Initial Applications of Statistical Catch-at-Age Assessment Methodology to the Gulf of Maine Winter Flounder Resource

Rebecca A. Rademeyer and Doug S. Butterworth

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Abstract

Application of SCAA to the Gulf of Maine flounder resource, though initial at this stage, suggests that with some downweighting of catch-at-age data in the likelihood, the serious retrospective problem of previous VPA assessments of this resource disappear. There are indications from the model fits considered that survey selectivity is domed (assuming commercial selectivity to be asymptotically flat at higher ages) and/or natural mortality is higher than the conventionally assumed 0.2.

Introduction

This paper presents the results of some initial applications of Statistical Catch-at-Age methodology to data for the Gulf of Maine winter flounder resource.

Data and Methodology

The catch and survey based data (including catch-at-age information) and some biological data are listed in Tables in Appendix A, from Nitschke (2011).

The details of the SCAA assessment methodology are provided in Appendix B. The Beverton-Holt stock-recruitment steepness *h* is fixed at 0.9 for the analyses that follow. The contribution of all catch-at-age data to the negative log-likelihood is down-weighted by a multiplicative factor w^{CAA}.

Results and Discussion

Case 1: Base Case with w^{CAA}=0.1, *M*=0.2 and commercial selectivity-at-age flat for ages 5 and above. (Figs 1-5)
Particular reasons for this choice were to not have all selectivities domed, and especially the fact that unlike the GARM3 VPA assessment (Nitschke, 2008) there is virtually no retrospective pattern (Fig. 5). Note (Fig. 1) that the spawning biomass estimates are much greater than for that GARM3 VPA. The survey selectivities are domed (Fig. 3) and fit the CAA data well, but forcing the commercial selectivity to be flat leads to systematic overestimation of the commercial plus-group numbers by the model (Fig. 4).

Case 2: Split the commercial selectivity vector estimation between 1997 and 1998
This split makes very little difference to the results; hence no plts are shown.

Case 3: Force selectivity at age for the NEFSC surveys to be flat from age 5 and above (Fig. 6)
This leads to an appreciable deterioration to the for to the data: -lnL increases by 13. The primary reason for this deterioration is evident from the CAA residual plots in Fig. 6, which show a poor fit to the plus group proportions at age for the two NEFSC surveys.

Case 4: Fix natural mortality $M = 0.4$ (Fig. 7)
This leads to a 6 point improvement in the log-likelihood for the fit, with reduced residuals for the plus group for the commercial CAA data.

Case 5: Estimate a (constant) M bounded above by 0.6 (Fig. 8)
The estimated M hits the upper constraint of 0.6. There is a further improvement in the negative log-likelihood of 3 points, with the residuals for the plus group for the commercial CAA data reduced to near zero. Spawning biomass is however estimated to be lower in circumstances of an increased estimate for the pre-exploitation level.

Case 6: Force selectivities-at-age for all surveys to be flat above age 5 (Fig. 9)
This leads to further appreciable increases in –lnL, and further deterioration in the fits to the plus group proportions in the CAA for all data sets.

Case 7: Different weightings ($w^{survCAA}$) for the survey CAA data in the likelihood (Figs 10-12), where the reference alternative value for $w^{survCAA}$ is 0.3 (results in Table 1 are shown for this choice) in place of the 0.1 for the Base Case, but results for additional choices for $w^{survCAA}$ are shown in Fig. 11.
Results are qualitatively different for $w^{survCAA} = 0.3$, with substantial deterioration in the fits to trends in the survey abundance series (Fig. 10) and a bad retrospective pattern (Fig. 12). Fig 11 shows how as $w^{survCAA}$ is increased the fit moves closer to the VPA solution, but with a large jump between $w^{survCAA}$ values of 0.27 and 0.28 which is suggestive of a multi-modal likelihood and some conflict between the survey trend and CAA data.

Case 8: Allowance for doming in the commercial as well as the survey selectivity vectors (Fig. 13)
Unsurprisingly the negative log-likelihood improves, and the commercial plus group proportions for the CAA data are better fitted. The estimated magnitude of the spawning biomass increases markedly.

Concluding remarks

This does not pretend to be a comprehensive analysis, but some important points nevertheless seem reasonably established:

- Survey selectivity must be domed (though to a lesser extent as M might be set higher than 0.2).
- There is some conflict between the CAA data and the trends in the survey estimates, but if the former are given lower weight, their fit to the data does not appear visually to deteriorate substantially.
- Downweighting of the CAA data leads to higher estimated abundance, but also to the disappearance of the retrospective pattern that marks the VPA results.

References

Nitschke P. 2008. I. Gulf of Maine winter flounder. Appendix to the Report of the 3rd Groundfish Assessment Review Meeting (GARM III): Assessment of 19 Northeast Groundfish Stocks through 2007, Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008 http://www.nefsc.noaa.gov/publications/crd/crd0816/pdfs/garm3i.pdf

Nitschke P. 2011. Working paper (Nitschke, pers. comm)

Table 1: Results of SCAA for the Gulf of Maine winter flounder – see main text and Appendix B for specifications and definitions of some of the symbols used. Biomass units are '000t. Values input rather than estimated are shown in bold.

	1) Base Case (BC)	2) Case 2: as BC but two commercial selectivity periods	3) Case 3: as BC but NEFSC surveys selectivity flat from age 5	4) Case 4: as BC but M=0.4 throughout	5) Case 5: as BC but M estimated	6) Case 6: as BC but flat selectivity from age 5 for all surveys	7) Case 7: as Case 6 but weight of survey CAA likelihood is 0.3 instead of 0.1	8) as BC but commercial selectivity domed
'-lnL:overall	-123.2	-123.5	-110.1	-129.1	-132.3	-101.3	-156.9	-133.5
'-lnL:Survey	-72.4	-72.4	-71.6	-72.4	-72.7	-79.5	1.8	-72.8
'-lnL:CAA	8.0	7.4	7.2	2.3	-0.1	7.8	-1.6	-1.9
'-lnL:CAAsurv	-42.7	-42.8	-29.0	-42.4	-42.9	-14.4	-142.5	-42.6
'-lnL:RecRes	-17.2	-17.2	-17.4	-17.1	-17.0	-15.8	-14.9	-17.1
'-lnL:SelSmoothing	1.0	1.5	0.7	0.6	0.4	0.5	0.3	0.9
h	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**
M	**0.20**	**0.20**	**0.20**	**0.40**	**0.60**	**0.20**	**0.20**	**0.20**
Theta	0.50	0.54	0.35	0.79	0.25	0.25	0.41	0.62
Phi	0.12	0.11	0.19	0.08	0.34	0.30	0.30	0.15
ρ_{SR}	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ksp	37.97	37.90	38.98	20.35	55.94	41.00	23.09	53.06
B^{sp}_{2010}	15.88	15.98	15.78	11.39	10.33	16.46	4.73	23.53
B^{sp}_{2010}/K^{sp}	0.42	0.42	0.40	0.56	0.18	0.40	0.20	0.44
$B^{sp}_{2010}/B^{sp}_{1982}$	0.83	0.79	1.15	0.71	0.73	1.64	0.50	0.72
$MSYL^{sp}$	0.17	0.17	0.17	0.15	0.15	0.17	0.17	0.14
B^{sp}_{MSY}	6.33	6.43	6.56	3.10	8.42	6.93	3.94	7.18
MSY	1.89	1.97	1.98	2.59	7.24	2.09	1.21	2.37
σ_{comCAA}	0.21	0.21	0.21	0.17	0.15	0.21	0.14	0.14

	1) Base Case (BC)			2) Case 2			3) Case 3			4) Case 4		
Survey	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}
NEFSCspring	0.31	0.55	0.15	0.31	0.54	0.15	0.29	0.57	0.21	0.20	0.55	0.16
NEFSCfall	0.45	0.46	0.16	0.46	0.46	0.16	0.42	0.47	0.23	0.30	0.46	0.16
MADspring	4.08	0.25	0.14	4.07	0.25	0.14	4.04	0.25	0.14	1.98	0.25	0.13
MADfall	4.32	0.17	0.12	4.33	0.17	0.12	4.26	0.17	0.13	2.26	0.17	0.13
σ_{R_out}	0.27			0.27			0.24			0.29		

	5) Case 5			6) Case 6			7) Case 7			8) as BC but commercial selectivity domed		
Survey	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}	q $x10^6$	σ_{surv}	σ_{CAA}
NEFSCspring	0.18	0.54	0.16	0.27	0.58	0.22	0.71	0.63	0.16	0.22	0.55	0.15
NEFSCfall	0.24	0.47	0.16	0.40	0.46	0.24	0.94	0.72	0.15	0.31	0.46	0.16
MADspring	1.29	0.25	0.13	3.62	0.28	0.20	7.59	0.55	0.12	2.83	0.26	0.14
MADfall	1.31	0.17	0.13	3.89	0.12	0.19	8.30	0.58	0.12	3.01	0.17	0.13
σ_{R_out}	0.30			0.29			0.33			0.29		

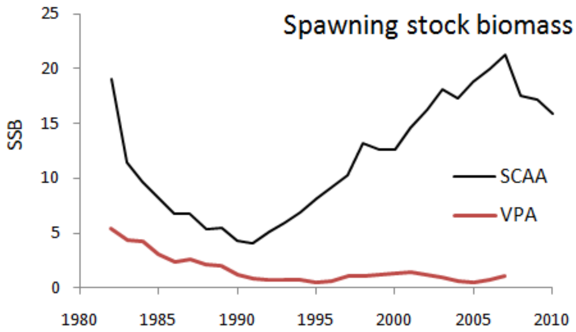

Fig. 1: Spawning stock biomass trajectories for the Base Case, compared to the GARM3 VPA (Nitschke, 2008).

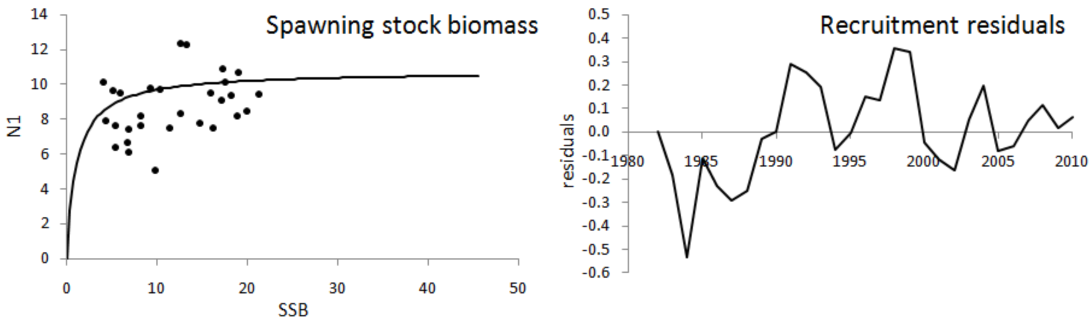

Fig. 2: Stock-recruit relationship and estimated stock-recruit residuals for the Base Case.

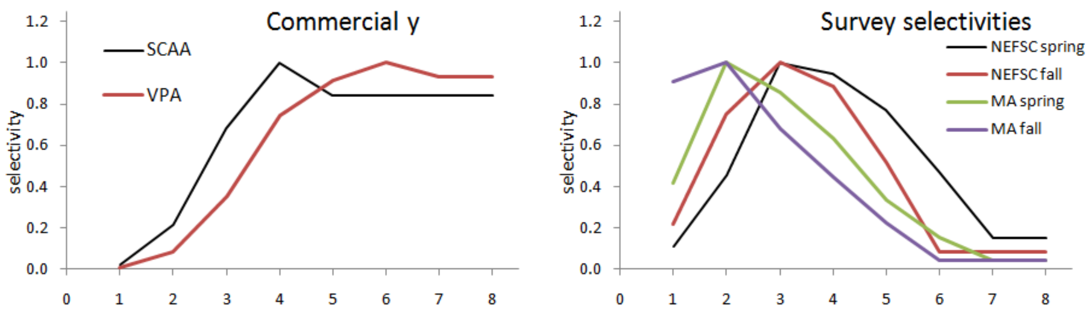

Fig. 3: Commercial and survey selectivities-at-age estimated for the Base Case.

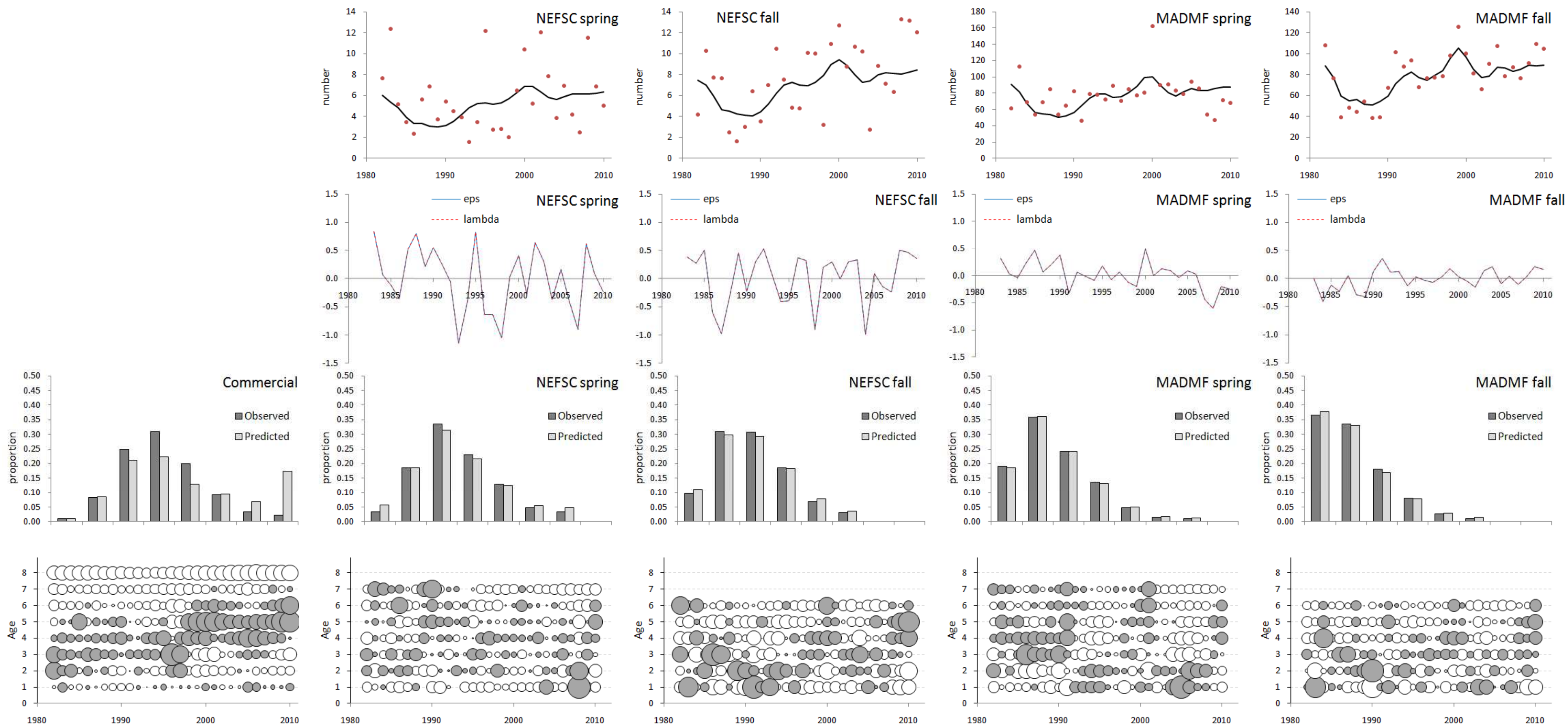

Fig. 4: The first two rows give the fit of the Base Case to the survey indices of abundance and corresponding survey standardised residuals. The third and fourth row plot the fit of the Base Case to the commercial and survey catch-at-age data. The third row compares the observed and predicted CAA as averaged over all years for which data are available, while the fourth row plots the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

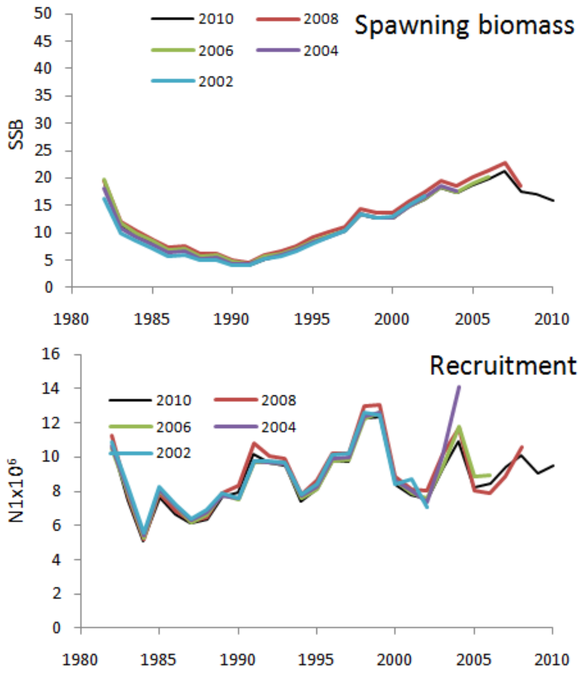

Fig. 5: Retrospective analysis of spawning biomass and recruitment for the Base Case.

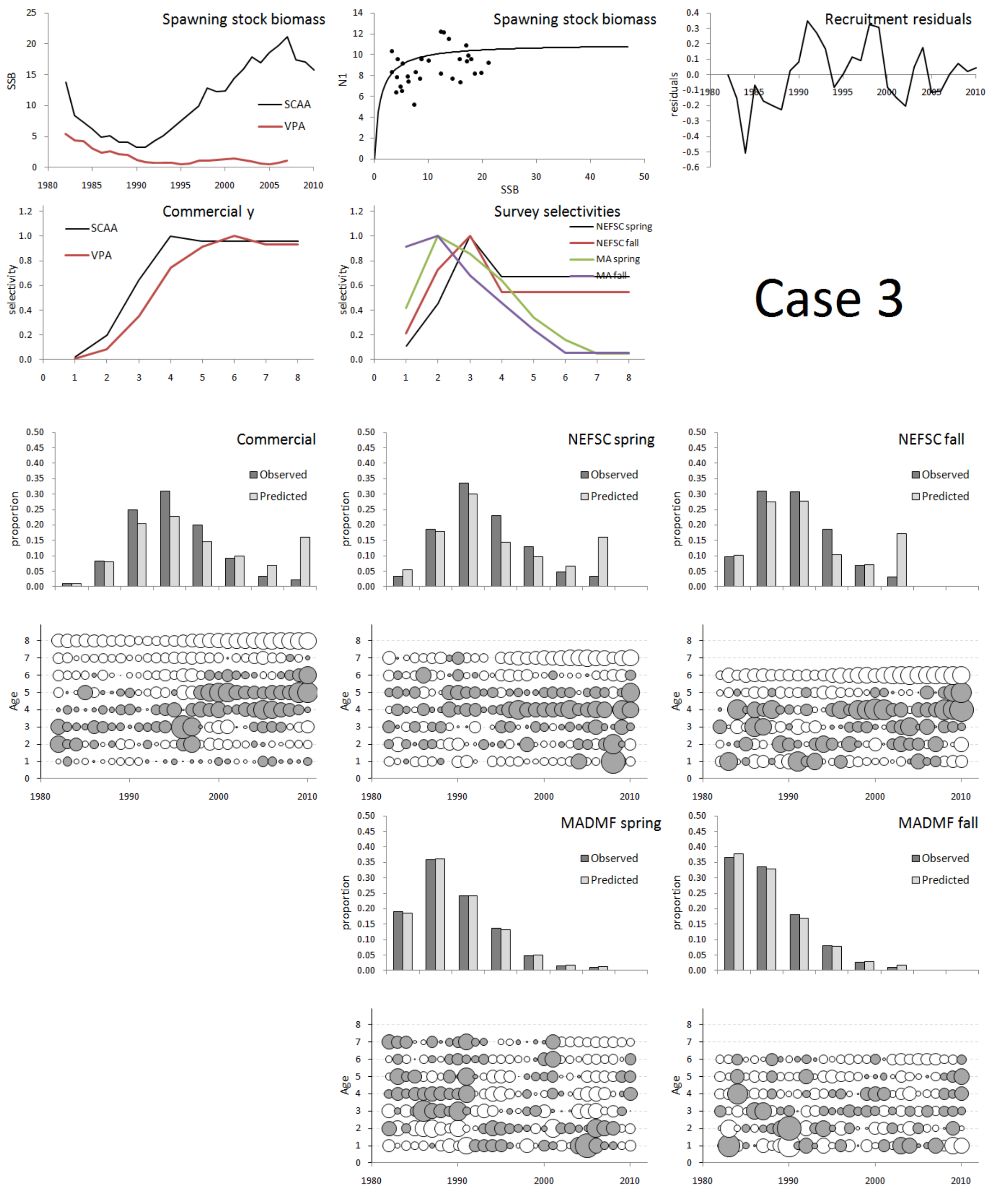

Fig. 6: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 3 (NEFSC survey selectivity flat). The fits to the commercial and survey CAA are also shown.

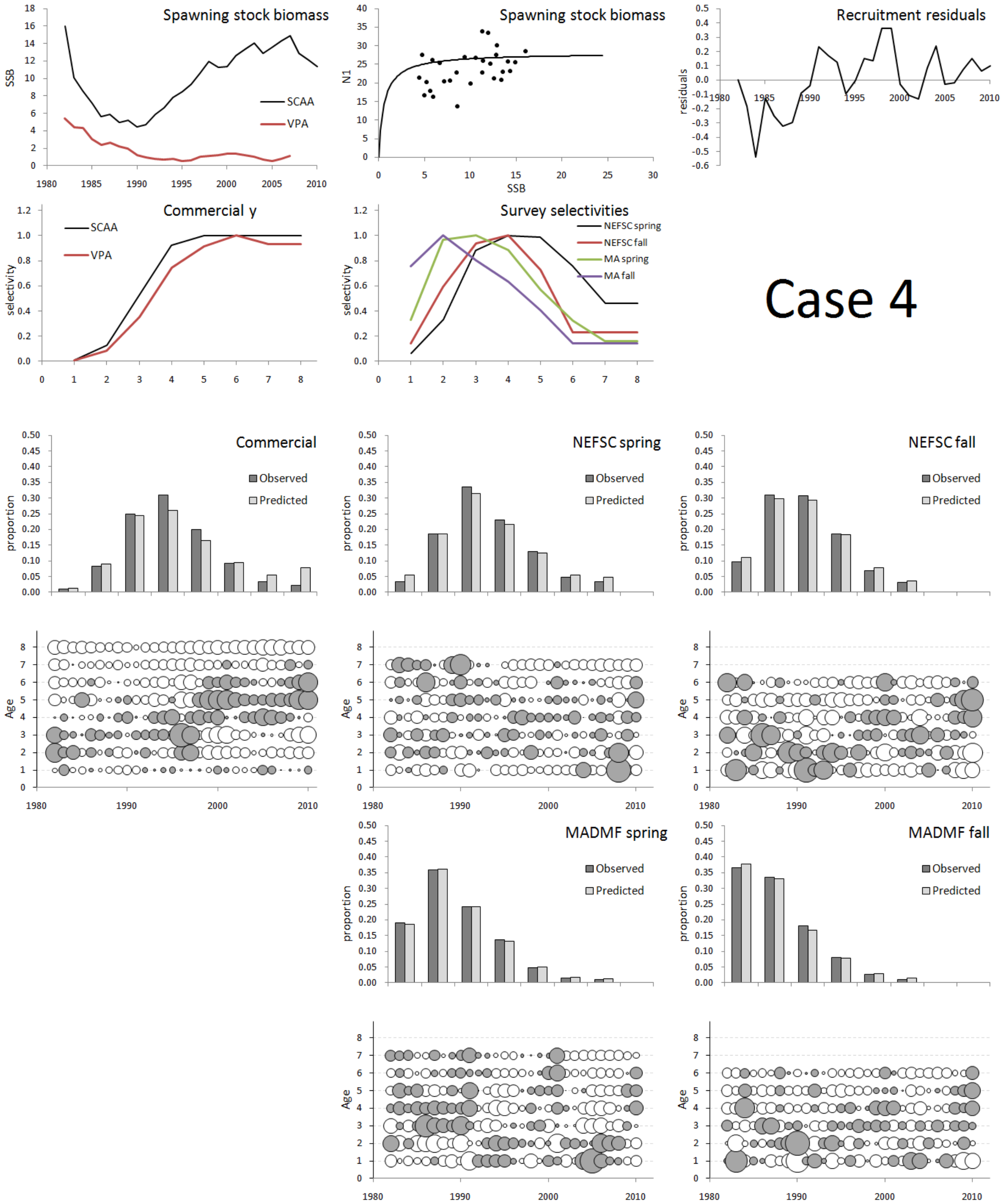

Fig. 7: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 4 (M = 0.4). The fits to the commercial and survey CAA are also shown.

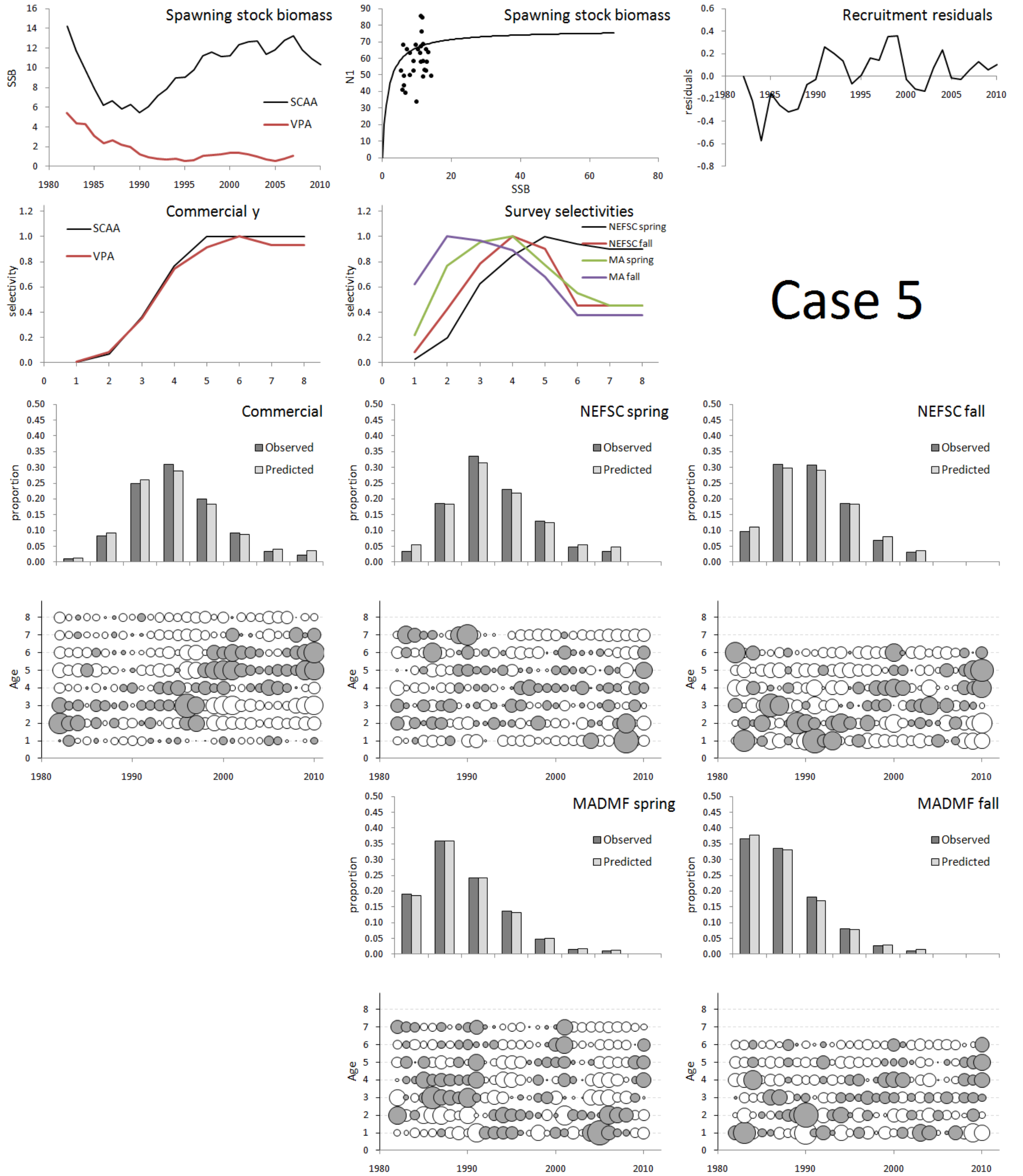

Fig. 8: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 5 (*M* estimated at 0.6). The fits to the commercial and survey CAA are also shown.

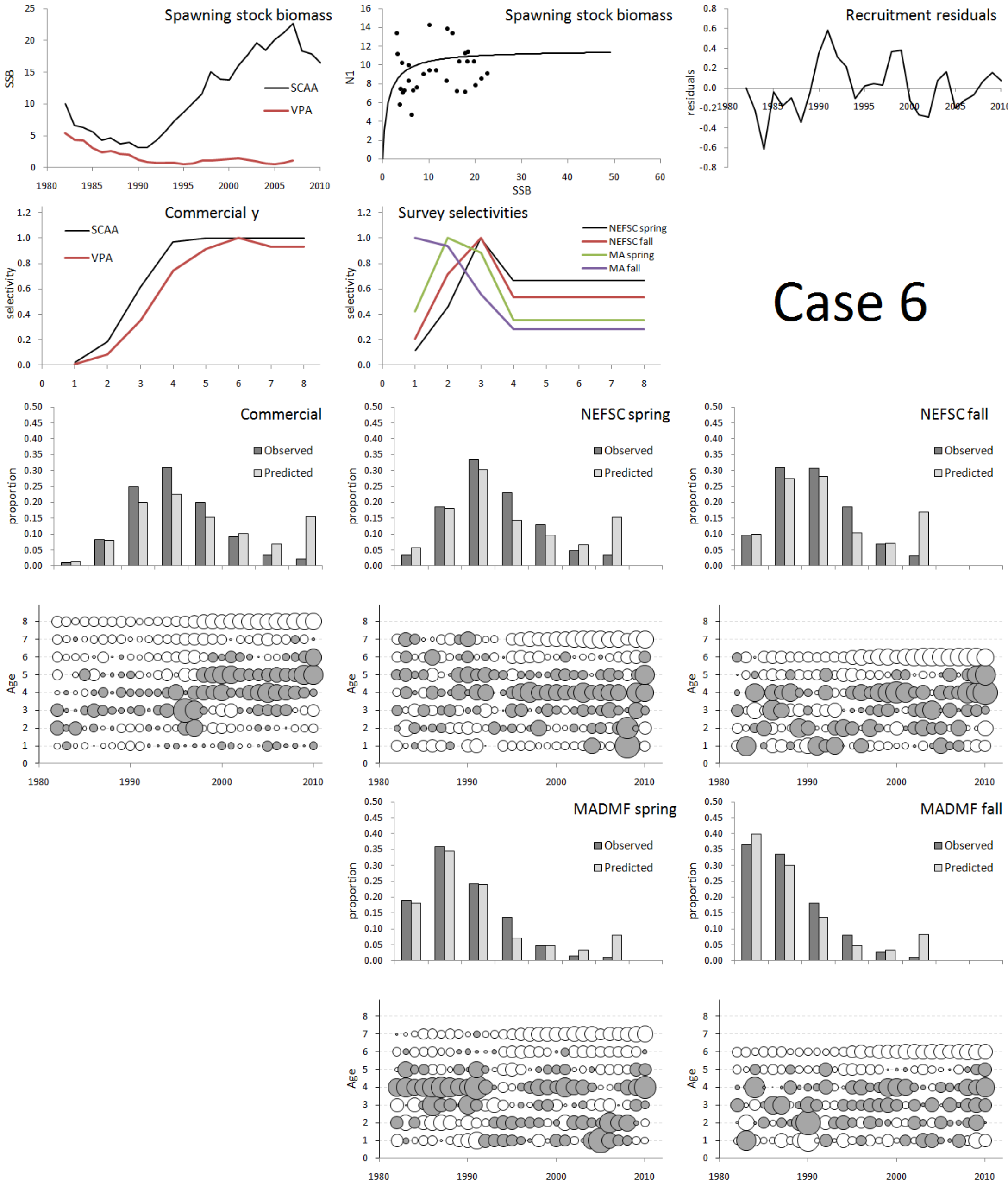

Fig. 9: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 6 (flat selectivities for all surveys). The fits to the commercial and survey CAA are also shown.

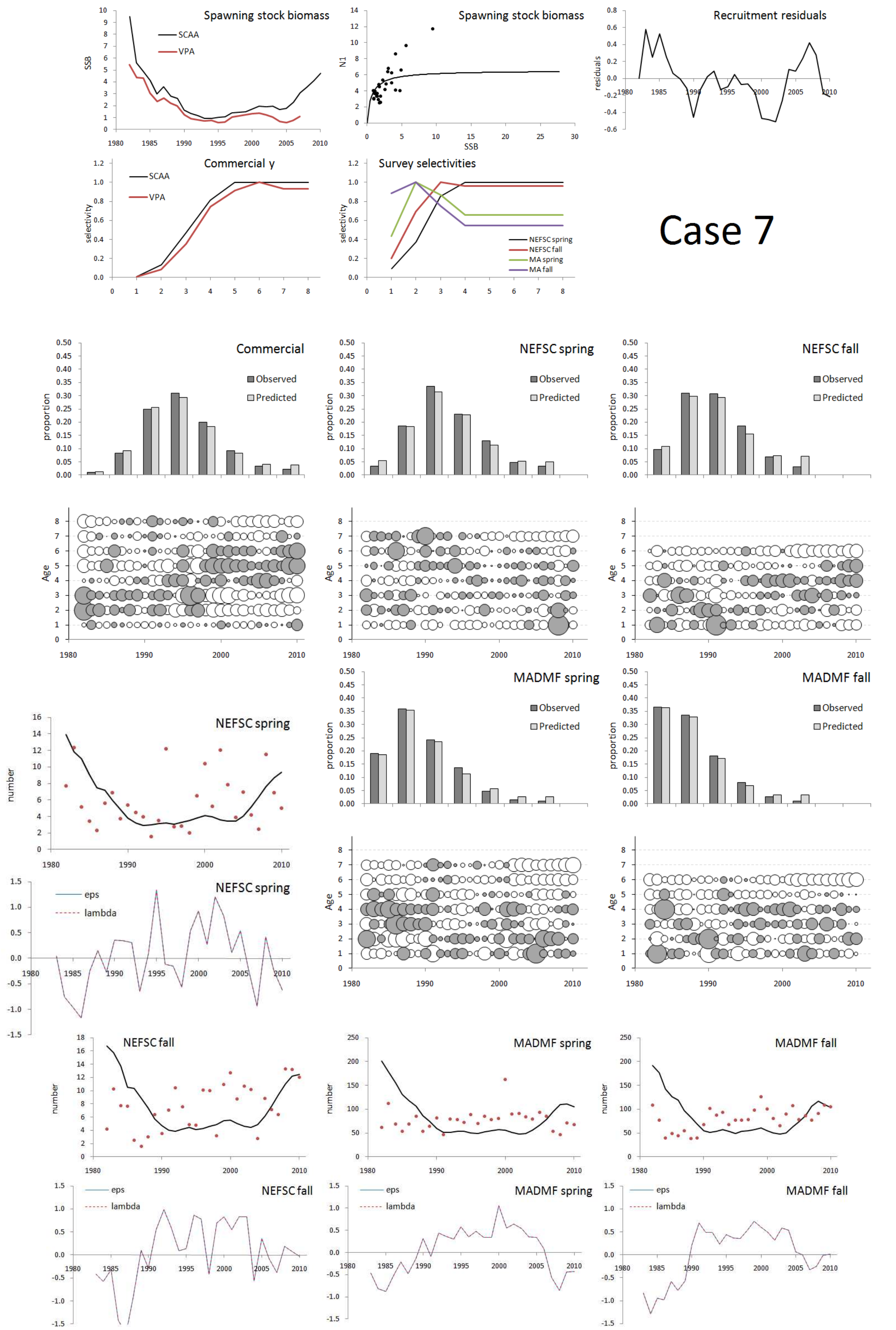

Fig. 10: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 7 (survey CAA data upweighted in the likelihood). The fits to the commercial and survey CAA and to the survey indices are also shown.

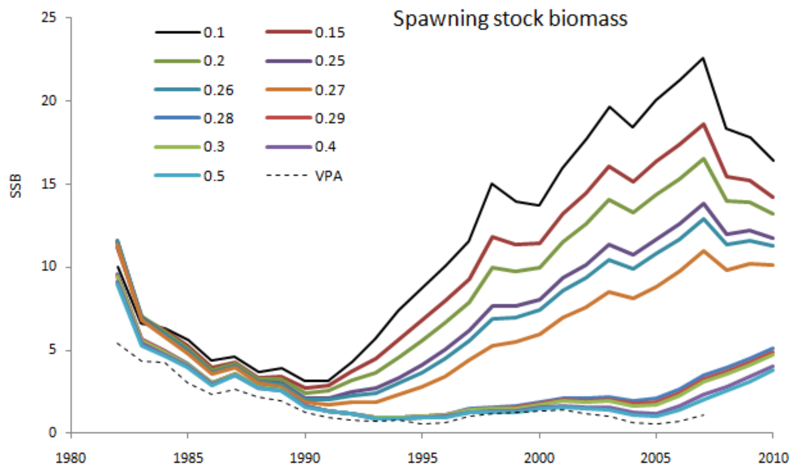

Fig. 11: Spawning stock biomass trajectories for Case 7 with different weightings (w^{CAA}) for the survey CAA data in the likelihood. The VPA results are also shown (Nitschke, 2008).

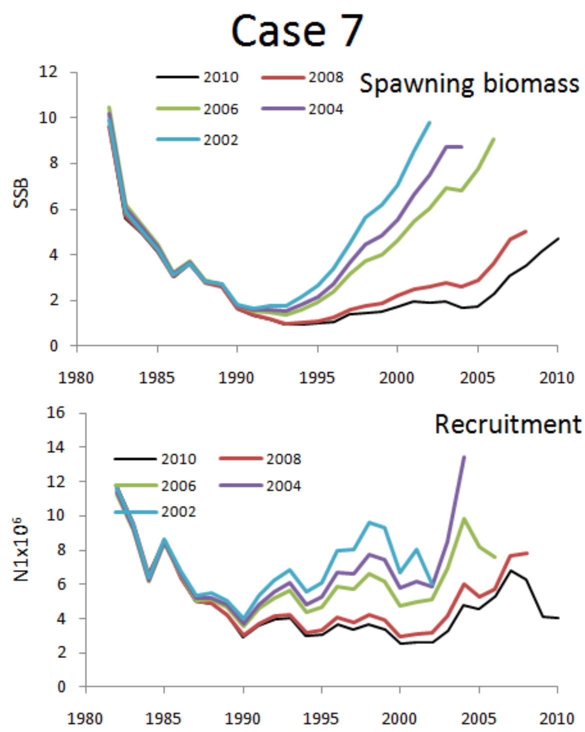

Fig. 12: Retrospective analysis of spawning biomass and recruitment for Case 7.

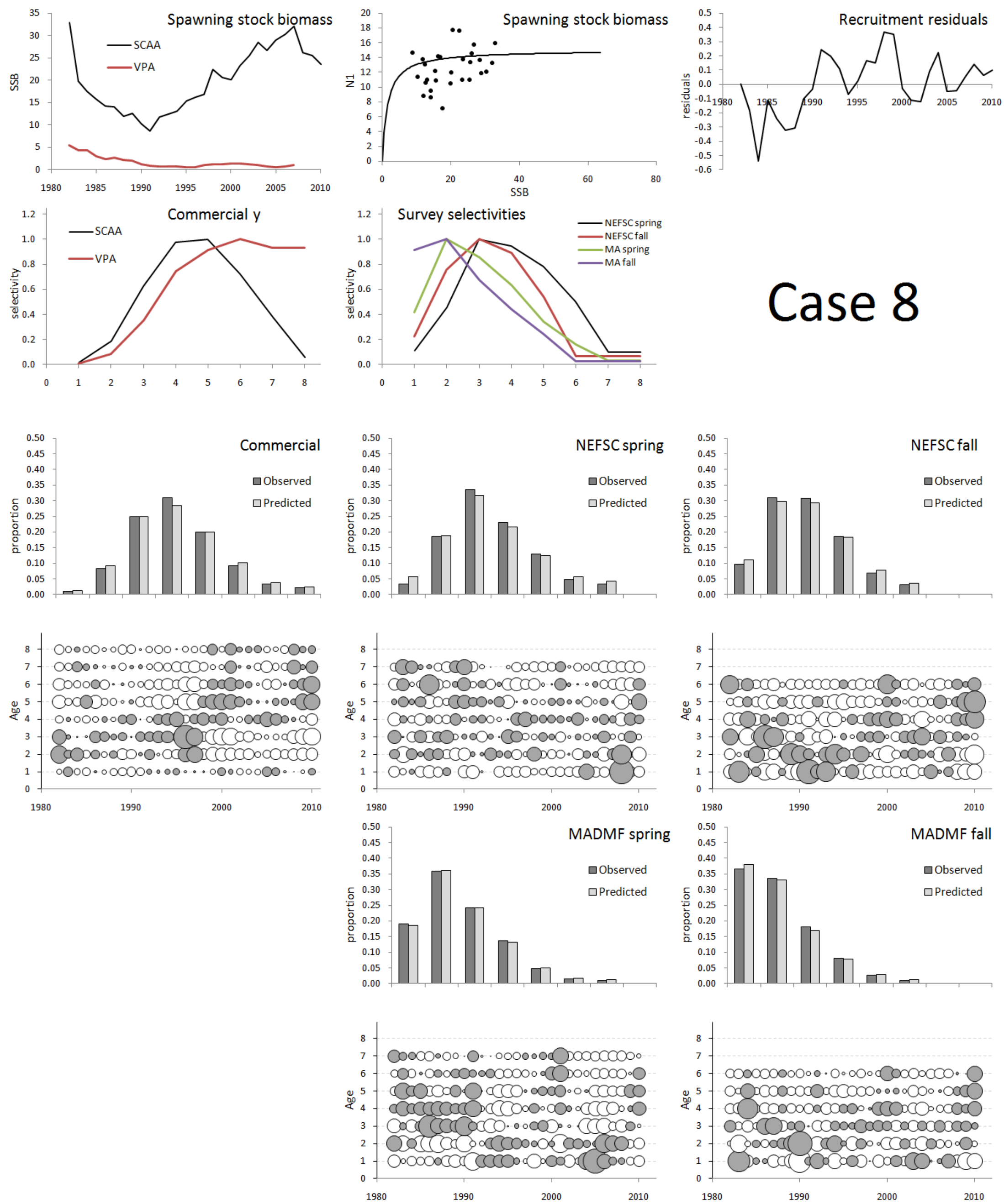

Fig. 13: Spawning stock biomass trajectories, stock-recruit relationship, recruitment residuals and selectivities for Case 8 (commercial selectivity domed). The fits to the commercial and survey CAA are also shown.

APPENDIX A – Data

Table A1: Total catch (metric tons) for Gulf of Maine winter flounder (Nitschke, 2011).

Year	Total catch (mt)	Year	Total catch (mt)
1982	6178	1997	660
1983	3035	1998	689
1984	2883	1999	399
1985	3327	2000	587
1986	1692	2001	756
1987	2713	2002	740
1988	1927	2003	801
1989	2315	2004	687
1990	1511	2005	387
1991	1136	2006	247
1992	947	2007	297
1993	778	2008	405
1994	640	2009	367
1995	776	2010	195
1996	674		

Table A2. Catch at age matrix (000s) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	112	2883	5267	3487	1402	617	276	104
1983	135	915	1955	1838	857	362	158	133
1984	23	916	2077	1901	856	348	312	225
1985	31	288	1598	2122	1925	398	218	136
1986	49	505	928	851	373	353	102	62
1987	53	486	2004	1224	794	311	138	136
1988	23	471	1188	1177	361	248	123	89
1989	24	238	1353	1478	777	213	51	38
1990	9	263	836	1008	504	172	49	29
1991	18	304	864	610	234	119	57	41
1992	44	390	734	585	207	72	28	18
1993	28	197	758	669	149	69	9	3
1994	18	81	503	623	152	44	16	7
1995	27	70	335	765	392	122	18	18
1996	16	217	733	350	79	13	7	11
1997	19	286	592	449	117	22	8	12
1998	20	64	264	474	333	115	41	12
1999	7	13	79	240	227	103	29	28
2000	17	29	89	394	380	142	34	15
2001	13	21	84	384	432	242	101	56
2002	4	31	167	383	408	187	65	34
2003	9	41	168	390	419	247	78	46
2004	10	89	202	345	250	195	64	47
2005	15	54	165	259	139	55	17	16
2006	7	14	104	160	89	27	14	12
2007	5	23	93	193	135	57	16	9
2008	8	21	75	181	205	116	66	40
2009	6	22	54	146	219	144	41	26
2010	6	10	20	70	120	84	40	16

Table A3a. Total fishery mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.084	0.224	0.375	0.487	0.595	0.802	0.943	2.037
1983	0.123	0.257	0.358	0.502	0.644	0.795	0.946	1.164
1984	0.082	0.264	0.306	0.401	0.543	0.708	0.855	1.115
1985	0.043	0.174	0.312	0.447	0.584	0.809	0.927	1.122
1986	0.050	0.309	0.410	0.510	0.664	0.813	1.005	1.221
1987	0.035	0.259	0.392	0.527	0.690	0.858	1.070	1.284
1988	0.038	0.396	0.426	0.487	0.648	0.754	1.022	1.204
1989	0.040	0.229	0.427	0.582	0.629	1.004	1.175	1.397
1990	0.034	0.301	0.421	0.538	0.625	0.763	0.979	1.226
1991	0.038	0.277	0.451	0.583	0.599	0.695	0.744	0.929
1992	0.027	0.227	0.406	0.533	0.638	0.788	1.051	1.465
1993	0.028	0.238	0.367	0.439	0.645	0.667	1.115	1.453
1994	0.028	0.090	0.369	0.470	0.610	0.747	1.068	1.229
1995	0.038	0.105	0.341	0.421	0.535	0.635	0.833	1.563
1996	0.028	0.321	0.454	0.541	0.643	0.722	0.767	1.321
1997	0.038	0.240	0.421	0.512	0.628	0.889	0.784	0.921
1998	0.029	0.202	0.392	0.472	0.615	0.755	0.910	1.557
1999	0.039	0.114	0.377	0.487	0.542	0.665	0.838	1.219
2000	0.041	0.146	0.353	0.473	0.581	0.698	0.817	1.03
2001	0.034	0.115	0.319	0.448	0.538	0.693	0.852	1.194
2002	0.050	0.182	0.415	0.496	0.593	0.705	0.882	1.285
2003	0.035	0.156	0.366	0.482	0.560	0.704	0.889	1.436
2004	0.035	0.207	0.352	0.494	0.628	0.763	0.923	1.269
2005	0.042	0.172	0.380	0.505	0.669	0.895	1.038	1.346
2006	0.048	0.138	0.404	0.535	0.715	0.811	1.032	1.365
2007	0.043	0.200	0.386	0.487	0.639	0.815	0.964	1.476
2008	0.046	0.153	0.375	0.474	0.549	0.671	0.784	1.097
2009	0.043	0.155	0.329	0.449	0.565	0.678	0.692	1.115
2010	0.031	0.065	0.314	0.427	0.507	0.604	0.717	0.947

Table A3b. Spawning stock biomass mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.048	0.177	0.324	0.424	0.515	0.738	0.870	2.037
1983	0.084	0.147	0.283	0.434	0.560	0.688	0.871	1.164
1984	0.056	0.180	0.280	0.379	0.522	0.675	0.825	1.115
1985	0.016	0.119	0.287	0.370	0.484	0.663	0.810	1.122
1986	0.022	0.115	0.267	0.399	0.545	0.689	0.902	1.221
1987	0.010	0.114	0.348	0.465	0.593	0.755	0.933	1.284
1988	0.016	0.118	0.332	0.437	0.584	0.721	0.936	1.204
1989	0.015	0.093	0.411	0.498	0.554	0.807	0.941	1.397
1990	0.012	0.110	0.311	0.479	0.603	0.693	0.991	1.226
1991	0.016	0.097	0.368	0.495	0.568	0.659	0.753	0.929
1992	0.009	0.093	0.335	0.490	0.610	0.687	0.855	1.465
1993	0.016	0.080	0.289	0.422	0.586	0.652	0.937	1.453
1994	0.015	0.050	0.296	0.415	0.518	0.694	0.844	1.229
1995	0.013	0.054	0.175	0.394	0.501	0.622	0.789	1.563
1996	0.010	0.110	0.218	0.430	0.520	0.622	0.698	1.321
1997	0.017	0.082	0.368	0.482	0.583	0.756	0.752	0.921
1998	0.015	0.088	0.307	0.446	0.561	0.689	0.899	1.557
1999	0.020	0.058	0.276	0.437	0.506	0.640	0.795	1.219
2000	0.025	0.076	0.201	0.422	0.532	0.615	0.737	1.03
2001	0.015	0.069	0.216	0.398	0.505	0.635	0.771	1.194
2002	0.028	0.079	0.219	0.398	0.515	0.616	0.782	1.285
2003	0.014	0.088	0.258	0.447	0.527	0.646	0.792	1.436
2004	0.016	0.085	0.234	0.425	0.550	0.654	0.806	1.269
2005	0.023	0.078	0.281	0.422	0.575	0.750	0.890	1.346
2006	0.024	0.076	0.264	0.451	0.601	0.737	0.961	1.365
2007	0.023	0.098	0.231	0.444	0.585	0.763	0.884	1.476
2008	0.025	0.081	0.274	0.428	0.517	0.655	0.799	1.097
2009	0.035	0.084	0.224	0.410	0.518	0.610	0.681	1.115
2010	0.018	0.053	0.223	0.369	0.477	0.588	0.700	0.969

Table A3c. January-1 mean weights-at-age (kg) for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	0.048	0.177	0.324	0.424	0.515	0.738	0.870	2.037
1983	0.084	0.147	0.283	0.434	0.560	0.688	0.871	1.164
1984	0.056	0.180	0.280	0.379	0.522	0.675	0.825	1.115
1985	0.016	0.119	0.287	0.370	0.484	0.663	0.810	1.122
1986	0.022	0.115	0.267	0.399	0.545	0.689	0.902	1.221
1987	0.010	0.114	0.348	0.465	0.593	0.755	0.933	1.284
1988	0.016	0.118	0.332	0.437	0.584	0.721	0.936	1.204
1989	0.015	0.093	0.411	0.498	0.554	0.807	0.941	1.397
1990	0.012	0.110	0.311	0.479	0.603	0.693	0.991	1.226
1991	0.016	0.097	0.368	0.495	0.568	0.659	0.753	0.929
1992	0.009	0.093	0.335	0.490	0.610	0.687	0.855	1.465
1993	0.016	0.080	0.289	0.422	0.586	0.652	0.937	1.453
1994	0.015	0.050	0.296	0.415	0.518	0.694	0.844	1.229
1995	0.013	0.054	0.175	0.394	0.501	0.622	0.789	1.563
1996	0.010	0.110	0.218	0.430	0.520	0.622	0.698	1.321
1997	0.017	0.082	0.368	0.482	0.583	0.756	0.752	0.921
1998	0.015	0.088	0.307	0.446	0.561	0.689	0.899	1.557
1999	0.020	0.058	0.276	0.437	0.506	0.640	0.795	1.219
2000	0.025	0.076	0.201	0.422	0.532	0.615	0.737	1.03
2001	0.015	0.069	0.216	0.398	0.505	0.635	0.771	1.194
2002	0.028	0.079	0.219	0.398	0.515	0.616	0.782	1.285
2003	0.014	0.088	0.258	0.447	0.527	0.646	0.792	1.436
2004	0.016	0.085	0.234	0.425	0.550	0.654	0.806	1.269
2005	0.023	0.078	0.281	0.422	0.575	0.750	0.890	1.346
2006	0.024	0.076	0.264	0.451	0.601	0.737	0.961	1.365
2007	0.023	0.098	0.231	0.444	0.585	0.763	0.884	1.476
2008	0.025	0.081	0.274	0.428	0.517	0.655	0.799	1.097
2009	0.035	0.084	0.224	0.410	0.518	0.610	0.681	1.115
2010	0.018	0.053	0.223	0.369	0.477	0.588	0.700	0.969

Table A4: Proportion mature-at-age for Gulf of Maine winter flounder (Nitschke, 2011).

1	2	3	4	5	6	7	8+
0.00	0.04	0.35	0.88	0.99	1.00	1.00	1.00

Table A5: Survey data for Gulf of Maine winter flounder (Nitschke, 2011).

	NEFSC spring	NEFSC fall	MADMF spring	MADMF fall
Month	4	10	5	5
Ages	1-8+	1-8+	1-8+	1-8+
1982	7.67	4.201	61.61	108.20
1983	12.367	10.304	112.49	76.66
1984	5.155	7.732	68.95	39.54
1985	3.469	7.638	54.21	48.68
1986	2.342	2.502	68.98	44.65
1987	5.609	1.605	85.18	54.43
1988	6.897	3	54.04	38.42
1989	3.717	6.402	64.70	39.25
1990	5.415	3.527	82.13	67.66
1991	4.517	7.035	46.63	101.72
1992	3.932	10.447	79.00	87.58
1993	1.556	7.559	78.02	93.53
1994	3.481	4.87	72.58	67.79
1995	12.185	4.765	89.36	76.74
1996	2.736	10.099	70.49	77.01
1997	2.806	10.008	85.40	78.40
1998	2.001	3.218	77.77	98.45
1999	6.51	10.921	80.78	125.74
2000	10.383	12.705	162.19	99.95
2001	5.242	8.786	89.74	81.07
2002	12.066	10.691	91.08	65.81
2003	7.839	10.182	83.69	90.48
2004	3.879	2.763	79.12	107.59
2005	6.92	8.807	94.04	78.59
2006	4.173	7.117	85.55	86.99
2007	2.5	6.378	53.58	76.67
2008	11.543	13.319	46.86	90.92
2009	6.846	13.176	71.32	109.00
2010	5.023	12.046	68.24	104.67

Table A6a: NEFSC spring survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	92.06	1075.75	1900.83	474.97	570.39	62.23	0.00	116.13
1983	229.12	401.15	2462.32	1546.13	918.71	560.03	654.61	149.20
1984	117.19	640.90	901.25	554.72	315.92	92.45	154.91	107.51
1985	3.36	289.22	823.35	330.86	329.13	49.86	86.58	28.77
1986	17.96	433.05	217.59	308.31	54.06	202.14	59.71	18.13
1987	81.71	891.46	1480.03	368.52	187.09	32.68	66.93	30.61
1988	332.32	610.85	1895.85	706.61	190.39	82.21	29.61	12.03
1989	0.00	260.85	636.15	586.17	366.68	64.58	96.26	69.40
1990	12.82	448.05	1042.22	522.76	487.56	235.44	4.20	277.58
1991	34.70	619.24	985.48	540.22	285.31	54.34	8.62	0.00
1992	153.40	577.22	533.12	529.81	270.53	96.15	34.81	5.71
1993	0.00	250.89	345.92	148.98	98.55	9.51	17.18	0.00
1994	13.49	403.22	645.77	470.88	310.94	103.70	0.00	0.00
1995	161.96	1226.23	3090.63	1658.95	493.72	49.30	138.51	0.00
1996	39.12	180.65	538.43	509.44	240.20	14.83	8.28	0.00
1997	28.93	284.63	413.07	499.20	249.38	59.71	18.08	17.18
1998	58.31	328.96	335.67	269.41	118.20	5.32	0.00	3.97
1999	172.59	654.05	1276.04	940.03	398.47	183.79	18.13	0.00
2000	85.68	859.33	2136.77	1399.95	900.91	330.30	65.87	32.12
2001	39.40	289.84	787.19	833.64	462.88	333.04	121.50	66.15
2002	89.04	914.29	1670.48	1999.27	1280.52	513.98	188.71	96.54
2003	65.42	356.38	1203.79	1294.40	895.20	430.20	77.06	64.47
2004	299.30	466.35	494.33	414.36	186.42	209.70	100.51	0.00
2005	64.08	866.55	1278.73	789.99	438.54	288.94	102.41	43.15
2006	35.37	126.48	1065.67	664.02	332.99	85.01	25.86	0.00
2007	70.18	287.04	349.44	418.44	217.81	38.73	17.52	0.00
2008	1524.69	2335.33	1503.76	654.45	358.68	73.93	9.29	0.00
2009	33.63	618.24	1489.88	1100.43	474.02	69.00	41.86	4.20
2010	20.32	158.60	819.32	752.16	685.34	316.42	39.51	19.59

Table A6b: NEFSC fall survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	166.83	636.37	971.76	230.63	117.64	46.56	153.90	27.09
1983	1198.31	2012.87	1743.29	564.01	151.83	59.60	36.66	0.00
1984	250.50	1310.80	935.83	1216.16	332.60	124.30	61.90	95.31
1985	728.04	1533.42	1075.86	641.74	182.78	52.33	60.50	0.00
1986	16.85	403.67	645.88	272.60	30.61	11.42	0.00	18.92
1987	43.43	255.37	474.91	106.11	10.63	0.00	0.00	7.84
1988	237.79	572.96	338.53	394.66	85.91	30.89	18.13	0.00
1989	259.11	2015.33	792.01	419.62	52.66	37.72	0.00	6.27
1990	53.22	1039.03	610.79	221.90	30.61	12.03	6.04	0.00
1991	1452.33	1585.02	607.55	215.52	17.01	26.19	16.68	0.00
1992	1073.90	2072.97	1341.52	913.06	424.66	8.28	12.09	0.00
1993	927.61	1765.90	1015.75	385.09	130.45	5.65	0.00	0.00
1994	208.97	1288.30	846.18	354.03	22.05	5.65	0.00	0.00
1995	200.97	865.54	869.63	563.11	81.60	86.02	0.00	0.00
1996	987.88	1328.70	1440.52	1472.48	334.78	80.81	0.00	0.00
1997	231.19	2418.72	1787.72	823.63	320.68	18.80	0.00	0.00
1998	124.41	498.25	630.83	436.13	77.96	33.24	0.00	0.00
1999	453.37	1552.06	2040.57	1595.32	381.06	81.32	8.00	0.00
2000	349.16	1134.00	2238.63	1980.58	780.70	535.30	91.73	0.00
2001	200.58	927.38	1451.49	1564.59	539.55	203.93	23.73	5.93
2002	374.90	1535.49	1921.20	1317.96	698.88	109.52	11.70	13.32
2003	310.55	1779.16	1912.69	1004.00	562.33	111.15	18.24	0.00
2004	162.91	510.73	596.58	107.28	93.68	16.68	36.82	21.71
2005	699.89	1714.19	1313.43	751.88	327.61	54.51	30.67	36.49
2006	361.92	589.64	1718.72	758.82	490.53	22.22	41.25	0.00
2007	434.28	1174.69	760.78	774.43	315.69	109.30	0.00	0.00
2008	257.83	1391.66	2267.90	1873.80	1145.37	485.99	0.00	31.56
2009	80.31	1558.66	2246.74	1757.39	1320.20	382.96	20.99	6.16
2010	21.77	576.66	1908.49	2241.48	1448.19	307.47	190.11	46.84

Table A6c: Massachusetts spring survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	1658.16	6361.20	1836.79	1947.30	419.94	111.03	354.05	14.45
1983	3175.87	6278.94	6590.91	4132.55	1984.33	537.40	211.29	270.09
1984	1309.41	5596.43	3427.98	2620.57	907.69	55.09	216.20	82.31
1985	2136.45	1672.36	3405.67	2706.69	1008.58	146.04	49.75	23.13
1986	2295.95	3780.69	5293.35	2403.82	349.06	43.77	16.58	39.63
1987	3593.98	3635.32	7003.94	2556.53	169.83	334.75	85.54	182.30
1988	1650.94	3169.97	3910.95	2118.61	170.88	56.20	13.38	45.67
1989	2065.50	4331.80	3825.33	2021.71	823.53	166.82	28.18	75.85
1990	3265.41	4208.90	6244.24	2282.77	471.16	312.09	108.94	38.78
1991	984.48	3502.56	2550.99	1649.27	683.00	110.68	53.05	103.32
1992	4447.96	6709.79	2828.85	1562.76	476.95	173.95	39.07	48.72
1993	4039.88	7104.62	2796.09	1358.03	435.10	264.34	49.42	38.14
1994	3310.73	7781.04	3075.77	1000.02	169.00	26.08	36.60	21.32
1995	4474.23	7433.04	4751.29	1288.26	294.75	117.69	32.78	32.10
1996	3212.26	5900.09	3246.03	1531.28	419.30	165.27	42.62	17.48
1997	3199.00	7320.28	3758.75	1838.01	1030.33	220.03	134.86	105.44
1998	2106.16	5871.00	4368.13	2399.67	833.70	248.73	169.48	37.69
1999	3181.83	5455.98	4427.92	2024.19	1045.28	268.24	134.22	116.41
2000	5997.82	13694.80	6182.92	3527.20	2279.87	1248.05	381.06	128.22
2001	3038.06	2156.92	5664.30	4172.67	1605.77	1067.98	528.95	268.38
2002	1891.06	6962.83	4197.19	3884.95	1482.33	263.39	94.94	2.54
2003	3172.08	6338.79	3738.01	2264.07	1262.44	353.59	108.26	18.25
2004	5569.03	6461.18	1671.73	1208.82	911.14	381.53	70.33	37.83
2005	7223.85	8227.77	2691.42	870.50	305.58	57.54	7.07	5.98
2006	4302.98	8758.47	2948.09	1189.54	331.10	70.95	26.99	10.00
2007	2302.69	4893.18	2081.50	1254.46	398.77	94.72	13.44	8.78
2008	2072.08	4453.26	1452.02	1133.50	417.03	93.32	27.65	13.15
2009	2115.48	4797.99	3989.67	1995.28	1290.75	364.95	103.95	45.75
2010	1832.75	3890.83	3509.46	2881.02	1191.91	539.98	194.14	28.37

Table A6d: Massachusetts fall survey catch-at-age data for Gulf of Maine winter flounder (Nitschke, 2011).

	1	2	3	4	5	6	7	8+
1982	9419.66	7334.77	4407.41	810.44	147.11	46.47	20.97	20.49
1983	8909.33	3589.56	2474.79	572.97	229.08	14.04	1.57	13.73
1984	1715.39	2715.77	1434.21	1640.61	449.45	121.07	53.19	8.84
1985	4897.43	2810.59	1411.26	638.41	160.34	38.18	18.47	8.58
1986	3738.84	3230.42	1830.09	319.49	43.50	0.00	0.00	21.28
1987	3325.39	4315.82	3177.09	249.97	9.26	15.26	23.15	24.37
1988	2789.74	3194.71	935.84	672.78	185.46	99.42	34.14	0.00
1989	2794.61	3609.79	1286.50	292.09	65.44	22.56	10.62	10.62
1990	1801.47	9234.03	2325.97	532.45	48.99	0.00	0.00	7.15
1991	10419.18	6327.18	2900.09	604.12	8.99	70.76	26.93	0.00
1992	9367.51	4532.62	1891.98	1295.20	675.75	67.61	21.44	57.21
1993	7523.20	7769.60	2747.19	747.78	331.78	65.28	21.44	21.46
1994	2918.62	6752.77	3179.56	1042.23	47.30	0.00	5.38	5.46
1995	5419.59	4880.19	3341.76	1844.44	133.38	76.55	10.93	34.33
1996	7524.31	3352.89	2575.63	1884.97	265.84	92.20	4.78	4.78
1997	4814.83	6418.38	3467.90	1051.98	317.18	14.93	0.00	0.00
1998	8603.17	5826.52	3839.39	1490.50	272.57	155.48	15.22	20.72
1999	7886.42	8744.32	4914.05	3132.82	783.29	126.35	15.71	26.70
2000	5374.73	5949.39	4929.16	2799.49	787.06	559.15	132.26	0.00
2001	6126.97	3548.97	2918.46	2868.44	787.16	327.31	37.26	22.14
2002	3776.65	4675.99	2613.62	1531.07	686.63	93.81	16.02	15.98
2003	10176.70	4439.24	2015.05	979.79	458.87	61.36	25.65	0.00
2004	11968.46	4887.41	3668.01	544.31	411.16	145.38	127.40	16.35
2005	5186.41	7090.88	2258.30	1090.90	435.57	40.02	31.92	38.62
2006	6248.84	4626.76	4821.72	1472.35	616.90	11.46	39.26	9.48
2007	7590.02	4281.27	1958.21	1358.60	422.81	107.75	14.14	2.76
2008	5706.92	5761.15	3592.51	2148.16	1096.47	307.90	0.00	35.38
2009	4210.96	9523.65	4708.05	2278.75	1288.61	365.94	16.37	34.91
2010	4923.51	6220.98	4294.42	3028.39	1596.86	618.12	341.24	66.76

Appendix B - The Age-Structured Production Model

The model used for these assessments is an Age-Structured Production Model (ASPM) (e.g. Hilborn, 1990). Models of this type fall within the more general class of Statistical Catch-at-Age Analyses. The approach used in an ASPM assessment involves constructing an age-structured model of the population dynamics and fitting it to the available abundance indices by maximising the likelihood function. The model equations and the general specifications of the model are described below, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \tag{B1}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_{y,a}/2} - C_{y,a}\right) e^{-M_{y,a}/2} \qquad \text{for } 1 \le a \le m-2 \tag{B2}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{y,m-1}/2} - C_{y,m-1}\right) e^{-M_{y,m-1}/2} + \left(N_{y,m}\, e^{-M_{y,m}/2} - C_{y,m}\right) e^{-M_{y,m}/2} \tag{B3}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 1-year-old fish) at the start of year *y*,

$M_{y,a}$ denotes the natural mortality rate for fish of age *a* in year *y*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (age 8 here) (taken to be a plus-group).

B.1.2. Recruitment

The number of recruits at the start of year *y* is assumed to follow a Beverton-Holt stock-recruit curve, and allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_R^1)^2/2)} \tag{B4}$$

where

α and β are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation $\sigma_R = 0.5$

B_y^{sp} is the spawning biomass, computed as:

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{strt} N_{y,a} e^{-M_{y,a}\delta} \qquad \text{(B5)}$$

where

$w_{y,a}^{sp}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature,

δ is the proportion of the natural mortality that occurs before spawning (0.25 here).

B.1.3. Total catch and catches-at-age

The catch by mass in year *y* is given by:

$$C_y = \sum_{a=1}^{m} w_{y,a}^{mid} C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{mid} N_{y,a} e^{-M_{y,a}/2} S_{y,a} F_y \qquad \text{(B6)}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y*,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a}$ = 1, the age-class *a* is said to be fully selected, and

F_y is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mid-year mass-at-age (using the individual weights of the landed fish) and applying natural and fishing mortality for half the year:

$$B_y^{ex} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a} N_{y,a} e^{-M_{y,a}/2} (1 - S_{y,a} F_y / 2) \qquad \text{(B7)}$$

For survey estimates (in numbers):

$$N_y^{surv,i} = \sum_{a=1}^{m} S_a^i N_{y,a} e^{-M_{y,a}\frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y \frac{\varpi^1}{12}\right) \qquad \text{(B8)}$$

where

S_a^i is the survey selectivity for age *a* and survey *i*,

ϖ^i is the month in which survey *i* has taken place.

B.1.4. Initial conditions

For the first year (y_0) considered in the model therefore, the stock is assumed to be at a level $B_{y_0}^{sp}$ (estimated in the model fitting procedure), with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \qquad \text{for } 1 \le a \le m \qquad \text{(B9)}$$

where

$$N_{start,1} = 1 \qquad \text{(B10)}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{y_0,a-1}} (1 - \phi S_{y_0,a-1}) \qquad \text{for } 2 \le a \le m-1 \qquad \text{(B11)}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{y_0,m-1}} (1 - \phi S_{y_0,m-1}) \Big/ (1 - e^{-M_{y_0,m}} (1 - \phi S_{y_0,m})) \qquad \text{(B12)}$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

B.2. The (penalised) likelihood function

The model is fit to survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, the fishing selectivities, the annual catches or natural mortality, facilitated through the incorporation of the penalty functions described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell n L$) are as follows.

B.2.1. Survey abundance data

The likelihood is calculated assuming that an observed survey index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \qquad \text{(B13)}$$

where

I_y^i is the survey index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}^i N_y^{surv,i}$ is the corresponding model estimate, where $N_y^{surv,i}$ is the model estimate, given by equation (B8),

$\hat{q}^i$ is the constant of proportionality (catchability) for index *i*, and

ε_y^i from $N\left(0, \left(\sigma_y^i\right)^2\right)$.

For these analyses, selectivities are estimated as detailed in section B.3.1 below.

The contribution of the survey abundance data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{survey} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \quad \text{(B14)}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*.

Homoscedasticity of residuals is assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I_y^i) - \ell\text{n}(q^i N_y^{surv,i})\right)^2} \quad \text{(B15)}$$

where

n_i is the number of data points for survey index *i*.

The catchability coefficient q^i for survey index *i* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln N_y^{surv,i}\right) \quad \text{(B16)}$$

To allow for first order serial correlation between the survey residuals, a serial correlation coefficient ρ^i would be estimated for each survey index:

$$\varepsilon_y^i = \lambda_y^i - \rho\lambda_{y-1}^i \quad \text{(B17)}$$

where

$$\lambda_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right)$$

and the summation in equation (B.16) extends over one less year.

B.2.2. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n}\, L^{CAA} = w^{CAA} \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2\right]$$

(B18)

where

w^{comCAA} is a multiplicative factor to downweight the commercial CAA likelihood,

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*, where

$$\hat{C}_{y,a} = N_{y,a}\ e^{-M_{y,a}/2}\ S_{y,a}\ F_y \tag{B19}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a p_{y,a} \left(\ell n\ p_{y,a} - \ell n\ \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \tag{B20}$$

B.2.3. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age (thus they are also weighted by a factor $w^{survCAA}$), assuming an adjusted log-normal error distribution (equation (B18)) where:

$p_{y,a} = C^{surv}_{y,a} / \sum_{a'} C^{surv}_{y,a'}$ is the observed proportion of fish of age *a* in year *y*, with

$$C^{surv,i}_{y,a} = S^i_a N_{y,a} e^{-M_{y,a}\frac{\varpi^1}{12}} \left(1 - S_{y,a} F_y \frac{\varpi^1}{12}\right) \tag{B21}$$

$\hat{p}_{y,a}$ is the expected proportion of fish of age *a* in year *y* in the survey.

B.2.4. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{SRpen} = \sum_{y=y1}^{1988} \left[\varepsilon_y^2 / 2\left(\sigma_R^1\right)^2\right] + \sum_{1989}^{y2} \left[\varepsilon_y^2 / 2\left(\sigma_R^2\right)^2\right] \tag{B22}$$

where

ε_y from $N\left(0, \left(\sigma_R\right)^2\right)$

B.3. Model parameters

B.3.1. Fishing selectivity-at-age:

The commercial selectivity is estimated separately for ages 1 to 4 and is assumed to be flat for ages 5 and above (except for case 8) for which selectivity is also estimated separately for ages 5 and above. The survey fishing selectivities are estimated separately for ages 1 to a_{plus} (the plus group age) and flat thereafter. a_{plus}=7 for the spring surveys and 6 for the fall surveys.

B.3.2.: Other parameters reported in Table 1 and elsewhere

σ_R_out

$$\sigma_R\_\text{out} = \sum_{y=y1}^{y2} \left(\varsigma_y\right)^2 \Big/ \sum_{y=y1}^{y2} 1 \tag{B23}$$

where $y1$=1982 and $y2$=2010.

Calculation of MSY

The equilibrium catch for a fully selected fishing proportion *F* is calculated as:

$$C(F) = \sum_a w_a^{mid} S_a F N_a(F) e^{-(M_a/2)} \tag{B24}$$

where $w_a^{mid} = \sum_{y1=2006}^{2010} w_{y,a}^{mid} \Big/ 5$, $S_a = S_{2010,a}$ and $M_a = M_{2010,a}$

and where numbers-at-age *a* are given by:

$$N_a(F) = \begin{cases} R_1(F) & \text{for } a = 1 \\ N_{a-1}(F) e^{-M_{a-1}}\left(1 - S_{a-1}F\right) & \text{for } 1 < a < m \\ \dfrac{N_{m-1}(F) e^{-M_{m-1}}\left(1 - S_{m-1}F\right)}{\left(1 - e^{-M_m}\left(1 - S_m F\right)\right)} & \text{for } a = m \end{cases} \tag{B25}$$

where

$$R_1(F) = \frac{\alpha B^{sp}(F)}{\beta + B^{sp}(F)} \tag{B26}$$

The maximum of $C(F)$ is then found by searching over *F* to give F_{MSY}, with the associated spawning biomass and yield given by

$$B_{\text{MSY}}^{sp} = \sum_a f_a w_a^{strt} N_a\left(F_{\text{MSY}}\right) e^{-M_a \delta} \tag{B27}$$

$$MSY = \sum_a w_a^{mid} S_a F_{\text{MSY}} N_a\left(F_{\text{MSY}}\right) e^{-(M_a/2)} \tag{B28}$$

where $w_a^{strt} = \sum_{y1=2006}^{2010} w_{y,a}^{strt} \Big/ 5$ and $f_a = \sum_{y1=2006}^{2010} f_{y,a} \Big/ 5$

ADDITIONAL REFERENCE

Hilborn, R. 1990. Estimating the parameters of full age-structured models from catch and abundance data. International North Pacific Fisheries Commission Bulletin, 50: 207-213.