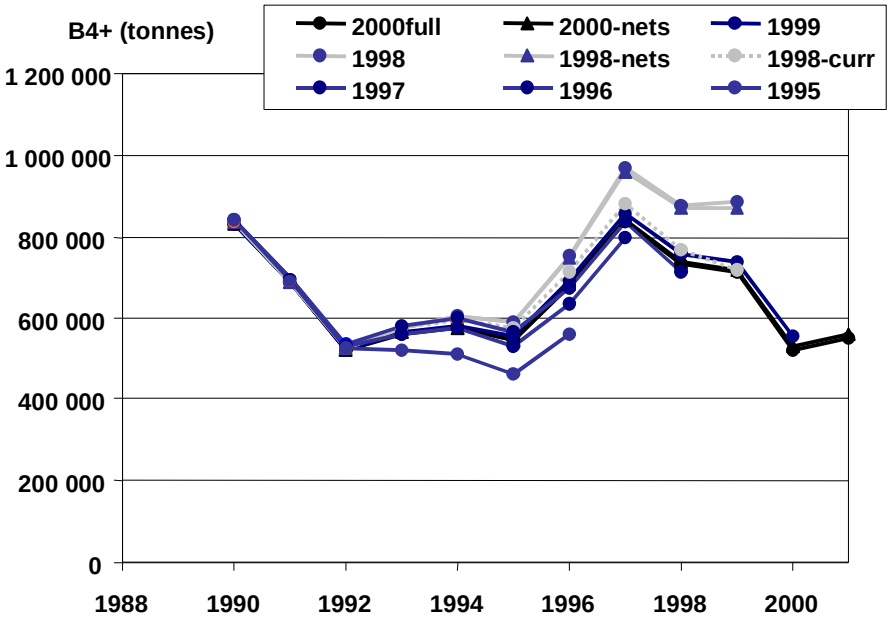

Figure 16. Retrospective analysis of the Comb model fitted to nine different datasets, described in text below.

2000full: Data up to spring survey 2000
2000-nets: Data up to spring survey 2000, ignoring all biomass indices from net surveys
1999: Data from 1971 to 1999
1998: Data from 1971 to 1998
1998-nets: Data from 1971 to 1998, ignoring all biomass indices from net surveys
1998-curr: Data from 1971 to 1998, ignoring all biomass indices from the current (1998) year
1997: Data from 1971 to 1997
1996: Data from 1971 to 1996
1995: Data from 1971 to 1995

4.5 MCMC runs

A thousand parameter co-ordinates were saved from a million Markov Chain Monte Carlo simulations to create Bayesian posterior likelihood profiles. These can be used both to construct confidence bounds around the parameter point estimates and to project the impacts of a harvest control rule.

4.5.1 Recruitment confidence bounds

The Comb model and Gear model correspond well with each other in terms of recruitment estimates and Bayesian confidence bounds (Figs 17 and 18).

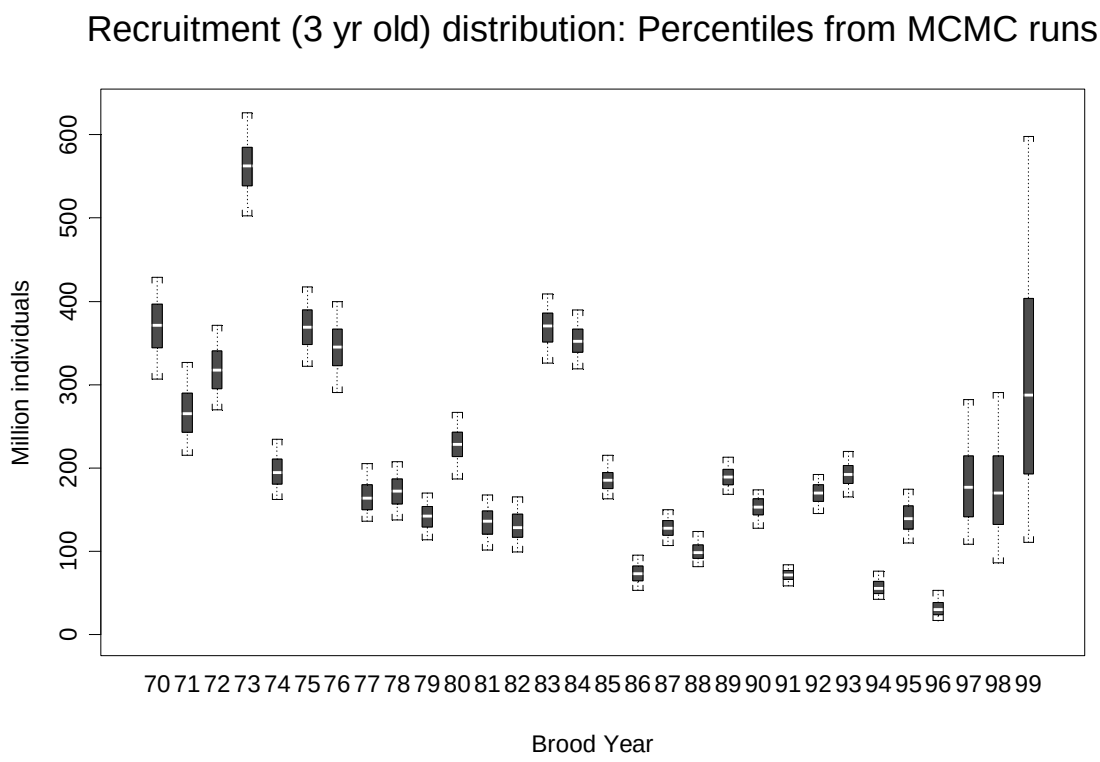

Figure 17. Recruitment at brood year from the Comb model fit. The graph is a doctored boxplot, showing the 95%, 75%, 50%, 25% and 5% percentiles instead of the regular boxplot output. The confidence bounds are not expected to encompass but a part of the uncertainty, but reflect the relative certainty for each year.

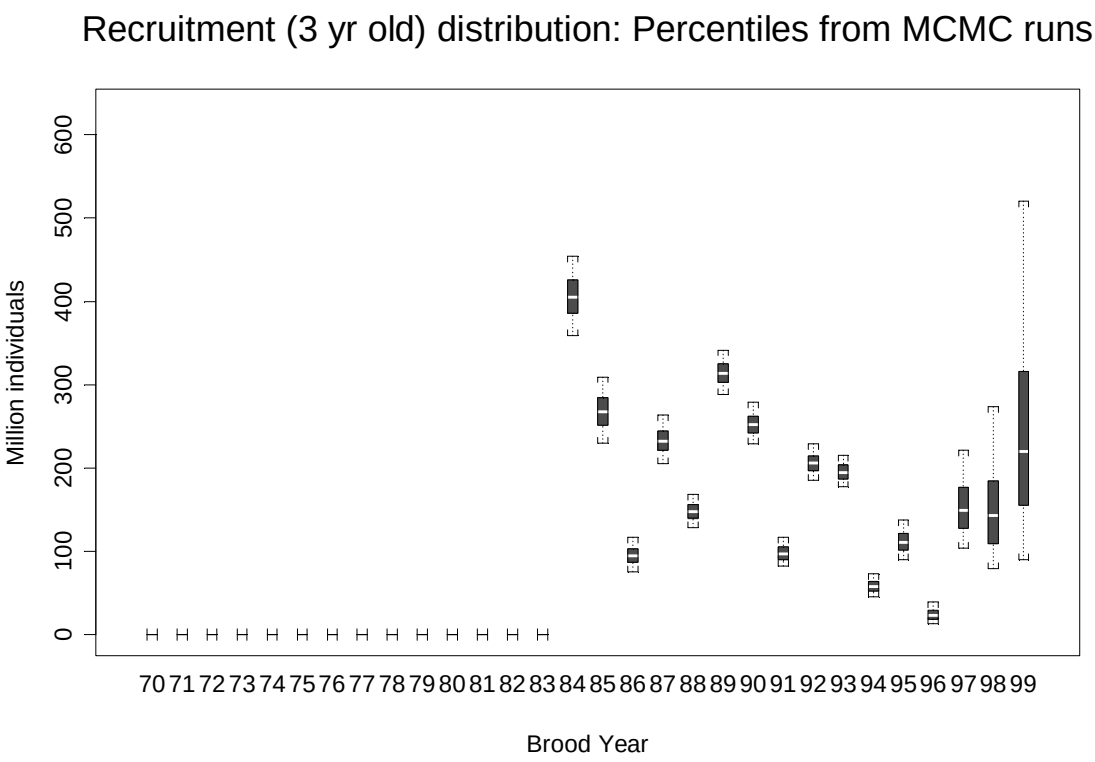

Figure 18. Recruitment at brood year from the Gear model fit. The graph is a doctored boxplot, showing the 95%, 75%, 50%, 25% and 5% percentiles instead of the regular boxplot output. The confidence bounds are not expected to encompass but a part of the uncertainty, but reflect the relative certainty of each year.

4.5.2 Projections

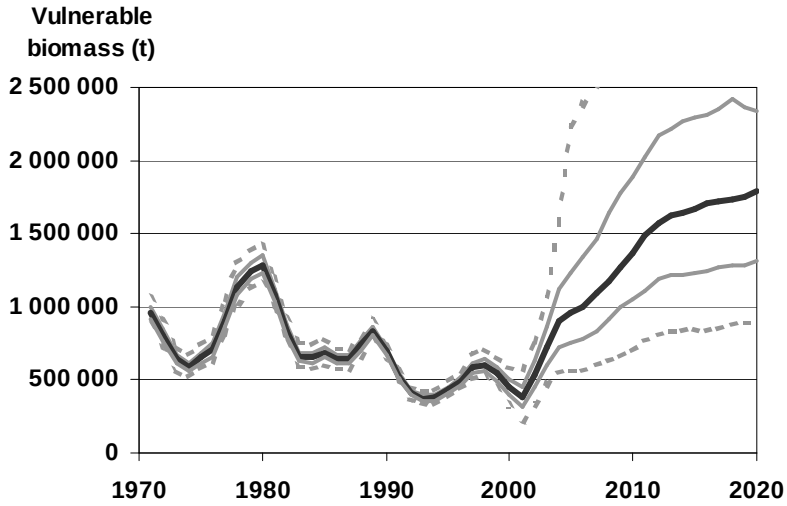

Figure 19. Vulnerable biomass projected with MCMC implementing a 25% harvest control rule. The 95%, 75%, 50%, 25% and 5% posterior percentiles are shown.

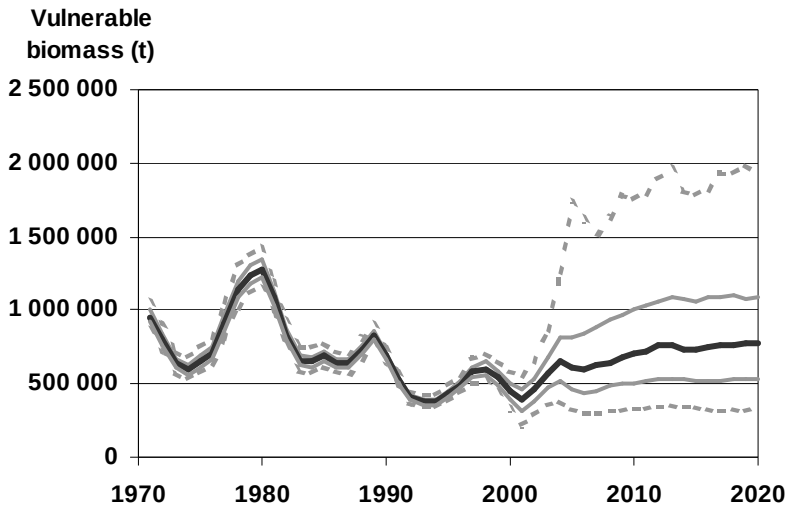

Figure 20. Vulnerable biomass projected with MCMC implementing a 40% harvest control rule. The 95%, 75%, 50%, 25% and 5% posterior percentiles are shown.

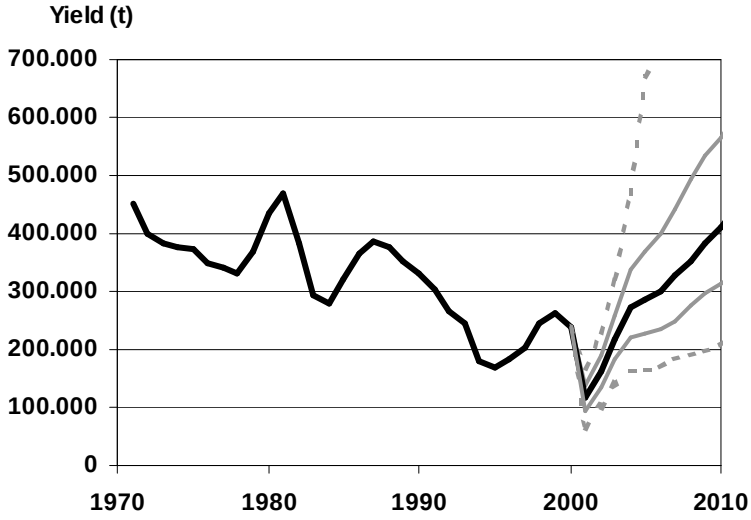

Figure 21. Yield projected with MCMC implementing a 25% harvest control rule. The 95%, 75%, 50%, 25% and 5% posterior percentiles are shown.

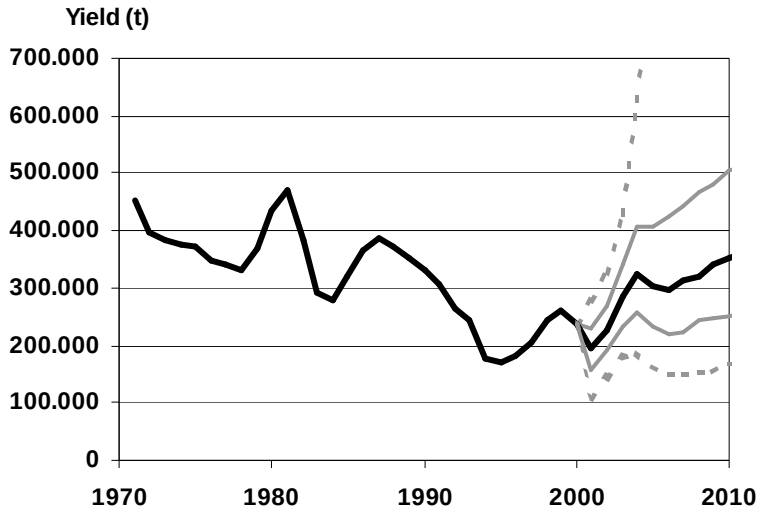

Figure 22. Yield projected with MCMC implementing a 40% harvest control rule. The 95%, 75%, 50%, 25% and 5% posterior percentiles are shown.

5 DISCUSSION

An important objective of this assessment is to serve as a reference for comparing the Coleraine model fits to other models fitted to the Icelandic cod data. That comparison will be summarized in a seperate document.

The most noteworthy conclusions from the Coleraine model fits are:

A. In the most recent years, harvest has exceeded the 25% target considerably. This can best be seen in Figure 3 where the fishable biomass and yield are graphed together with the yield axis set at 25% of the biomass axis. If the 25% harvest control rule was followed the curves should continually overlap, as they did in 1996 and 1997. In 1998 and 1999, the yield has been increasing when it should have been decreased. During the last three decades, the harvest seems to have ranged between 25% and 50% of the fishable biomass (Figure 5) which may explain the low abundance during the 1990s.

B. Projections of harvest control rules demonstrate that the 25% harvest control rule would be a sound approach for rebuilding the stock (Figure 19) if it was followed. It also seems that a 40% harvest control rule doesn't cause any great risk of a collapse (Figure 20), but would efficiently keep the stock down at levels comparable with the 1980s and 1990s which conforms with Figure 5. It only takes the 25% harvest control rule a few years to surpass the 40% one in terms of annual yield (Figures 21 and 22). The sharp increase in yield for both harvest control rules can be explained by recent large cohorts entering the fishable stock. An important source of uncertainty in the projections is recruitment variability.

C. Five-fold recruitment variation is not uncommon (Figures 17 and 18) and the trends cannot be explained very well with the spawning stock biomass (Figures 8 and 9). Since large cohorts contribute greatly to the overall stock biomass (Figure 10), it is a fundamental management goal to improve the likelihood of high recruitment. Guðrún Marteinsdóttir and others have found substantial evidence that old females are important for recruitment, which creates an important link between management and recruitment.

D. Estimating the gear selectivity with Coleraine results in realistic curves (Figures 6 and 7) which can be used to model gear-specific management actions.

E. Retrospective analysis (Figure 16) shows fairly good robustness of the Comb model fit as new years of data are added, but also reveals that the model would have overestimated the biomass temporarily when the high 1998 survey results (Figure 1) were added for the first time. When the most current data are included, all three 1998 surveys create a large positive residual (Figures 11, 12 and 13). This, as well as the retrospective analysis, supports the theory of some working group members that the catchability fluctuates in time, violating commonly used assumptions in stock assessment.