Initial Applications of Statistical Catch-at-Age Assessment Methodology to the Southern New England/Mid-Atlantic Winter Flounder Resource

Rebecca A. Rademeyer and Doug S. Butterworth

April 2010

Abstract

SCAA is applied to the SNE winter flounder resource, for which past VPA assessments have been plagued by retrospective patterns. It is shown that these patterns can be removed by the combination of allowance for autocorrelation in the residuals of survey series fits to underlying abundance trends, and an increase in natural mortality over time commencing sometime during the 1990s.

Introduction

This paper presents the results of some initial applications of Statistical Catch-at-Age methodology to data for the Southern New England/Mid-Atlantic winter flounder resource. This exercise has focused on attempts to remove the retrospective pattern evident in past assessments, which has been reduced though not eliminated by the approach of allowing an estimable change in survey catchability *q* between 1993 and 1994 (Terceiro, 2008).

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. They are as kindly provided by Mark Terceiro on 17 March. The aim of the paper is primarily methodological, and the work was carried out before subsequent updates to these data became available. The key run will be repeated with these updated data and the results presented in a subsequent document.

The details of the SCAA assessment methodology are provided in Appendix B.

Various approaches were attempted to remove the retrospective pattern which occurs in this assessment as for earlier VPAs (Terceiro, 2008). These included adding auto-correlation to the recruitment time series, which proved unsuccessful. The most successful approach was found to be the combination of allowing estimable auto-correlation in the residuals about the fits to each survey index and an increase in natural mortality over recent years, where best results were found to be provided by having this increase occur smoothly from M=0.3 prior to 1995 to 0.6 by 2005 and thereafter (the higher value was estimated in the model fit, subject to an upper bound of 0.6).

Results are illustrated in terms of three Base Cases, with the following characteristics:

	Base Case 1 (BC1)	Base Case 2 (BC2)	Base Case 3 (New Base Case, NBC)
Survey indices	split in 1993/1994, different q's estimated for the two periods but same selectivity	Not split	Not split
First order autocorrelation in the surveys	No	Estimated for each survey index	Estimated for each survey index
Natural mortality	0.2 throughout	0.2 throughout	0.3 pre-1995, linear increase from 0.3 in 1995 to 0.6* in 2005, 0.6* thereafter
Commercial selectivity	two periods: 1981-1993, 1994-2010	two periods: 1981-1993, 1994-2010	two periods: 1981-1993, 1994-2010
Starts in	1981	1981	1981

* Estimate hit upper bound

A series of variants of the NBC are also considered.

Results and Discussion

Results for the three Base Cases are given in Table 1. Retrospective patterns for spawning biomass and recruitment trajectories are compared in Fig. 1 for each of the three Base Cases. A full set of results are shown for the New Base Case in Figs 2-6, which show the estimated spawning biomass trend, the stock-recruitment relationship and residuals, the selectivity-at-age vectors, and the model fits to data for the survey indices of abundance and the various sources of proportions-at-age information. Fig. 7 plots the biomass loss to the increase in *M* in the NBC.

Tables 2 and 3 give results for variants to the NBC, with retrospective patterns plotted in Fig. 8 and the spawning biomass trajectories for variant 8 (starting in 1964) plotted in Fig. 9.

Results shown in Table 1 (Mohn's ρ) and in Fig. 1 show that the NBC approach of allowing for autocorrelation in the residuals for the survey indices, and for natural mortality to increase after 1995, effectively removes the retrospective pattern in this assessment.

The reason the autocorrelation (which of itself does little to remove this pattern) is required is evident from inspection of Fig. 5. Fig. 5a shows that with the surveys split in 1993/1994, the NEFSC fall survey fits the survey trend reasonably. However if the split is removed (Fig. 5b) the fit appears very poor, with clear systematic trends in residuals (Fig. 5b). If autocorrelation is taken into account though, the associated residuals no longer show these systematic trends, both in Fig. 5b and for the NBC in Fig. 5c. Hypothesising such auto-correlation is not unreasonable, as the environmental effects responsible for the fluctuations in survey *q* over time could well have some persistence and hence show positive autocorrelation. CAA residuals for the NBC (Fig. 6) appear acceptable.

Table 1 also shows that for the NBC, the variability in recruitment is more consistent over time (similar values of σ_R_out for earlier and later periods unlike for BC1 or BC2.

Table 2 compares results for different input values for natural mortality *M* and its changes over time. In log likelihood terms, the only (slight) improvement compared to the NBC is through commencing the increase in *M* in 1990 rather than 1995. Results in Table 3 show that replacing estimation of a separate autocorrelation parameter for each survey by a single estimable parameter is marginally preferable in AIC terms, but makes little difference to key results. Retrospective patterns are all minimal for these further scenarios (see Mohn's ρ values in Tables 2 and 3, and Fig. 8).

Fig. 2 compares the NBC estimate of the spawning biomass trajectory with that from the previous GARM assessment as provided by VPA. The trends are very similar, with the differences in scale attributable primarily for the higher (initial) *M* value of 0.3 for the NBC compared to 0.2 for that VPA.

Fig. 7 reports the additional loss of flounder to natural mortality arising from the increase in *M* over time for the NBC. Note that the assessment results would be essentially unchanged if this reflected catches not taken into account rather than additional natural predation.

Fig. 9 reports results of starting the assessment in 1964 rather than 1981. This requires assumptions to develop the total catch made over that period, which are detailed in Appendix A. Because no catch-at-age data are available for that period, there is no basis to estimate recruitment residuals, so a constant recruitment level is assumed. These results suggest that the peak in spawning biomass in about 1980 initiated as a result of reduction of catches in the 1970's, and was reversed by an increase in those catches in the 1980s, rather than reflecting a period of enhanced reproduction during favourable environmental conditions.

In summary, the adjustment of the assessment to include autocorrelation in the residuals of survey indices as measures of abundance, together with an increase in *M* over time initiating sometime during the 1990s, can resolve the retrospective pattern observed in past assessments of this resource. Ready biological justification is available for the introduction of the first of these features, but it is more difficult to suggest mechanisms to explain the second.

Further Work Planned

The New Base Case reported here will be updated given updated data.

Reference

Terceiro M. 2008. J. Southern New England/Mid-Atlantic 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/garm3j.pdf

Table 1: Results for the three Base Cases. Biomass units are '000t. The two recruitment values refer to the averages over two recruitment periods, i.e. 1989-2010 and 1981-1988 respectively. MSY and related quantities have been computed under each of these recruitment levels, assuming the natural mortality *M* that applies in the most recent year if *M* is taken to have changed over time. Further details regarding some of the quantities shown can be found in Appendix B, section B.3.2.

	Base Case 1						Base Case 2				New Base Case			
'-lnL:overall	-763.2						-798.7				-864.1			
'-lnL:Survey	-27.5						-37.2				-49.8			
'-lnL:CAA	-90.3						-92.8				-91.7			
'-lnL:CAAsurv	-640.9						-662.0				-701.7			
'-lnL:RecRes	-5.7						-7.9				-21.9			
'-lnL:SelSmoothing	1.1						1.1				0.9			
Mohn's rho: SSB	0.48						0.49				-0.03			
Mohn's rho: rec.	1.28						1.11				0.16			
Phi	0.59						0.85				0.83			
Bsp(1981)	20.8						19.5				20.8			
Bsp(2010)	5.0						6.4				4.1			
Bsp(2010)/Bsp(1981)	0.24						0.33				0.20			
M	0.20						0.20				0.3-0.6			
Recruitment	11.2	37.5					11.9	39.3			25.7	52.8		
Bsp(MSY)	4.6	15.5					5.2	17.1			2.0	4.1		
MSY	3.2	10.8					3.4	11.4			2.4	5.0		
σ_{comCAA}	0.10						0.10				0.10			
		first period			second period									
Survey	q x10^6	σ_{surv}	σ_{CAA}	q x10^6	σ_{surv}	σ_{CAA}	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	182.1	0.31	0.12	280.6	0.32	0.10	255.1	0.35	0.11	0.37	285.2	0.31	0.10	0.06
NEFSCfall	549.7	0.56	0.18	1790.5	0.54	0.13	1086.4	0.50	0.15	0.78	936.6	0.47	0.15	0.67
NEFSCwinter	364.7	0.41	0.20		-		358.9	0.34	0.20	0.48	233.5	0.30	0.19	0.21
MADFM	1.40	0.47	0.18	2.48	0.37	0.15	2.74	0.41	0.16	0.56	3.31	0.41	0.15	0.51
RIDFW	0.49	0.63	0.14	0.64	0.42	0.16	0.57	0.54	0.15	0.29	0.57	0.51	0.16	0.20
CTDEP	2.47	0.60	0.15	2.10	0.54	0.15	2.79	0.50	0.13	0.57	3.13	0.51	0.12	0.68
NY	0.23	0.73	0.08	0.23	0.90	0.25	0.21	0.86	0.19	0.03	0.11	0.92	0.20	0.28
NJDFW Ocean	3.23	0.46	0.16		-		4.22	0.44	0.16	0.02	4.13	0.42	0.16	-0.03
NJDFW River	0.32	0.22	0.18		-		0.42	0.23	0.18	0.23	0.39	0.27	0.18	0.58
MADFM YOY	0.01	0.51	-	0.02	0.61	-	0.01	0.48	-	0.66	0.01	0.44	-	0.50
CTDEP YOY	0.38	0.70	-	0.62	0.60	-	0.53	0.66	-	0.29	0.24	0.65	-	0.26
RIDFW YOY	0.96	0.59	-	1.08	1.09	-	1.00	0.74	-	0.62	0.48	0.71	-	0.52
NY YOY	0.36	1.61	-	0.25	1.26	-	0.28	1.30	-	0.44	0.14	1.33	-	0.60
DEDFW YOY	0.01	1.30	-	0.01	0.88	-	0.01	1.01	-	-0.24	0.00	1.00	-	-0.23
URIGSO	0.70	0.36	0.16	0.98	0.60	0.15	0.82	0.53	0.15	0.34	0.53	0.51	0.13	0.31
σ_R_out (81-88, 89-10)	0.28	0.46					0.27	0.43			0.27	0.26		

Table 2: Results for variants on the New Base Case relating to different specifications for *M* and its changes over time.

	New Base Case				Variant 1: M_{start}=0.2				Variant 2: M_{start}=0.4				Variant 3: *M* changes over 1995-2000				Variant 4: *M* changes over 1995-2010				Variant 5: *M* changes over 1990-2005				Variant 6: *M* changes over 2000-2010			
'-lnL:overall	-864.1				-863.6				-860.2				-856.9				-859.3				-867.4				-860.5			
'-lnL:Survey	-49.8				-48.9				-52.1				-49.7				-51.5				-52.5				-47.2			
'-lnL:CAA	-91.7				-91.5				-93.6				-91.8				-94.1				-91.5				-92.8			
'-lnL:CAAsurv	-701.7				-702.2				-694.0				-698.1				-692.9				-703.4				-698.5			
'-lnL:RecRes	-21.9				-22.0				-21.4				-18.3				-21.9				-20.9				-23.2			
'-lnL:SelSmoothing	0.9				1.0				0.9				1.0				1.1				0.9				1.0			
Mohn's rho: SSB	-0.03				-0.03				0.04				0.01				0.05				-0.01				-0.01			
Mohn's rho: rec.	0.16				0.13				0.31				0.27				0.32				0.24				0.15			
Phi	0.83				0.84				0.82				0.83				0.83				0.86				0.83			
Bsp(1981)	20.8				18.6				24.1				21.0				21.3				20.6				21.0			
Bsp(2010)	4.1				3.7				5.3				5.2				4.4				4.8				3.6			
Bsp(2010)/Bsp(1981)	0.20				0.20				0.22				0.25				0.21				0.23				0.17			
M	0.3-0.6				0.2-0.54				0.4-0.6				0.3-0.55				0.3-0.6				0.3-0.6				0.3-0.6			
Recruitment	25.7	52.8			19.0	39.8			32.2	70.9			27.7	52.7			22.7	52.7			29.9	53.0			21.7	52.7		
Bsp(MSY)	2.0	4.1			2.8	5.8			2.6	5.7			2.5	4.7			1.5	3.5			2.6	4.6			1.6	3.8		
MSY	2.4	5.0			1.8	3.8			3.0	6.6			3.0	5.7			2.2	5.2			2.7	4.8			2.1	5.1		
σ_{comCAA}	0.10				0.10				0.10				0.10				0.10				0.10				0.10			
Survey	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	285.2	0.31	0.10	0.06	284.3	0.31	0.10	0.09	260.7	0.30	0.11	0.04	264.9	0.30	0.10	-0.01	250.2	0.31	0.11	0.08	299.7	0.30	0.10	0.03	288.9	0.33	0.10	0.21
NEFSCfall	936.6	0.47	0.15	0.67	1036.6	0.47	0.15	0.69	835.8	0.47	0.15	0.68	892.4	0.47	0.15	0.66	939.6	0.47	0.15	0.70	901.6	0.47	0.15	0.65	985.2	0.47	0.15	0.71
NEFSCwinter	233.5	0.30	0.19	0.21	269.5	0.30	0.19	0.21	211.2	0.30	0.19	0.24	223.7	0.30	0.19	0.23	250.5	0.30	0.19	0.23	217.4	0.31	0.19	0.26	256.6	0.31	0.19	0.29
MADFM	3.31	0.41	0.15	0.51	3.32	0.41	0.15	0.52	2.95	0.40	0.16	0.48	2.98	0.40	0.15	0.46	2.82	0.41	0.16	0.50	3.40	0.39	0.15	0.42	3.38	0.42	0.16	0.56
RIDFW	0.57	0.51	0.16	0.20	0.60	0.51	0.16	0.18	0.50	0.52	0.16	0.21	0.53	0.52	0.16	0.23	0.53	0.51	0.16	0.18	0.56	0.53	0.16	0.25	0.58	0.51	0.16	0.18
CTDEP	3.13	0.51	0.12	0.68	3.07	0.51	0.12	0.67	2.88	0.51	0.13	0.67	2.91	0.51	0.12	0.68	2.68	0.51	0.13	0.66	3.34	0.50	0.12	0.67	3.16	0.51	0.12	0.67
NY	0.11	0.92	0.20	0.28	0.15	0.92	0.21	0.29	0.09	0.90	0.20	0.21	0.11	0.91	0.20	0.26	0.13	0.91	0.20	0.21	0.10	0.89	0.20	0.21	0.13	0.92	0.20	0.28
NJDFW Ocean	4.13	0.42	0.16	-0.03	4.07	0.43	0.16	-0.02	3.85	0.41	0.16	-0.10	3.74	0.45	0.16	0.08	3.59	0.40	0.16	-0.13	4.34	0.42	0.16	-0.06	4.35	0.39	0.16	-0.18
NJDFW River	0.39	0.27	0.18	0.58	0.39	0.27	0.18	0.60	0.37	0.26	0.18	0.53	0.34	0.24	0.18	0.36	0.35	0.26	0.18	0.55	0.41	0.25	0.18	0.48	0.43	0.28	0.18	0.76
MADFM YOY	0.01	0.44	-	0.50	0.01	0.43	-	0.50	0.01	0.44	-	0.52	0.01	0.44	-	0.52	0.01	0.44	-	0.52	0.01	0.44	-	0.51	0.01	0.44	-	0.53
CTDEP YOY	0.24	0.65	-	0.26	0.33	0.65	-	0.28	0.20	0.64	-	0.21	0.23	0.63	-	0.18	0.28	0.64	-	0.24	0.21	0.63	-	0.15	0.29	0.66	-	0.33
RIDFW YOY	0.48	0.71	-	0.52	0.65	0.71	-	0.51	0.39	0.72	-	0.54	0.45	0.74	-	0.57	0.54	0.72	-	0.53	0.42	0.73	-	0.55	0.56	0.69	-	0.47
NY YOY	0.14	1.33	-	0.60	0.18	1.34	-	0.61	0.11	1.32	-	0.57	0.13	1.31	-	0.58	0.15	1.33	-	0.56	0.12	1.30	-	0.57	0.16	1.35	-	0.60
DEDFW YOY	0.00	1.00	-	-0.23	0.00	1.00	-	-0.23	0.00	0.98	-	-0.26	0.00	1.01	-	-0.21	0.00	0.98	-	-0.26	0.00	0.99	-	-0.25	0.00	0.98	-	-0.26
URIGSO	0.53	0.51	0.13	0.31	0.64	0.51	0.13	0.31	0.45	0.50	0.14	0.28	0.50	0.51	0.13	0.33	0.56	0.50	0.14	0.27	0.49	0.51	0.13	0.30	0.58	0.50	0.13	0.29
σ_R_out (81-88, 89-10)	0.27	0.26			0.26	0.26			0.28	0.27			0.27	0.32			0.27	0.26			0.27	0.28			0.27	0.24		

Table 3: Results for two further variants on the New Base Case.

	New Base Case				Variant 7: single ρ for surveys				Variant 8: start in 1960			
'-lnL:overall	-864.1				-851.1				-814.4			
'-lnL:Survey	-49.8				-36.9				-39.0			
'-lnL:CAA	-91.7				-91.8				-66.9			
'-lnL:CAAsurv	-701.7				-701.5				-688.9			
'-lnL:RecRes	-21.9				-21.9				-21.0			
'-lnL:SelSmoothing	0.9				0.9				1.4			
Mohn's rho: SSB	-0.03				-0.02				-0.03			
Mohn's rho: rec.	0.16				0.17				0.04			
Phi	0.83				0.83				0.83			
Bsp(1964)	-				-				9.40			
Bsp(1981)	20.8				20.8				34.5			
Bsp(2010)	4.1				4.1				4.9			
Bsp(2010)/Bsp(1981)	0.20				0.20				0.14			
M	0.3-0.6				0.60	0.60			0.60			
Recruitment	25.7	52.8			25.7	52.8			28.0	60.6		
Bsp(MSY)	2.0	4.1			2.0	4.1			1.8	3.9		
MSY	2.4	5.0			2.4	5.0			2.8	6.0		
σ_{comCAA}	0.10				0.10				0.11			
Survey	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ	q x10^6	σ_{surv}	σ_{CAA}	ρ
NEFSCspr	285.2	0.31	0.10	0.06	279.7	0.32	0.10	0.40	146.0	0.49	0.11	0.37
NEFSCfall	936.6	0.47	0.15	0.67	934.9	0.50	0.15	0.40	803.6	0.49	0.16	0.76
NEFSCwinter	233.5	0.30	0.19	0.21	232.7	0.30	0.19	0.40	208.3	0.30	0.20	0.20
MADFM	3.31	0.41	0.15	0.51	3.22	0.41	0.15	0.40	0.89	0.41	0.15	0.49
RIDFW	0.57	0.51	0.16	0.20	0.56	0.52	0.16	0.40	0.41	0.53	0.16	0.25
CTDEP	3.13	0.51	0.12	0.68	3.03	0.54	0.12	0.40	1.51	0.51	0.12	0.71
NY	0.11	0.92	0.20	0.28	0.11	0.92	0.20	0.40	0.11	0.92	0.20	0.31
NJDFW Ocean	4.13	0.42	0.16	-0.03	3.98	0.46	0.16	0.40	1.53	0.43	0.16	-0.02
NJDFW River	0.39	0.27	0.18	0.58	0.37	0.27	0.18	0.40	0.14	0.27	0.18	0.58
MADFM YOY	0.01	0.44	-	0.50	0.01	0.44	-	0.40	0.01	0.44	-	0.52
CTDEP YOY	0.24	0.65	-	0.26	0.24	0.65	-	0.40	0.22	0.64	-	0.26
RIDFW YOY	0.48	0.71	-	0.52	0.48	0.72	-	0.40	0.45	0.72	-	0.54
NY YOY	0.14	1.33	-	0.60	0.14	1.36	-	0.40	0.13	1.33	-	0.61
DEDFW YOY	0.00	1.00	-	-0.23	0.00	1.18	-	0.40	0.00	1.00	-	-0.21
URIGSO	0.53	0.51	0.13	0.31	0.53	0.51	0.13	0.40	0.49	0.51	0.13	0.33
σ_R_out (81-88, 89-10)	0.27	0.26			0.27	0.26			0.29	0.28		

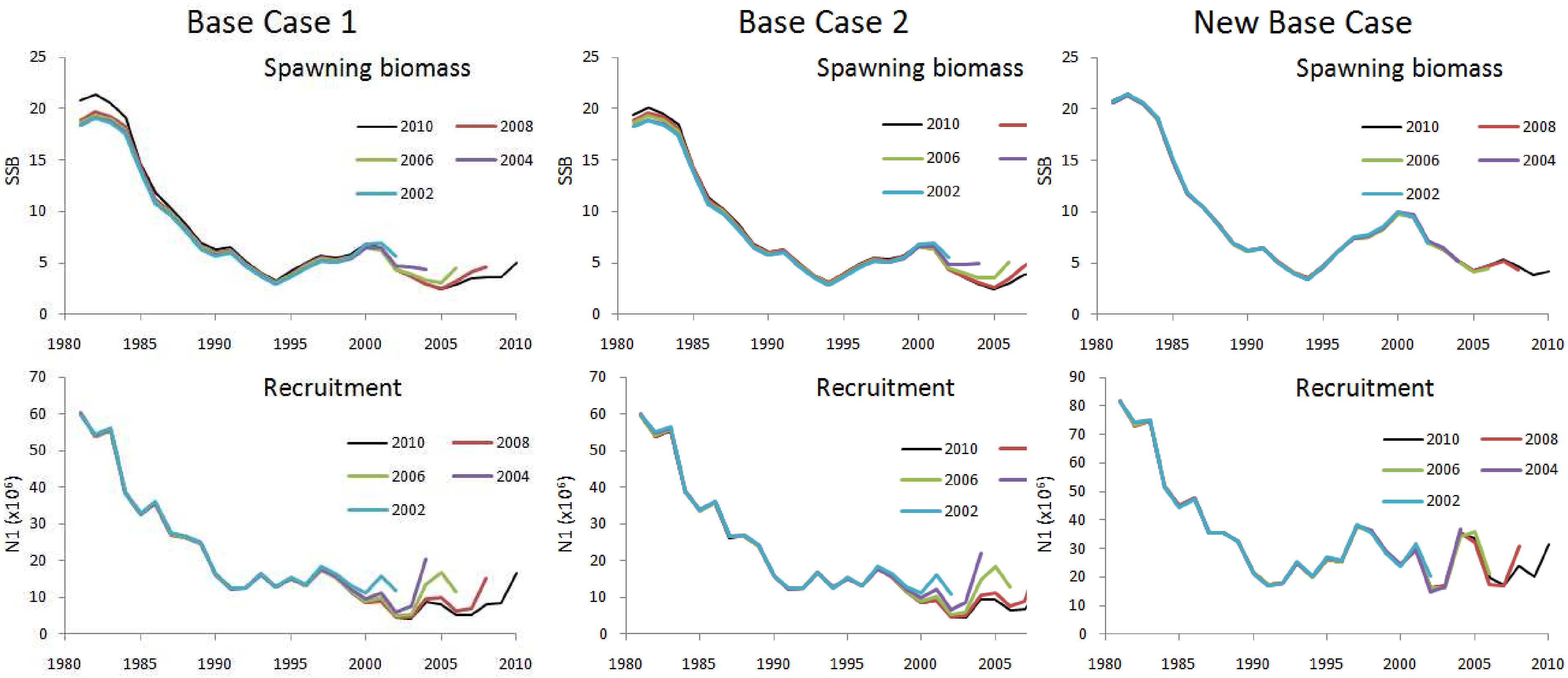

Fig. 1: Retrospective analysis of spawning biomass and recruitment for the three Base Cases.

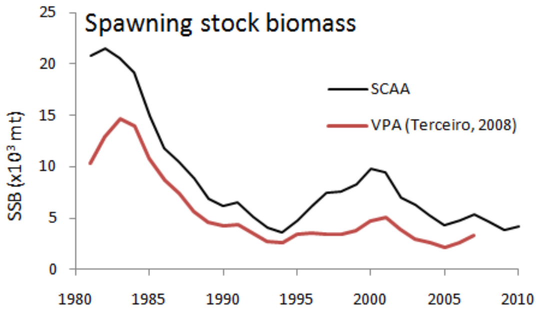

Fig. 2: Spawning stock biomass trajectories for the New Base Case, compared to the GARM3 SPLIT VPA run (Terceiro, 2008).

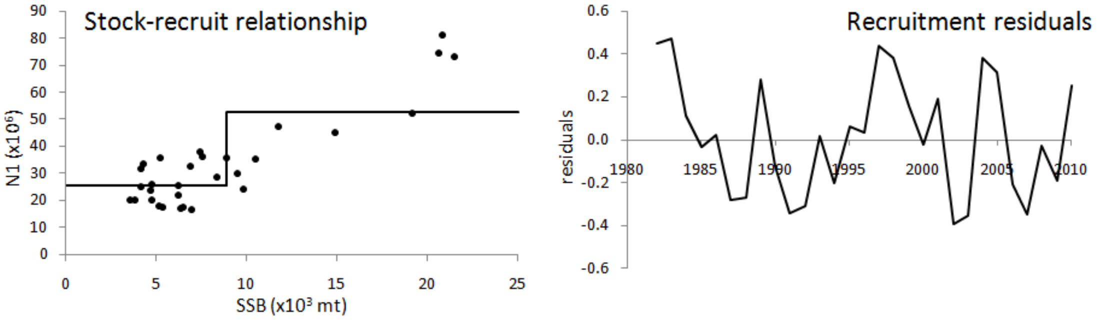

Fig. 3: Stock-recruit relationship and estimated stock-recruit residuals for the New Base Case. The change from high to lower recruitment is taken to occur at the minimum spawning biomass over the pre-1989 period.

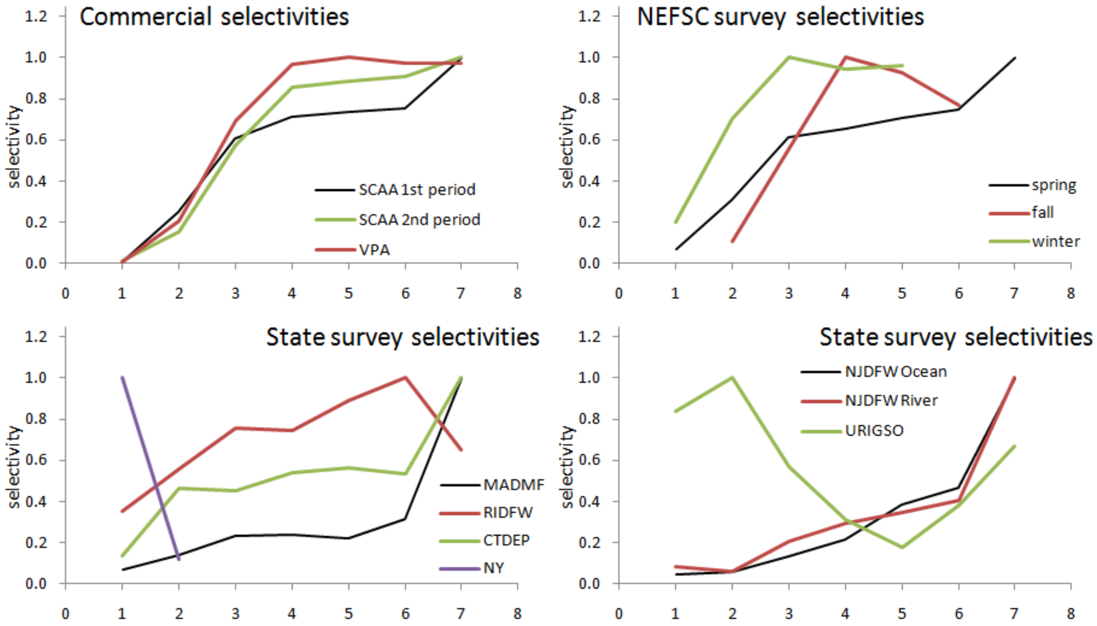

Fig. 4: Commercial and survey selectivities-at-age estimated for the New Base Case.

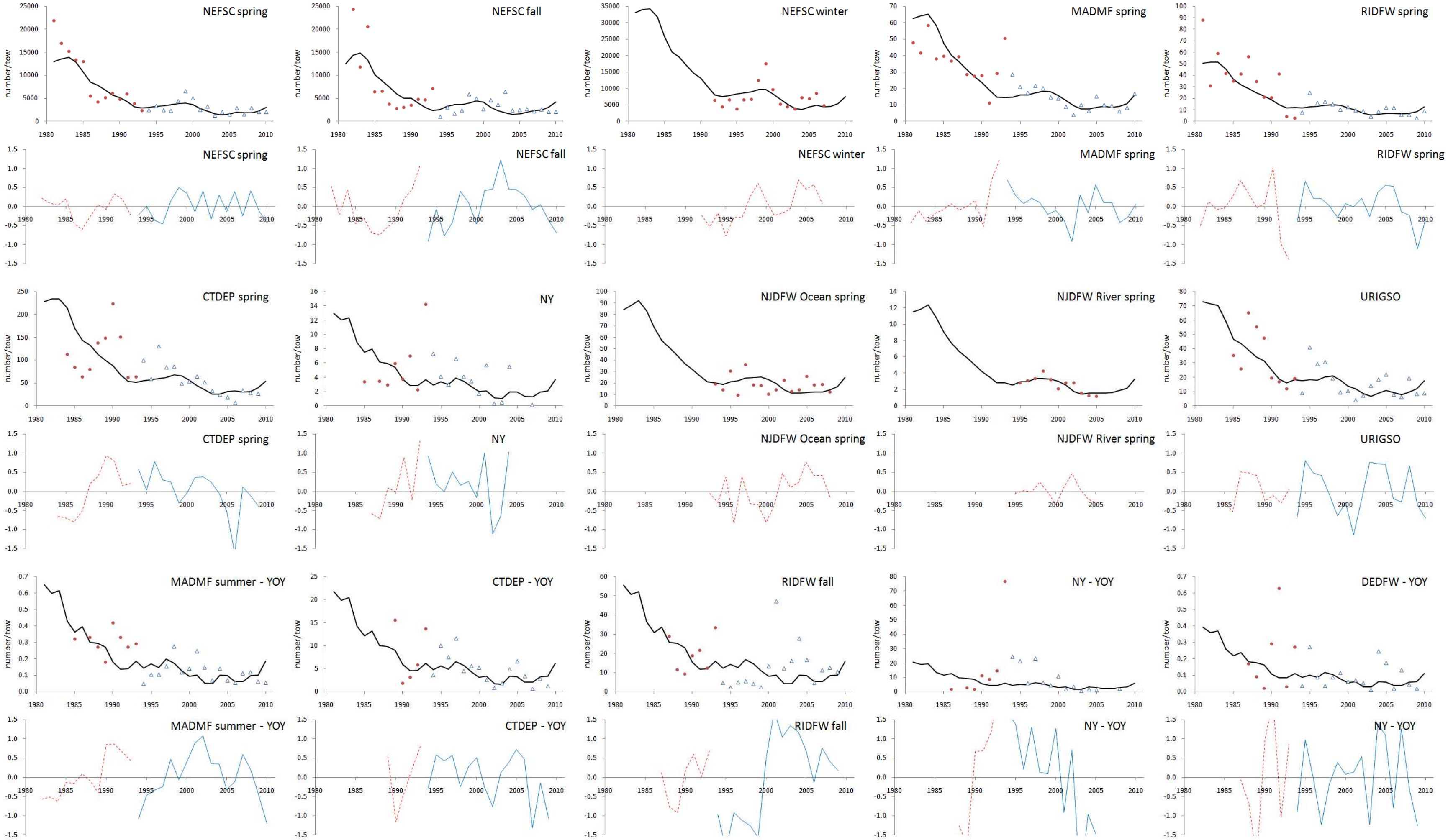

Fig. 5a: Fit of the Base Case 1 to the survey indices of abundance and corresponding survey standardised residuals. The survey data for the second period have been scaled by the ratio of the pre- and post-1993 indices *q*.

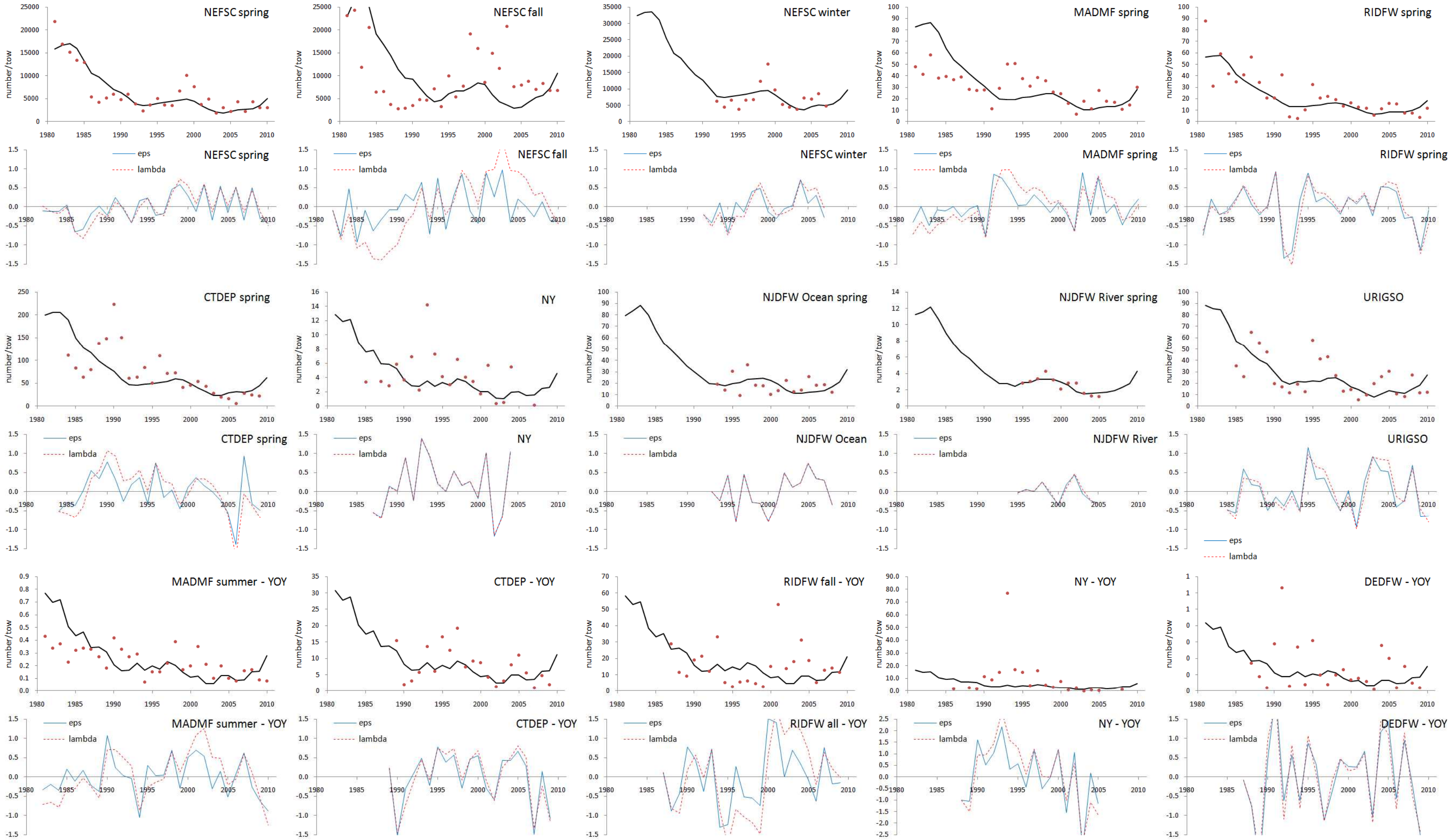

Fig. 5b: Fit of the Base Case 2 to the survey indices of abundance and corresponding survey standardised residuals. Residuals are shown both before ("lambda") and after ("eps") adjustment for serial correlation.

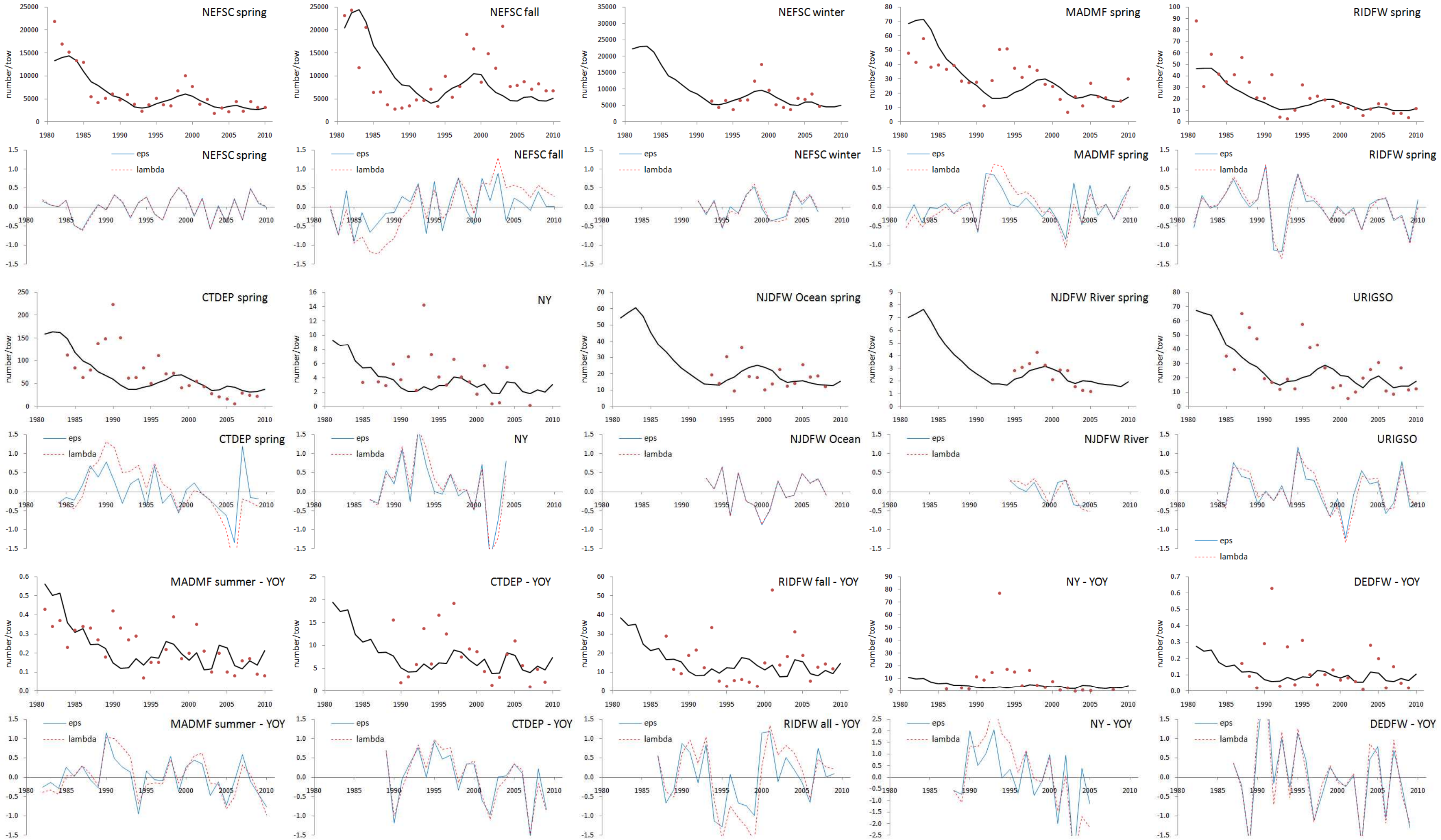

Fig. 5c: Fit of the New Base Case to the survey indices of abundance and corresponding survey standardised residuals. Residuals are shown both before ("lambda") and after ("eps") adjustment for serial correlation.

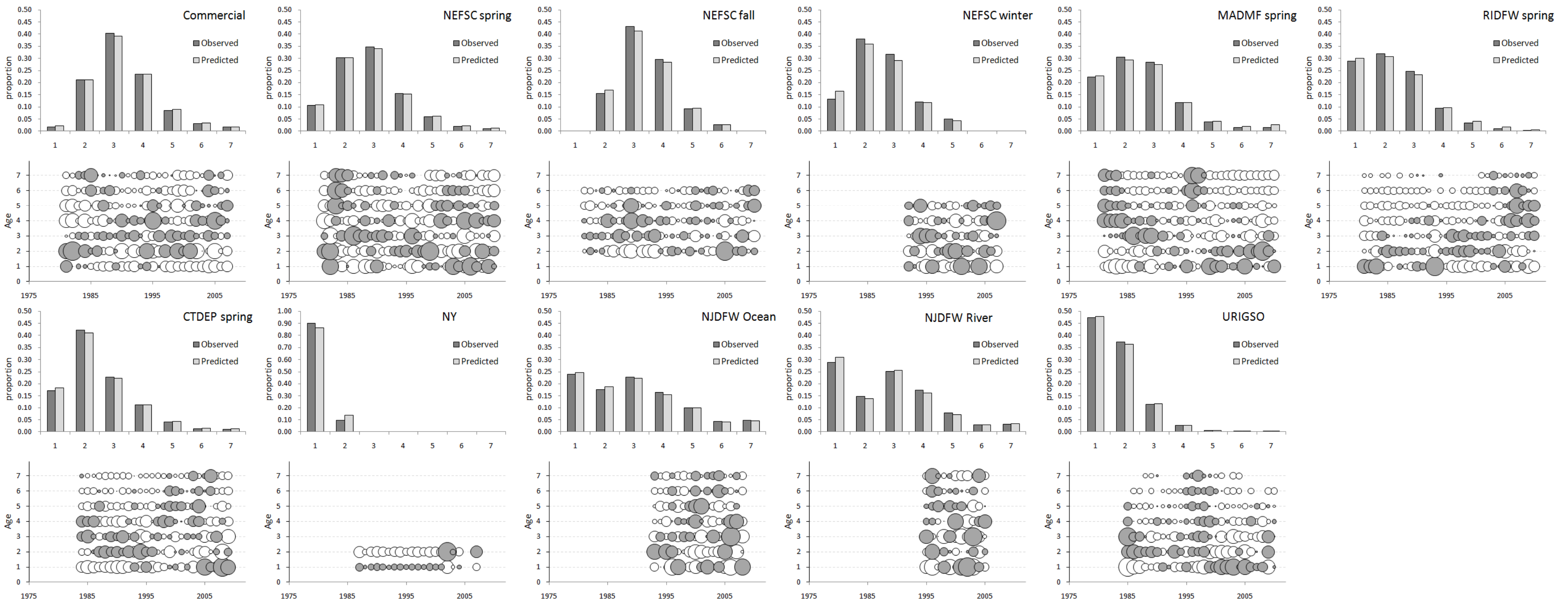

Fig. 6: Fit of the New Base Case to the commercial and survey catch-at-age data. The first and third rows compare the observed and predicted CAA as averaged over all years for which data are available, while the second and fourth rows plot the standardised residuals, with the size (area) of the bubbles 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.

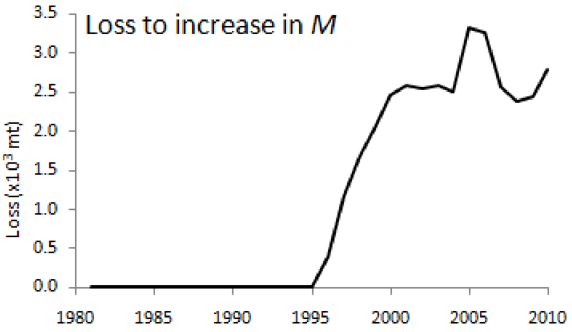

Fig. 7: Additional annual biomass loss from resource due to increase in *M* from 0.3 to 0.6 for the NBC.

Fig. 8: Retrospective analysis of spawning biomass and recruitment for the New Base Case and some variants.

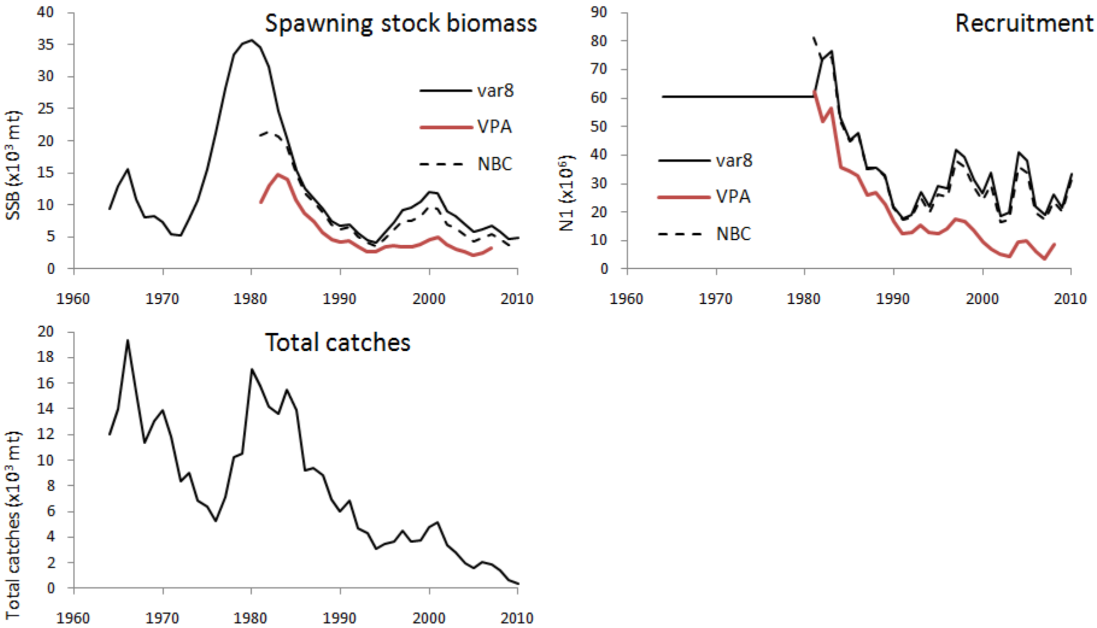

Fig. 9: Spawning stock biomass, recruitment and catch trajectories for the variant 8 of the New Base Case (starting in 1964), compared to the NBC and GARM3 SPLIT VPA run (Terceiro, 2008).

APPENDIX A – Data

Table A1: Total catch (metric tons) for SNE/MA winter flounder (M. Terceiro, pers. commn). Pre-1981, only the commercial landings are available; to compute the total catches, the average 1981-1985 ratio of commercial landings (0.62), commercial discards (0.09), recreational landings (0.28) and recreational discards (0.01) is assumed to apply over the pre-1981 period.

Year	Total catch (mt)	Year	Total catch (mt)	Year	Total catch (mt)
1964	*12053*	1980	*17138*	1996	3702
1965	*13995*	1981	15764	1997	4483
1966	*19315*	1982	14143	1998	3614
1967	*15285*	1983	13582	1999	3745
1968	*11402*	1984	15526	2000	4754
1969	*13074*	1985	13891	2001	5147
1970	*13874*	1986	9217	2002	3412
1971	*11881*	1987	9352	2003	2827
1972	*8370*	1988	8795	2004	1942
1973	*8988*	1989	6915	2005	1563
1974	*6869*	1990	5999	2006	2023
1975	*6422*	1991	6842	2007	1883
1976	*5266*	1992	4729	2008	1432
1977	*7117*	1993	4311	2009	639
1978	*10204*	1994	3092	2010	400
1979	*10552*	1995	3434		

Table A2. Catch at age matrix (000s) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	1380	14183	14401	3608	666	182	111
1982	575	14153	12374	3713	608	212	202
1983	616	7232	13273	6111	1791	695	544
1984	493	11470	13940	4890	1770	873	803
1985	274	7342	12771	6013	2922	1819	1404
1986	216	6327	9101	4218	1053	442	357
1987	74	5265	8988	3084	2690	751	424
1988	85	3946	9401	3963	1206	978	303
1989	468	5275	7208	3541	861	226	214
1990	36	2110	6276	2933	768	196	142
1991	52	3029	7146	3349	860	252	113
1992	25	1507	4460	2582	673	162	53
1993	292	2200	3520	1897	714	188	138
1994	251	2612	2339	1280	337	97	39
1995	88	654	3112	2202	506	83	20
1996	171	1050	3289	2181	556	129	40
1997	88	1841	3488	2252	584	96	39
1998	16	1371	3043	1788	555	185	74
1999	5	2146	4062	1577	375	82	18
2000	43	1336	3436	2473	822	146	72
2001	35	1689	3503	2274	883	231	124
2002	14	478	1897	1830	925	324	115
2003	15	498	1802	1199	501	223	136
2004	36	378	999	858	331	223	167
2005	32	417	765	755	328	134	81
2006	39	758	1598	686	277	133	108
2007	7	334	1492	1033	299	85	32
2008	34	249	724	784	312	162	92
2009	83	195	271	268	211	66	30
2010	83	195	271	268	211	66	30

Table A3a. Total fishery mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.129	0.274	0.477	0.798	1.063	1.242	1.196
1982	0.092	0.263	0.440	0.697	1.052	1.257	1.840
1983	0.197	0.237	0.354	0.517	0.768	1.047	1.552
1984	0.148	0.261	0.370	0.546	0.695	0.915	1.284
1985	0.111	0.282	0.364	0.482	0.522	0.467	0.613
1986	0.129	0.292	0.398	0.480	0.685	0.879	0.961
1987	0.046	0.287	0.384	0.551	0.475	0.564	0.853
1988	0.039	0.279	0.351	0.508	0.634	0.517	0.827
1989	0.118	0.258	0.378	0.508	0.660	0.716	1.073
1990	0.082	0.295	0.394	0.525	0.672	0.808	0.990
1991	0.093	0.317	0.420	0.534	0.603	0.823	1.168
1992	0.079	0.287	0.427	0.599	0.802	0.945	1.395
1993	0.169	0.334	0.460	0.592	0.689	0.878	1.167
1994	0.162	0.311	0.429	0.550	0.750	0.985	1.281
1995	0.267	0.420	0.470	0.559	0.789	1.089	1.741
1996	0.136	0.380	0.464	0.607	0.824	0.851	1.085
1997	0.245	0.443	0.515	0.644	0.771	0.957	1.477
1998	0.196	0.362	0.465	0.568	0.665	1.090	1.116
1999	0.136	0.359	0.439	0.524	0.684	0.903	1.147
2000	0.106	0.407	0.492	0.622	0.729	0.975	1.079
2001	0.089	0.436	0.519	0.640	0.783	1.051	1.234
2002	0.135	0.372	0.499	0.617	0.747	0.927	1.143
2003	0.167	0.426	0.517	0.672	0.854	1.000	1.135
2004	0.094	0.384	0.549	0.619	0.786	0.945	1.251
2005	0.129	0.342	0.488	0.675	0.834	1.013	1.318
2006	0.118	0.379	0.468	0.652	0.872	1.065	1.289
2007	0.065	0.388	0.473	0.634	0.861	1.097	1.372
2008	0.110	0.355	0.477	0.597	0.754	0.939	1.238
2009	0.126	0.326	0.434	0.594	0.757	1.006	0.941
2010	0.126	0.326	0.434	0.594	0.757	1.006	0.941

Table A3b. Spawning stock biomass mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.102	0.234	0.420	0.728	1.005	1.179	1.196
1982	0.067	0.207	0.376	0.614	0.959	1.189	1.840
1983	0.179	0.173	0.321	0.490	0.744	1.049	1.552
1984	0.119	0.238	0.319	0.473	0.630	0.863	1.284
1985	0.080	0.228	0.326	0.441	0.530	0.533	0.613
1986	0.099	0.212	0.355	0.438	0.609	0.739	0.961
1987	0.025	0.220	0.351	0.494	0.477	0.602	0.853
1988	0.021	0.153	0.328	0.463	0.605	0.503	0.827
1989	0.087	0.137	0.342	0.449	0.605	0.688	1.073
1990	0.052	0.217	0.342	0.471	0.612	0.755	0.990
1991	0.064	0.202	0.373	0.483	0.576	0.769	1.168
1992	0.049	0.197	0.387	0.532	0.700	0.814	1.395
1993	0.138	0.207	0.393	0.531	0.658	0.852	1.167
1994	0.118	0.254	0.395	0.518	0.693	0.874	1.281
1995	0.237	0.306	0.410	0.512	0.700	0.962	1.741
1996	0.092	0.338	0.449	0.557	0.724	0.830	1.085
1997	0.215	0.299	0.465	0.577	0.712	0.910	1.477
1998	0.160	0.318	0.458	0.550	0.658	0.971	1.116
1999	0.094	0.293	0.412	0.504	0.643	0.815	1.147
2000	0.066	0.283	0.443	0.554	0.653	0.866	1.079
2001	0.055	0.272	0.479	0.586	0.725	0.930	1.234
2002	0.092	0.231	0.477	0.582	0.710	0.876	1.143
2003	0.127	0.290	0.463	0.609	0.766	0.907	1.135
2004	0.061	0.291	0.505	0.583	0.746	0.914	1.251
2005	0.090	0.222	0.451	0.630	0.755	0.931	1.318
2006	0.079	0.265	0.422	0.592	0.801	0.982	1.289
2007	0.037	0.261	0.439	0.573	0.785	1.016	1.372
2008	0.077	0.202	0.445	0.552	0.712	0.912	1.238
2009	0.096	0.227	0.406	0.552	0.699	0.914	0.941
2010	0.096	0.227	0.406	0.552	0.699	0.914	0.941

Table A3c. January-1 mean weights-at-age (kg) for SNE/MA winter flounder (M. Terceiro, pers. commn).

	1	2	3	4	5	6	7+
1981	0.090	0.216	0.395	0.695	0.978	1.149	1.196
1982	0.057	0.184	0.347	0.577	0.916	1.156	1.840
1983	0.171	0.148	0.305	0.477	0.732	1.050	1.552
1984	0.107	0.227	0.296	0.440	0.599	0.838	1.284
1985	0.068	0.204	0.308	0.422	0.534	0.570	0.613
1986	0.087	0.180	0.335	0.418	0.575	0.677	0.961
1987	0.019	0.192	0.335	0.468	0.478	0.622	0.853
1988	0.015	0.113	0.317	0.442	0.591	0.496	0.827
1989	0.075	0.100	0.325	0.422	0.579	0.674	1.073
1990	0.042	0.187	0.319	0.446	0.584	0.730	0.990
1991	0.053	0.161	0.352	0.459	0.563	0.744	1.168
1992	0.038	0.163	0.368	0.502	0.654	0.755	1.395
1993	0.125	0.162	0.363	0.503	0.642	0.839	1.167
1994	0.101	0.229	0.379	0.503	0.666	0.824	1.281
1995	0.224	0.261	0.382	0.490	0.659	0.904	1.741
1996	0.075	0.319	0.442	0.534	0.679	0.819	1.085
1997	0.202	0.246	0.442	0.547	0.684	0.888	1.477
1998	0.145	0.298	0.454	0.541	0.654	0.917	1.116
1999	0.079	0.265	0.399	0.494	0.623	0.775	1.147
2000	0.052	0.235	0.420	0.523	0.618	0.817	1.079
2001	0.044	0.215	0.460	0.561	0.698	0.875	1.234
2002	0.076	0.182	0.466	0.566	0.691	0.852	1.143
2003	0.110	0.240	0.439	0.579	0.726	0.864	1.135
2004	0.049	0.253	0.484	0.566	0.727	0.898	1.251
2005	0.075	0.179	0.433	0.609	0.719	0.892	1.318
2006	0.065	0.221	0.400	0.564	0.767	0.942	1.289
2007	0.028	0.214	0.423	0.545	0.749	0.978	1.372
2008	0.064	0.152	0.430	0.531	0.691	0.899	1.238
2009	0.084	0.189	0.393	0.532	0.672	0.871	0.941
2010	0.084	0.189	0.393	0.532	0.672	0.871	0.941

Table A4: Proportion mature-at-age for SNE/MA winter flounder (M. Terceiro, pers. commn).

1	2	3	4	5	6	7+
0.00	0.00	0.53	0.95	1.00	1.00	1.00

Table A5: Survey data in terms of total numbers for SNE/MA winter flounder (M. Terceiro, pers. commn).

	NEFSC spring	NEFSC fall	NEFSC winter	MADMF	RIDFW	CTDEP	NYDEC	NJDFW Ocean	NJDFW Rivers	URIGSO	YOY-MADMF	YOY-CTDEP	YOY-RIDFW	YOY-NYDEC	YOY-DEDFW
Month	4	10	3	5	5	5	5	5	5	5	1	1	1	1	1
Ages	1-7+	2-6+	1-5+	1-7+	1-7+	1-7+	1-2+	1-7+	1-7+	1-7+	1	1	1	1	1
1964	-	22029	-	-	-	-	-	-	-	-	-	-	-	-	-
1965	-	32829	-	-	-	-	-	-	-	-	-	-	-	-	-
1966	-	37305	-	-	-	-	-	-	-	-	-	-	-	-	-
1967	-	23655	-	-	-	-	-	-	-	-	-	-	-	-	-
1968	5919	21871	-	-	-	-	-	-	-	-	-	-	-	-	-
1969	13658	19446	-	-	-	-	-	-	-	-	-	-	-	-	-
1970	6609	16963	-	-	-	-	-	-	-	-	-	-	-	-	-
1971	4928	12387	-	-	-	-	-	-	-	-	-	-	-	-	-
1972	4516	9270	-	-	-	-	-	-	-	-	-	-	-	-	-
1973	15094	18457	-	-	-	-	-	-	-	-	-	-	-	-	-
1974	5907	6461	-	-	-	-	-	-	-	-	-	-	-	-	-
1975	1654	4879	-	-	-	-	-	-	-	-	-	-	-	-	-
1976	3698	5273	-	-	-	-	-	-	-	-	-	-	-	-	-
1977	5047	5705	-	-	-	-	-	-	-	-	-	-	-	-	-
1978	8028	11338	-	-	-	-	-	-	-	-	-	-	-	-	-
1979	3555	8987	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	18284	24152	-	-	-	-	-	-	-	-	-	-	-	-	-
1981	21831	23138	-	47.80	87.98	-	-	-	-	-	0.43	-	-	-	-
1982	16918	24324	-	41.45	30.95	-	-	-	-	-	0.34	-	-	-	-
1983	15151	11859	-	58.13	58.95	-	-	-	-	-	0.37	-	-	-	-
1984	13360	20524	-	38.03	41.64	111.96	-	-	-	-	0.23	-	-	-	-
1985	12973	6462	-	39.50	34.98	83.57	3.35	-	-	35.04	0.32	-	-	-	-
1986	5446	6583	-	36.78	41.02	63.65	-	-	-	25.87	0.34	-	-	1.52	-
1987	4260	3703	-	39.16	56.22	79.93	3.43	-	-	65.05	0.33	-	29.00	-	0.17
1988	5155	2832	-	28.37	34.44	137.59	2.88	-	-	55.21	0.27	-	11.60	2.67	0.09
1989	6026	2977	-	27.40	20.88	148.19	5.89	-	-	47.41	0.18	15.50	9.19	1.47	0.02
1990	4816	3461	-	27.72	20.44	223.09	3.70	-	-	19.62	0.42	1.90	18.92	11.20	0.29
1991	5978	4792	-	11.02	40.97	150.21	6.94	-	-	16.80	0.33	3.10	21.48	8.73	0.63
1992	3824	4720	6303	28.96	4.41	61.38	2.24	-	-	11.89	0.27	5.80	12.19	14.72	0.03
1993	2323	7140	4421	50.41	2.92	63.59	14.24	19.17	-	19.06	0.29	13.70	33.33	76.87	0.27
1994	3679	3340	6580	50.83	10.26	84.45	7.28	14.06	-	12.44	0.07	6.00	5.29	17.10	0.04
1995	5083	9923	3834	37.37	32.19	50.12	4.11	30.41	2.82	57.63	0.15	16.60	2.52	14.93	0.31
1996	3679	5421	6511	30.92	20.68	110.61	2.99	9.40	3.05	41.20	0.15	12.50	5.64	4.10	0.10
1997	3485	7696	6752	38.51	22.27	71.31	6.56	36.02	3.35	43.15	0.22	19.20	6.22	16.25	0.04
1998	6728	19096	12382	35.87	19.22	72.90	4.09	18.20	4.25	26.97	0.39	7.47	4.70	4.42	0.10
1999	10093	15950	17563	25.99	13.46	41.35	3.47	17.79	3.23	13.24	0.17	9.28	2.56	3.11	0.13
2000	7672	8616	9619	24.63	16.32	45.42	1.71	10.10	2.11	14.64	0.20	8.70	14.97	7.52	0.07
2001	3800	14885	5267	15.80	12.49	54.51	5.69	13.83	2.84	5.43	0.35	4.30	53.00	0.90	0.08
2002	4937	11666	4352	6.69	11.56	43.72	0.36	22.58	2.80	9.96	0.21	1.30	13.73	2.31	0.06
2003	1864	20839	3747	17.72	5.56	27.84	0.54	12.52	1.57	19.71	0.10	3.06	18.12	0.07	0.01
2004	3001	7672	7253	11.14	11.16	20.46	5.49	14.21	1.27	25.81	0.20	8.10	31.22	0.86	0.28
2005	2251	7987	6925	27.00	15.74	16.10	-	25.67	1.17	30.75	0.10	10.96	18.72	0.50	0.20
2006	4381	8761	8479	17.62	15.36	5.58	-	18.13	-	10.82	0.08	5.63	5.28	-	0.02
2007	2275	7091	4784	16.69	7.33	28.66	0.15	18.58	-	8.54	0.16	0.93	12.72	-	0.15
2008	4381	8350	-	10.65	7.36	24.12	-	12.01	-	27.03	0.17	4.73	14.17	1.11	0.05
2009	3098	6753	-	14.56	3.67	22.59	-	-	-	11.54	0.09	1.97	11.65	-	0.02
2010	3098	6753	-	29.84	11.56	-	-	-	-	12.31	0.08	-	-	-	-

Table A6: Survey catch-at-age data mean numbers for SNE/MA winter flounder (M. Terceiro, pers. commn).

NEFSC spring

	1	2	3	4	5	6	7+
1981	2396	9681	8253	1138	315	24	24
1982	2808	7745	3776	1791	508	218	73
1983	1404	2348	5179	2977	1960	895	387
1984	581	3292	5228	2057	1113	702	387
1985	992	2929	5228	1743	1234	484	363
1986	242	1186	2759	750	363	121	24
1987	339	1307	1694	678	145	48	48
1988	218	1162	2396	895	387	48	48
1989	339	2299	2178	823	266	48	73
1990	557	1186	2154	678	121	97	24
1991	339	1452	2953	992	121	48	73
1992	339	944	1501	871	121	48	0
1993	339	847	629	290	169	24	24
1994	387	1815	1041	266	97	48	24
1995	532	1815	2106	532	73	0	24
1996	169	1307	1597	411	145	24	24
1997	315	1210	1355	436	145	24	0
1998	799	2929	1743	895	315	48	0
1999	992	4574	3267	871	266	97	24
2000	678	1694	2880	1573	653	169	24
2001	411	629	1138	1065	484	48	24
2002	266	1452	1355	920	557	266	121
2003	290	266	799	242	121	97	48
2004	726	460	702	629	266	121	97
2005	242	1089	266	387	169	73	24
2006	726	1501	1501	387	194	48	24
2007	266	339	871	629	97	24	48
2008	436	1476	1162	992	266	24	24
2009	557	920	799	508	242	48	24
2010	557	920	799	508	242	48	24

NEFSC fall

	2	3	4	5	6+
1981	4260	11182	6632	1041	24
1982	5155	12174	6026	726	242
1983	1839	5349	3243	1138	290
1984	3945	9245	4986	1501	847
1985	411	2517	2832	629	73
1986	387	2856	2396	726	218
1987	557	2178	871	73	24
1988	73	1549	871	290	48
1989	73	726	1549	532	97
1990	678	2009	629	121	24
1991	194	2154	2057	363	24
1992	169	2469	1767	290	24
1993	315	4211	1912	629	73
1994	1041	1259	847	194	0
1995	1089	5397	2614	726	97
1996	1404	2251	1525	218	24
1997	1476	3388	1936	750	145
1998	3582	8665	5325	1331	194
1999	3364	6849	4623	992	121
2000	1041	2299	3534	1307	436
2001	2178	5567	4889	1718	532
2002	1186	4332	3897	1525	726
2003	1259	9705	5688	2759	1428
2004	968	2565	2783	1113	242
2005	4574	1912	678	678	145
2006	1743	4429	1767	508	315
2007	1138	3364	1912	532	145
2008	1452	3969	2493	387	48
2009	1089	1767	1694	1501	702
2010	1089	1767	1694	1501	702

NEFSC winter

	1	2	3	4	5+
1992	1261	1485	1882	1261	414
1993	967	2003	933	311	207
1994	622	2003	3039	432	484
1995	69	1295	2176	294	0
1996	1744	1502	2677	553	35
1997	743	2573	2280	933	225
1998	725	6079	3368	1658	553
1999	1451	10258	3851	1658	345
2000	397	4870	3661	414	276
2001	1796	950	1209	933	380
2002	138	2314	1278	259	363
2003	155	984	1796	432	380
2004	3747	1761	743	622	380
2005	674	4421	622	743	466
2006	0	4145	2988	881	466
2007	35	967	1779	1779	225

MADMF

	1	2	3	4	5	6	7+
1981	8.65	9.07	13.66	9.72	3.81	1.20	1.69
1982	3.06	11.88	12.72	8.80	2.66	1.07	1.26
1983	1.71	15.32	17.85	14.11	4.14	2.34	2.66
1984	1.28	9.59	11.82	10.18	3.35	1.22	0.59
1985	3.13	9.98	16.48	6.35	2.48	0.75	0.33
1986	3.27	7.07	19.36	5.69	0.83	0.13	0.43
1987	9.44	7.74	12.35	6.59	2.21	0.22	0.61
1988	3.61	7.02	14.66	2.45	0.35	0.07	0.21
1989	2.26	6.08	12.30	4.68	1.01	0.29	0.78
1990	4.43	11.73	8.03	2.99	0.40	0.02	0.12
1991	1.65	2.88	4.90	1.18	0.24	0.13	0.04
1992	8.06	7.40	6.73	4.21	1.67	0.60	0.29
1993	16.03	18.75	12.02	2.76	0.65	0.14	0.06
1994	12.15	17.35	14.96	4.72	0.62	0.59	0.44
1995	14.31	11.14	8.10	1.93	0.61	0.80	0.48
1996	4.98	10.12	7.72	2.86	2.00	1.46	1.78
1997	10.43	9.30	10.27	4.26	1.32	1.00	1.93
1998	8.62	13.09	7.21	3.51	1.47	1.22	0.75
1999	9.66	8.00	5.81	1.89	0.21	0.25	0.17
2000	6.41	7.78	6.68	1.74	1.09	0.46	0.47
2001	5.47	4.73	2.39	2.02	0.66	0.20	0.33
2002	0.94	3.00	1.55	0.82	0.29	0.08	0.01
2003	4.12	3.78	6.15	2.25	1.14	0.24	0.04
2004	3.46	3.15	1.97	1.67	0.56	0.21	0.12
2005	14.05	8.42	2.68	1.07	0.59	0.11	0.08
2006	3.19	9.61	2.98	1.12	0.32	0.20	0.20
2007	3.69	5.59	5.32	1.63	0.35	0.09	0.02
2008	3.15	5.14	1.73	0.42	0.13	0.02	0.06
2009	2.60	6.03	4.09	1.06	0.68	0.06	0.04
2010	14.20	6.94	5.57	1.74	0.93	0.40	0.06

Table A6: continued

RIDFW

	1	2	3	4	5	6	7+
1981	45.67	27.88	12.86	1.27	0.23	0.05	0.02
1982	13.42	9.74	5.02	2.31	0.33	0.11	0.02
1983	29.49	9.79	10.98	6.00	2.13	0.56	0.00
1984	6.67	16.79	13.94	2.96	0.83	0.35	0.10
1985	6.01	15.69	10.35	2.24	0.60	0.08	0.01
1986	11.94	15.63	9.59	2.63	1.14	0.09	0.00
1987	15.30	24.59	13.14	2.66	0.41	0.08	0.04
1988	8.93	12.37	9.53	2.92	0.68	0.01	0.00
1989	4.79	8.20	4.95	2.33	0.51	0.07	0.03
1990	6.46	6.36	4.88	2.16	0.48	0.04	0.06
1991	11.21	14.36	12.00	2.78	0.41	0.10	0.11
1992	1.30	0.95	1.17	0.75	0.20	0.04	0.00
1993	2.32	0.35	0.17	0.06	0.02	0.00	0.00
1994	2.84	4.56	1.97	0.63	0.19	0.04	0.03
1995	9.36	11.36	9.87	1.47	0.13	0.00	0.00
1996	3.11	8.36	7.47	1.56	0.15	0.03	0.00
1997	4.90	8.77	6.86	1.48	0.26	0.00	0.00
1998	2.11	9.47	5.90	1.60	0.13	0.01	0.00
1999	1.71	6.52	4.26	0.82	0.09	0.06	0.00
2000	2.88	4.98	5.51	2.19	0.66	0.10	0.00
2001	2.46	3.47	3.67	2.23	0.63	0.02	0.01
2002	1.60	4.76	3.21	1.24	0.54	0.15	0.06
2003	1.72	0.86	1.76	0.50	0.30	0.28	0.14
2004	5.47	3.97	1.03	0.44	0.12	0.09	0.04
2005	8.86	2.41	1.73	1.38	0.79	0.43	0.14
2006	2.07	4.72	5.24	2.24	0.74	0.30	0.05
2007	1.19	1.12	2.03	1.62	0.86	0.43	0.08
2008	3.29	1.00	1.00	1.12	0.67	0.22	0.06
2009	0.37	1.17	0.80	0.70	0.47	0.12	0.04
2010	3.24	2.68	3.13	1.24	1.06	0.18	0.03

CTDEP

	1	2	3	4	5	6	7+
1984	8.21	44.01	31.83	20.96	4.23	1.23	1.49
1985	4.11	28.46	32.88	14.17	2.33	0.82	0.8
1986	6.69	26	15.53	12.26	2.05	0.5	0.62
1987	7.32	44.69	14.56	5.05	6.55	1.28	0.48
1988	14.49	71.87	39.1	8.59	1.83	1.46	0.25
1989	13.56	78.43	41.23	10.85	2.84	0.98	0.3
1990	11.31	131.52	64.97	8.97	4.09	1.96	0.27
1991	8.52	66.99	60.39	9.31	4.05	0.8	0.15
1992	6.8	31.32	12.78	8.97	1.1	0.36	0.05
1993	19.11	19.87	15.46	4.81	3.24	0.8	0.3
1994	9.57	64.14	5.86	3.01	1.14	0.49	0.24
1995	14.35	23.69	9.77	1.36	0.63	0.2	0.12
1996	11.46	59.07	24.17	14.41	0.97	0.28	0.25
1997	12.53	25.53	19.41	9.45	3.76	0.51	0.12
1998	11.22	32.4	12.23	12.67	3.15	0.99	0.24
1999	6.56	12.42	11.27	6.09	3.2	1.14	0.67
2000	7.11	16.66	8.4	7.7	3.42	1.53	0.6
2001	8.45	19.6	10.85	8.06	5.46	1.28	0.81
2002	6.27	19.9	9.56	4.43	1.95	1.02	0.59
2003	2.47	7.83	8.71	4.79	1.95	0.77	1.32
2004	6.34	3.84	3.49	3.88	1.91	0.64	0.36
2005	7.06	6.18	0.84	0.81	0.67	0.21	0.33
2006	1.14	2.6	1.1	0.19	0.14	0.17	0.24
2007	2.98	10.83	10.7	3.1	0.61	0.15	0.29
2008	11.48	3.48	4.19	4.12	0.65	0.12	0.08
2009	7.56	11.21	1.02	1.31	1.21	0.22	0.06

NYDEC

	1	2+
1985	3.05	0.3
1986	-	-
1987	3.31	0.12
1988	2.57	0.31
1989	5.54	0.35
1990	3.44	0.26
1991	6.35	0.59
1992	2.04	0.2
1993	14.12	0.12
1994	6.96	0.32
1995	3.84	0.27
1996	2.84	0.15
1997	6.45	0.11
1998	3.8	0.29
1999	3.25	0.22
2000	1.56	0.15
2001	5.52	0.17
2002	0.17	0.19
2003	0.45	0.09
2004	5.38	0.11
2005	-	-
2006	-	-
2007	0.11	0.04

NJDFW Ocean

	1	2	3	4	5	6	7+
1993	5.1	6.5	2.5	2.4	1.7	0.4	0.57
1994	3.7	4.2	3.9	1.4	0.4	0.3	0.16
1995	8	10.1	8.6	2.4	0.9	0.3	0.11
1996	0.6	2.9	2.6	1.9	0.9	0.3	0.2
1997	16.6	5.4	6.1	6	1.5	0.3	0.12
1998	4.5	3.9	4.8	3.3	1.2	0.4	0.1
1999	2.4	2.2	5.9	3.1	2.9	0.7	0.59
2000	0.7	0.3	2.1	3.3	2	0.9	0.8
2001	3.9	0.6	1.3	2.7	3.8	0.7	0.83
2002	5.81	3.21	4.55	2.22	2.8	2.16	1.83
2003	2.08	1.1	4.79	1.24	1.09	0.87	1.35
2004	6.48	0.72	1.42	2.08	0.56	1.38	1.57
2005	4.97	10.04	2.55	2.76	2.61	1.32	1.42
2006	0.64	2.49	9.43	3.23	0.62	0.75	0.97
2007	3.8	0.67	4.33	6.09	1.51	0.62	1.56
2008	5.57	1.59	0.83	1.75	1.69	0.21	0.37

NJDFW Rivers

	1	2	3	4	5	6	7+
1995	0.6	0.3	1.4	0.4	0.1	0.01	0.01
1996	0.3	0.9	0.7	0.7	0.2	0.1	0.15
1997	1.1	0.4	0.9	0.4	0.4	0.1	0.05
1998	1.9	0.9	0.4	0.7	0.2	0.1	0.05
1999	0.2	0.5	1.4	0.5	0.4	0.1	0.13
2000	0.4	0.2	0.4	0.8	0.2	0.1	0.01
2001	1.4	0.3	0.2	0.4	0.4	0.1	0.04
2002	1.21	0.48	0.49	0.18	0.27	0.13	0.04
2003	0.05	0.22	0.9	0.18	0.03	0.1	0.09
2004	0.67	0.02	0.1	0.29	0.05	0	0.14
2005	0.42	0.24	0.17	0.2	0.09	0.02	0.03

URIGSO

	1	2	3	4	5	6	7+
1985	2.09	18.31	12.15	1.94	0.56	0	0
1986	6.87	13.85	4.23	0.83	0.08	0.02	0
1987	16.69	35.86	10.75	1.54	0.2	0.02	0
1988	22.35	24	7.82	0.95	0.04	0	0.06
1989	19.74	24.18	2.4	0.93	0.12	0.03	0.01
1990	6.22	10.33	2.18	0.75	0.1	0	0.04
1991	7.81	5.84	2.55	0.47	0.07	0.05	0
1992	5.81	4.17	1.35	0.47	0.08	0.01	0
1993	9.03	8.76	0.9	0.3	0.06	0.02	0
1994	4.52	6.22	1.5	0.17	0.02	0.01	0
1995	34.71	13.64	7.26	1.38	0.21	0.26	0.17
1996	14.22	19.68	5.41	1.11	0.43	0.25	0.11
1997	18.06	15.55	6.97	1.56	0.41	0.24	0.36
1998	7.5	13.73	3.9	1.25	0.31	0.21	0.07
1999	7.08	3.07	2.07	0.72	0.09	0.15	0.06
2000	7.47	3.77	2.28	0.82	0.11	0.14	0.05
2001	4.1	0.9	0.27	0.11	0.02	0.03	0.01
2002	5.39	3.18	0.99	0.34	0.06	0.01	0
2003	14.16	4.3	0.82	0.26	0.12	0.03	0.01
2004	18.36	6.47	0.5	0.32	0.09	0.04	0.02
2005	23.59	6.31	0.66	0.16	0.03	0	0
2006	5.2	4.04	1.22	0.34	0.03	0.01	0
2007	4.41	2.88	0.95	0.24	0.06	0	0
2008	18.74	7.41	0.72	0.15	0.01	0	0
2009	3.65	5.92	1.65	0.21	0.11	0.01	0
2010	7.73	3.16	1.1	0.25	0.05	0.02	0

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^{TM}, 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:

$$N_{y+1,1} = R_{y+1} \qquad \text{(B1)}$$

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

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

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 (taken to be a plus-group).

B.1.2. Recruitment

In line with the approach used at GARM in 2008 (Terciero, 2008), the number of recruits at the start of year *y* is assumed to have two constant levels, depending on the spawning biomass level which corresponds in this case to two particular periods, and allowing for annual fluctuation about the deterministic relationship:

$$R_y = \begin{cases} A^1 e^{\left(\varsigma_y - \left(\sigma_R^1\right)^2/2\right)} & \text{for } 1981 \le y \le 1988 \\ A^2 e^{\left(\varsigma_y - \left(\sigma_R^2\right)^2/2\right)} & \text{for } y \ge 1989 \end{cases} \qquad \text{(B4)}$$

where

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation $\sigma_R^1 = 0.5$ for the period 1981-1988 and $\sigma_R^2 = 0.3$ for the period 1989-2010; these residuals are treated as estimable parameters in the model fitting process. The value for the earlier period was chosen to be rather uninformative. For the second period, it is rounded to a value slightly above the standard deviations of recruitment residuals shown in a number of these assessments. This value choice is intended to be somewhat informative for the most recent recruitment estimates for which the corresponding cohorts have been sampled relatively few times so that their initial magnitudes are not well estimated by the catch-at-age data alone,

A^1 and A^2 are constants, and

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 (0.2 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:

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

For survey estimates (in numbers):

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

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:

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

where

$$N_{start,1} = 1 \tag{B10}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{y0,a-1}} (1 - \phi S_{y_0,a-1}) \qquad \text{for } 2 \le a \le m-1 \tag{B11}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{y0,m-1}} (1 - \phi S_{y_0,m-1}) \Big/ (1 - e^{-M_{y0,m}} (1 - \phi S_{y_0,m})) \tag{B12}$$

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 (- $\ell \text{n} L$) 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:

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

where

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

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

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

ε^i_y from $N\left(0, \left(\sigma^i_y\right)^2\right)$.

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:

$$-\ell\text{n}\, L^{survey} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma^i_y\right) + \left(\varepsilon^i_y\right)^2 / 2\left(\sigma^i_y\right)^2\right] \qquad \text{(B14)}$$

where

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

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

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I^i_y) - \ell\text{n}(q^i N^{surv,i}_y)\right)^2} \qquad \text{(B15)}$$

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:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I^i_y - \ln N^{surv,i}_y\right) \qquad \text{(B16)}$$

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

$$\varepsilon^i_y = \lambda^i_y - \rho\lambda^i_{y-1} \qquad \text{(B17)}$$

where

$$\lambda^i_y = \ell\text{n}\left(I^i_y\right) - \ell\text{n}\left(\hat{I}^i_y\right)$$

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:

$$-\ell\mathrm{n}\,L^{CAA}=\sum_{y}\sum_{a}\left[\ell n\left(\sigma_{com}/\sqrt{p_{y,a}}\right)+p_{y,a}\left(\ell n\,p_{y,a}-\ell n\,\hat{p}_{y,a}\right)^{2}/2\left(\sigma_{com}\right)^{2}\right] \qquad \text{(B18)}$$

where

$p_{y,a}=C_{y,a}/\sum_{a'}C_{y,a'}$ 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

$$\hat{C}_{y,a}=N_{y,a}\,e^{-M_{y,a}/2}\,S_{y,a}\,F_{y} \qquad \text{(B19)}$$

and

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

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

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, assuming an adjusted log-normal error distribution (equation (B18)) where:

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

$$C_{y,a}^{surv,i}=S_{a}^{i}N_{y,a}e^{-M_{y,a}\frac{\varpi^{1}}{12}}\left(1-S_{y,a}F_{y}\,\frac{\varpi^{1}}{12}\right) \qquad \text{(B21)}$$

$\hat{p}_{y,a}$ 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:

$$-\ell nL^{SRpen}=\sum_{y=y1}^{1988}\left[\varepsilon_{y}^{2}\Big/2\left(\sigma_{R}^{1}\right)^{2}\right]+\sum_{1989}^{y2}\left[\varepsilon_{y}^{2}\Big/2\left(\sigma_{R}^{2}\right)^{2}\right] \qquad \text{(B22)}$$

where

ε_{y} from $N\left(0,\left(\sigma_{R}^{1}\right)^{2}\right)$ for year *y*1 to 1988, and from $N\left(0,\left(\sigma_{R}^{2}\right)^{2}\right)$ for year 1989 to *y2*.

B.3. Model parameters

B.3.1. Fishing selectivity-at-age:

The commercial and survey fishing selectivities are estimated separately for ages 1-7+. The convention used is to set S_a to 1 for the age with the highest selectivity.

B.3.2.: Other parameters reported in Tables 1-3 and elsewhere

Mohn's ρ

Retrospective evaluations involved four model runs with successively earlier terminal years (2008, 2006, 2004 and 2002), in addition to the run with the full data set (2010). Mohn's ρ for a statistic S is calculated as:

$$\rho_S = \sum_{i=1}^{4} \frac{\left(s_{2010-2i} - S_{2010-2i}\right)}{S_{2010-2i}} \Bigg/ 4 \qquad \text{(B23)}$$

Where S_j is the estimated statistic (here spawning biomass or recruitment) for year j from the run with the full data set and s_j is the estimated statistic for year j from the model with j as the terminal year.

Loss to increased M

For each year of the assessment period, a "pseudo" numbers-at-age matrix (N^*) is computed, assuming M=M^1, the natural mortality at the start of the assessment period:

$$N^*_{y+1,a+1} = \left(N_{y,a}\, e^{-M^1/2} - C_{y,a}\right) e^{-M^1/2} \qquad \text{for } 1 \le a \le m-2 \qquad \text{(B24)}$$

$$N^*_{y+1,m} = \left(N_{y,m-1}\, e^{-M^1/2} - C_{y,m-1}\right) e^{-M^1/2} + \left(N_{y,m}\, e^{-M^1/2} - C_{y,m}\right) e^{-M^1/2} \qquad \text{(B25)}$$

The loss to increased M is then calculated as:

$$L = \sum_{y=1981}^{2010} \sum_{a=1}^{mm} \left(L^1_{y,a} - L^2_{y,a}\right) \qquad \text{(B26)}$$

where

$$L^1_{y,a} = w^{mid}_{y,a}\left(N_{y,a} - N_{y+1,a+1} + C_{y,a}\right) \qquad \text{(B27)}$$

$$L^2_{y,a} = w^{mid}_{y,a}\left(N_{y,a} - N^*_{y+1,a+1} + C_{y,a}\right) \qquad \text{(B28)}$$

σ_R_out

$$\sigma_R\_\text{out} = \sum_{y=y1}^{y2} \left(\varsigma_y\right)^2 \Bigg/ \sum_{y=y1}^{y2} 1 \qquad \text{(B29)}$$

This is calculated for two periods: a) $y1$=1981, $y2$=1988 and b) $y1$=1989, $y2$=2010

Calculation of MSY

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

$$C(F) = \sum_a w_a^{mid} S_a F N_a(F) e^{-(M_a/2)} \tag{B30}$$

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:

$$N_a(F) = \begin{cases} R_1(F) & \text{for } a = 1 \\ N_{a-1}(F) e^{-M_{a-1}} (1 - S_{a-1}F) & \text{for } 1 < a < m \\ \dfrac{N_{m-1}(F) e^{-M_{m-1}} (1 - S_{m-1}F)}{\left(1 - e^{-M_m}(1 - S_m F)\right)} & \text{for } a = m \end{cases} \tag{B31}$$

where

$$R_1(F) = A^1 \text{ or } A^2 \tag{B32}$$

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

$$B_{\text{MSY}}^{sp} = \sum_a f_a w_a^{strt} N_a(F_{\text{MSY}}) e^{-M_a \delta} \tag{B33}$$

$$MSY = \sum_a w_a^{mid} S_a F_{\text{MSY}} N_a(F_{\text{MSY}}) e^{-(M_a/2)} \tag{B34}$$

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.