Further Applications of Statistical Catch-at-Age Assessment Methodology to the 2J3K-O Greenland Halibut Resource

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Summary

The initial applications of statistical catch-at-age analysis to commercial catch and survey information in Butterworth and Rademeyer (2009a) are updated to take temporal variability in survey selectivity-at-age into account, and an associated updated Baseline assessment B2 is developed. Sensitivity of the results of B2 to a wide range of alternative specifications is explored. Generally results are more positive than for the most recent XSA assessment. However the SCAA results are not entirely satisfactory because of a conflict evident between survey trends and the proportions-at-age data, which underlies the wide-ish range of results that can be obtained. The overall impression gained from these analyses is that the status of the 2J3K-O Greenland halibut resource is less robustly determined than might be inferred from past XSA assessments..

Introduction

This paper continues the development of the application of Statistical Catch-at-Age (SCAA) methodology to the 2J3K-O Greenland halibut resource beyond the initial results presented in Butterworth and Rademeyer (2009a). Those initial analyses, fitted to survey results and commercial catch information, had introduced temporal variability into the commercial selectivity-at-age only. This paper extends those analyses to allow also for temporal variability in survey selectivity-at-age, and specify an associated updated Baseline assessment (termed B2). A number of sensitivities to this new baseline assessment are then reported.

Appendices A and B of Butterworth and Rademeyer (2009a) listed the data used and provided details of the assessment methodology. These are not repeated here. In the few instances where the methodology is taken further than detailed in that Appendix B, the necessary explanation is provided in the text below.

Results and Discussion

Selectivity-at-age variation over time

The best fit to the data obtained in the initial analyses of Butterworth and Rademeyer (2009a) was their variant 4, which allowed for variability in the commercial selectivity-at-age constrained by a log normal distribution-related penalty function with a standard deviation of the logged deviations of $\sigma_\Omega = 2$. Furthermore residual patterns for the annual survey indices of abundance were improved by allowing for serial correlation. These two specifications provide the basis for a revised baseline assessment also now incorporating variability in the survey selectivity-at-age. The results for the chosen baseline, for which the extent of survey selectivity variation is constrained by $\sigma_\Omega = 0.5$, are shown in Table 1. Figs 1-3 show respectively the corresponding biomass trajectories estimated, the time-averaged survey and commercial selectivities estimated, and the fits to the survey indices of abundance to this updated Baseline assessment B2.

Why the particular choice of $\sigma_\Omega = 0.5$? First the value should be less than that used for the commercial selectivity-at-age, because surveys are designed to be as comparable over time as possible, whereas the annual commercial selectivity is affected by changed relative amounts taken by the different commercial fleets together with changing distributional fishing patterns for each fleet. Fig. 4 shows standardised residual patterns for the fits to the survey catch proportions-at-age data as the σ_Ω value is increased. This increase improves the residual patterns, but the extra flexibility introduced also sees the resource status improve (see Table 1), perhaps to an extent that might be considered unrealistic.

The choice of σ_Ω = 0.5 for B2 is a "convenience", without pretending that it is necessarily the best choice to be made. Further discussion on this choice would be desirable. It is of interest in this context to compare the extent of variability evidenced by the selectivity-at-age vectors actually estimated. For the commercial selectivity-at-age, with σ_Ω = 2, for baseline B2 σ_Ω (output) is 0.58. This compares with σ_Ω (output) = 0.64 for the XSA assessment of Healey and Mahe (2008), which would argue against tighter constraints in the form of much smaller σ_Ω values for the commercial selectivity variation. Fig. 5 shows biomass trajectories estimated for B2 and variants with alternative choices to σ_Ω = 0.5 for the survey selectivity variation. Both the Figure and Table 1 also show results for σ_Ω for the commercial selectivity increased from the B2 choice of 2 to 3, but this has relatively little impact on results.

Retrospective assessments

The results of retrospective assessments for the updated Baseline B2 are shown in Table 2 and Fig. 6.

Aside from a more negative appraisal for the assessment with only the most recent year's data removed, the plots in Fig. 6 are very consistent and provide no indication of any systematic pattern

Variation in assumptions concerning the stock-recruitment relationship

Table 3 shows sensitivities to a number of variations in the baseline B2 assumptions of a Beverton-Holt stock recruitment function with steepness h = 0.5 and recruitment variability set on input to σ_R = 0.25. First lower values of h are considered. Next a refinement of the Ricker form is considered which can also produce shapes similar to Beverton-Holt:

$$R_y = \alpha B_y^{sp} \exp\left(-\beta\left(B_y^{sp}\right)^\gamma\right)$$

This is implemented with h=1.0 and γ=0.2 to allow for some decrease in recruitment at larger spawning biomass given that the Beverton-Holt form fits seeking limiting values of steepness may be a reflection of such a decreasing trend in the data. Finally σ_R is set to 0.35. The biomass trajectories corresponding to most of these sensitivities are shown in Fig. 7.

If steepness h for the Beverton-Holt form is lower than the 0.9 for the updated Baseline B2, the estimated MSY and recent rate of increase in biomass are reduced. However, if σ_R is increased, the estimated resource status is substantially improved. The Ricker-like relationship investigated provides a similar though less pronounced improvement. Comparison in likelihood terms of the variant with increased to the others is problematic; however amongst the other variants considered updated Baseline B2 is marginally preferred on this basis.

Other sensitivities

Table 4 includes sensitivities to allowing some variability in the value of the actual catch about that reported (though not for the last 10 years for which records were likely better kept), natural mortality in respect of both age and year, fixing commercial selectivity at large ages to be flat, and setting natural mortality M to be higher at 0.3 compared to the 0.2 of all Baseline assessments. The variations in catch and in natural mortality estimated are shown in Figs 9 and 10 respectively, with the associated biomass trajectories compared in Fig. 11. Trajectories for the last two of these sensitivities are shown in Fig. 12.

Biomass trajectories reflect less optimistic appraisals of resource status when greater variability in past catches of M is admitted. Forcing flat commercial selectivity for ages of 10 and above makes little difference to results (unlike the case in Butterworth and Rademeyer (2009a), which did not incorporate temporal variability in survey selectivities at age). Higher M leads to an increased cestimate of MSY and an improved resource status.

Table 5 and Fig 13 show the consequences of fitting the SCAA to only one of the survey series rather than all three together as for the updated Baseline B2. For all three cases the resource status is estimated to be less optimistic than for B2.

Table 6 shows the consequences of alternative non-equilibrium starting conditions for the resource at the time of the first reported catches in 1960. The data used in the fitting procedure are essentially unable to distinguish these alternatives, but this is of little import as estimates of current resource status are rather insensitive to these alternatives. Biomass trajectories for two of the more extreme cases are included amongst the plots in Fig. 12.

When allowing selectivity-at-age to vary in these analyses, the selectivity function each year was renormalized so that its peak value remained 1. Alternative approaches could be argued, and in principle have consequences for the assessment as they impact the catchability q for the survey (or CPUE) series to which model abundance trends are fitted. Fits were explored that did not implement this renormalisation, but this was found in this case to have very little impact on results.

Concluding remarks

Fig. 14 compares the updated Baseline B2 estimated biomass trajectories to those from the CPUE-based SCAA model fits (Butterworth and Rademeyer, 2009b), and the XSA results of Healey and Mahé (2008). The survey-based SCAA assessment (B2) is a little more optimistic than those based on CPUE, but both are considerably more positive about resource status than the XSA results.

Nevertheless the SCAA model fits are not entirely satisfactory – unless temporal variability in selectivity-at-age is only very weakly constrained, indications of non-random patterns in residuals for the fits to the proportions-at-age data remain. However, in the main, if such variability is not sufficiently constrained, solutions tend towards perhaps unrealistically high abundances.

Generally, solutions that do not indicate a reasonable current resource status and recent increase in abundance do not fit the survey trend data as well as those which do. This is one illustration of the conflict between the survey trends and proportions-at-age information which is the main contributor to the wide-ish range of results obtained here. Unfortunately the fact that the proportions-at-age data contributions to the likelihood are not corrected for evident non-independence means that these are overweighted, so that application of standard model selection approaches is questionable.

Overall, however, the impression gained from these analyses is that the status of the 2J3K-O Greenland halibut resource is less robustly determined than might be inferred from past XSA assessments.

References

Butterworth DS and Rademeyer RA. 2009a. Initial applications of Statistical Catch-at-Age assessment methodology to the Greenland Halibut resource.

Butterworth DS and Rademeyer RA. 2009b. CPUE-based assessments of the Greenland halibut resource using SCAA.

Healey BP and Mahé J-C. 2008. An assessment of Greenland halibut (*Reinhardtius hippoglossoides*) in NAFO Subarea 2 and Divisions 3KLMNO. NAFO SRC Doc. 08/48, Ser. No N5550.

Table 1: Results of fits of various SCAA variants to the commercial catch and survey data compared to the Baseline assessment B1 of Butterworth and Rademeyer (2009a). The variants considered here are the updated Baseline B2 and alternatives for different values of the extent of variability (measured by σ_Ω) of either the survey or the commercial selectivity-at-age (see text for further details). Biomass units are '000t. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs.

	Baseline B1			Baseline B2 (σ_Ω comm = 2, σ_Ω survey = 0.5, serial correlation in the survey residuals)			1) As B2 but σ_Ω survey = 1.0			2) As B2 but σ_Ω survey = 2.0			3) As B2, but σ_Ω comm = 3		
'-lnL:overall	-52.8			-500.4			-610.1			-659.1			-506.4		
'-lnL:Survey	-27.9			-49.3			-51.5			-56.1			-49.8		
'-lnL:CAA	-56.3			-225.0			-223.3			-220.5			-226.7		
'-lnL:CAAsurv	-4.2			-367.2			-429.7			-455.5			-367.4		
'-lnL:RecRes	35.6			30.1			29.1			27.0			30.6		
'-lnL:SelPen	-			111.1			65.3			46.0			106.9		
'-lnL:CatchPen	-			-			0.0			0.0			0.0		
-lnL:M Pen	-			-			0.0			0.0			0.0		
h	**0.90**	-		**0.90**			**0.90**			**0.90**			**0.90**		
θ	**1**	-		**1**			**1.0**			**1.0**			**1**		
ϕ	**0**	-		**0**			**0**			**0**			**0**		
ρ	**0**	-		0.63			0.59			0.45			0.63		
K^{sp}	603	(0.15)		576	(0.19)		630	(0.23)		737			597	(0.20)	
B^{sp}_{2008}	364	(0.34)		372	(0.42)		460	(0.45)		653			408	(0.41)	
B^{sp}_{2008}/K	0.60	(0.20)		0.65	(0.24)		0.73	(0.23)		0.89			0.68	(0.22)	
MSYL^{sp}	0.17	(0.09)		0.17	(0.62)		0.17	(0.62)		0.17			0.17	(0.95)	
B^{sp}_{MSY}	105	(0.23)		100	(0.68)		109	(0.70)		127			103	(1.00)	
MSY	45	(0.15)		43	(0.18)		47	(0.22)		55			45	(0.19)	
σ_{comCAA}	0.14			0.07			0.07			0.07			0.07		
Survey	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$
CanFall1	92	0.29	0.11	118	0.29	0.06	115	0.29	0.05	100	0.28	0.05	114	0.29	0.06
CanFall2	172	0.28	0.07	197	0.15	0.05	182	0.14	0.05	166	0.12	0.04	189	0.15	0.05
EU	61272	0.48	0.11	69290	0.29	0.07	64221	0.27	0.06	55082	0.25	0.06	66110	0.28	0.07
CanSpr	10	0.53	0.12	11	0.39	0.05	10	0.38	0.05	8	0.36	0.05	10	0.39	0.05
σ_R_out	0.24			0.22			0.22			0.21			0.23		

Table 2: Results of fits of the updated Baseline B2 and five retrospective on this assessment to the commercial catch and survey data. Biomass units are '000t. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs. Note that abundance estimates that apply to 2008 for the baseline B2 assessment refer to the corresponding final years of the assessments for shorter periods.

	Baseline B2			Retrospective, one year			Retrospective, two years			Retrospective, three years			Retrospective, four years			Retrospective, five years		
'-lnL:overall	-500.4			-481.7			-474.9			-455.1			-454.9			-434.6		
'-lnL:Survey	-49.3			-47.9			-45.9			-44.8			-43.8			-40.7		
'-lnL:CAA	-225.0			-224.8			-215.5			-207.7			-196.8			-188.0		
'-lnL:CAAsurv	-367.2			-346.3			-343.3			-333.9			-326.9			-316.1		
'-lnL:RecRes	30.1			34.2			29.6			25.8			20.4			21.8		
'-lnL:SelPen	111.1			103.1			100.1			105.4			92.2			88.4		
'-lnL:CatchPen	-			-			-			-			-			-		
-lnL:M Pen	-			-			-			-			-			-		
h	**0.90**			**0.90**			**0.90**			**0.90**			**0.90**			**0.90**		
θ	**1**			**1**			**1**			**1**			**1.0**			**1.0**		
ϕ	**0**			**0**			**0**			**0**			**0**			**0**		
ρ	0.63			0.65			0.60			0.59			0.56			0.61		
K^{sp}	576	(0.19)		493			595			574			568			541		
$B^{sp}{}_{2008}$	372	(0.42)		219			298			279			279			234		
$B^{sp}{}_{2008}/K$	0.65	(0.24)		0.44			0.50			0.49			0.49			0.43		
MSYL^{sp}	0.17	(0.62)		0.18			0.18			0.18			0.17			0.17		
$B^{sp}{}_{MSY}$	100	(0.68)		87			105			102			98			89		
MSY	43	(0.18)		38			45			44			43			41		
σ_{comCAA}	0.07			0.07			0.07			0.07			0.07			0.07		
Survey	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$
CanFall1	118	0.29	0.06	139	0.30	0.06	114	0.29	0.06	118	0.29	0.06	119	0.29	0.06	125	0.29	0.06
CanFall2	197	0.15	0.05	242	0.14	0.04	197	0.16	0.05	212	0.12	0.04	258	0.13	0.04	287	0.16	0.05
EU	69290	0.29	0.07	85146	0.30	0.07	67382	0.29	0.07	68437	0.31	0.07	68339	0.29	0.07	69261	0.28	0.08
CanSpr	11	0.39	0.05	12	0.41	0.07	11	0.40	0.05	11	0.40	0.05	13	0.38	0.05	15	0.33	0.03
σ_R_out	0.22			0.24			0.23			0.21			0.19			0.20		

Table 3: Results of fits of various SCAA variants related to aspects of the stock-recruitment relationship assumed (see text for details) to the commercial catch and survey data, compared to the updated Baseline assessment B2 . Biomass units are '000t. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs.

	Baseline B2			4) As B2 but h = 0.7			5) As B2 but h = 0.5			6) As B2 but with Ricker-type SR relationship			7) As B2 but $\sigma_R = 0.35$		
'-lnL:overall	-500.4			-499.1			-497.0			-499.5	0.0		-528.6		
'-lnL:Survey	-49.3			-50.0			-50.6			-50.1			-51.8		
'-lnL:CAA	-225.0			-224.8			-224.4			-225.2			-226.3		
'-lnL:CAAsurv	-367.2			-366.3			-365.3			-368.2			-386.2		
'-lnL:RecRes	30.1			30.6			31.3			32.3			24.3		
'-lnL:SelPen	111.1			111.4			112.0			111.7			111.4		
'-lnL:CatchPen	-			-			-			-			-		
-lnL:M Pen	-			-			-			-			-		
h	**0.90**			**0.70**			**0.50**			**1**			**0.90**		
θ	**1**			**1**			**1**			**1**			**1**		
ϕ	**0**			**0**			**0**			**0**			**0**		
ρ	0.63			0.62			0.61			0.63			0.59		
K^{sp}	576	(0.19)		620	(0.19)		681	(0.20)		635	(0.24)		1208	(0.46)	
B^{sp}_{2008}	372	(0.42)		395	(0.44)		415	(0.48)		503	(0.42)		1191	(0.63)	
B^{sp}_{2008}/K	0.65	(0.24)		0.64	(0.25)		0.61	(0.29)		0.79	(0.19)		0.99	(0.20)	
MSYL^{sp}	0.17	(0.62)		0.28	(0.47)		0.38	(0.39)		0.20	(0.60)		0.17	(0.59)	
B^{sp}_{MSY}	100	(0.68)		174	(0.53)		255	(0.46)		129	(0.69)		207	(0.79)	
MSY	43	(0.18)		35	(0.18)		27	(0.19)		53	(0.23)		88	(0.45)	
σ_{comCAA}	0.07			0.07			0.07			0.07			0.07		
Survey	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$
CanFall1	118	0.29	0.06	111	0.29	0.06	103	0.29	0.06	103	0.29	0.06	64	0.28	0.06
CanFall2	197	0.15	0.05	199	0.14	0.05	204	0.13	0.05	163	0.15	0.05	88	0.15	0.05
EU	69290	0.29	0.07	66842	0.29	0.07	64655	0.30	0.07	57793	0.28	0.07	32333	0.26	0.06
CanSpr	11	0.39	0.05	11	0.39	0.05	11	0.38	0.05	9	0.39	0.05	5	0.39	0.05
σ_R_out	0.22			0.23			0.23			0.23			0.35		

Table 4: Results of fits of various SCAA variants (see text for details) to the commercial catch and CPUE data compared to the updated Baseline assessment B2. Biomass units are '000t. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs.

	Baseline B2			8) As B2 but with variation in catches ($\sigma_C = 0.1$) (no variation in the last 10 years)			9) As 8) but $\sigma_C = 0.2$			10) As B2 but with variation in M ($\sigma_M = 0.2$)			11) As 10) but $\sigma_M = 0.4$			12) As B2 but with flat commercial selectivity from age 10			13) As B2 but M=0.3		
'-lnL:overall	-500.4			-501.6			-510.7			-528.1			-579.8			-493.7			-495.4		
'-lnL:Survey	-49.3			-49.1			-44.0			-47.6			-41.9			-49.1			-47.3		
'-lnL:CAA	-225.0			-226.4			-230.5			-229.5			-240.1			-224.4			-224.7		
'-lnL:CAAsurv	-367.2			-368.6			-378.9			-393.4			-444.5			-367.3			-369.8		
'-lnL:RecRes	30.1			30.1			26.0			25.3			17.9			29.8			32.0		
'-lnL:SelPen	111.1			111.3			105.9			106.7			95.9			117.2			114.4		
'-lnL:CatchPen	-			1.2			10.7			0.0			0.0			0.0			0.0		
-lnL:M Pen	-			0.0			0.0			10.4			32.7			0.0			0.0		
h	**0.90**			**0.90**			**0.90**			**0.90**			**0.90**			**0.90**			**0.90**		
θ	**1**			**1**			**1**			**1.0**			**1.0**			**1.0**			**1.0**		
ϕ	**0**			**0**			**0**			**0**			**0**			**0**			**0**		
ρ	0.63			0.63			0.66			0.63			0.68			0.64			0.64		
K^{sp}	576	(0.19)		562	(0.20)		331	(0.05)		530	(0.21)		412	(0.08)		519	(0.18)		301	*	
$B^{sp}{}_{2008}$	372	(0.42)		353	(0.44)		20	(0.54)		264	(0.57)		27	(0.50)		311	(0.43)		243	*	
$B^{sp}{}_{2008}/K$	0.65	(0.24)		0.63	(0.25)		0.06	(0.52)		0.50	(0.38)		0.07	(0.47)		0.60	(0.26)		0.81	*	
MSYL^{sp}	0.17	(0.62)		0.17	(0.63)		0.18	(0.62)		0.17	(0.64)		0.18	(0.62)		0.18	(0.62)		0.15	*	
$B^{sp}{}_{MSY}$	100	(0.68)		97	(0.69)		58	(0.62)		92	(0.72)		72	(0.63)		91	(0.68)		46	*	
MSY	43	(0.18)		42	(0.19)		27	(0.05)		40	(0.20)		33	(0.07)		39	(0.17)		51	*	
σ_{comCAA}	0.07			0.07			0.07			0.07			0.06			0.07			0.07		
Survey	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$	q's x10^6	σ_{surv}	$\sigma_{survCAA}$
CanFall1	118	0.29	0.06	122	0.29	0.06	220	0.32	0.05	131	0.29	0.06	183	0.32	0.05	132	0.29	0.06	88	0.31	0.06
CanFall2	197	0.15	0.05	203	0.15	0.05	427	0.12	0.05	222	0.15	0.04	364	0.14	0.04	219	0.15	0.05	105	0.17	0.05
EU	69290	0.29	0.07	71664	0.29	0.07	162315	0.38	0.07	80085	0.31	0.07	147706	0.40	0.06	77680	0.29	0.07	50922	0.28	0.07
CanSpr	11	0.39	0.05	11	0.39	0.05	23	0.40	0.06	12	0.40	0.05	20	0.40	0.05	12	0.39	0.05	7	0.39	0.05
σ_R_out	0.22			0.22			0.21			0.21			0.17			0.22			0.23		

* not converged

Table 5: Results of fits of various SCAA variants to the commercial catch and survey data compared to the updated Baseline assessment B2. The variants here in turn fit to one of the survey series only, instead of all three as for B2. Biomass units are '000t. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs.

	Baseline B2			14a) As B2 but using only Canadian Fall survey data			14b) As B2 but using only EU summer survey data			14c) As B2 but using only Canadian Spring survey data		
'-lnL:overall	-500.4			-482.8			-468.8			-460.5		
'-lnL:Survey	-49.3			-30.0			-14.4			-4.8		
'-lnL:CAA	-225.0			-225.1			-225.1			-224.8		
'-lnL:CAAsurv	-367.2			-364.7			-369.2			-368.1		
'-lnL:RecRes	30.1			28.4			29.3			28.2		
'-lnL:SelPen	111.1			108.7			110.6			109.1		
'-lnL:CatchPen	-			0.0			0.0			0.0		
-lnL:M Pen	-			0.0			0.0			0.0		
h	**0.90**			**0.90**			**0.90**			**0.90**		
θ	**1**			**1**			**1**			**1.0**		
ϕ	**0**			**0**			**0**			**0**		
ρ	0.63			0.45			0.77			0.70		
K^{sp}	576	(0.19)		460	(0.16)		520	(0.16)		441	(0.15)	
$B^{sp}{}_{2008}$	372	(0.42)		197	(0.53)		275	(0.43)		161	(0.56)	
$B^{sp}{}_{2008}/K$	0.65	(0.24)		0.43	(0.38)		0.53	(0.27)		0.36	(0.42)	
MSYL^{sp}	0.17	(0.62)		0.17	(0.64)		0.17	(0.63)		0.17	(0.63)	
$B^{sp}{}_{\mathrm{MSY}}$	100	(0.68)		80	(0.65)		90	(0.68)		77	(0.64)	
MSY	43	(0.18)		35	(0.15)		39	(0.15)		34	(0.13)	
σ_{comCAA}	0.07			0.07			0.07			0.07		
Survey	q's x10^6	σ_{surv}	$\sigma_{\mathrm{survCAA}}$	q's x10^6	σ_{surv}	$\sigma_{\mathrm{survCAA}}$	q's x10^6	σ_{surv}	$\sigma_{\mathrm{survCAA}}$	q's x10^6	σ_{surv}	$\sigma_{\mathrm{survCAA}}$
CanFall1	118	0.29	0.06	148	0.28	0.06	-	-	-	-	-	-
CanFall2	197	0.15	0.05	262	0.14	0.05	-	-	-	-	-	-
EU	69290	0.29	0.07	-	-	-	79746	0.29	0.07	-	-	-
CanSpr	11	0.39	0.05	-	-	-	-	-	-	15	0.40	0.05
σ_R_out	0.22			0.22			0.22			0.22		

Table 6: Total negative log-likelihood and estimated current depletion for a series of θ and ϕ values that reflect a resource in other than pre-exploitation equilibrium at the time of the first recorded catches in 1960. Note that the updated Baseline B2 assessment corresponds to the shaded entry with θ = 1.0 and ϕ = 0.0

		ϕ			
		0	0.2	0.4	0.6
θ	1.2	-500.7 0.64	-501.3 0.65	-500.5 0.67	-498.2 0.69
	1.0	-500.4 0.65	-501.2 0.65	-500.8 0.66	-499.3 0.73
	0.8	-499.9 0.65	-501.0 0.64	-501.1 0.70	-499.9 0.72
	0.6	-499.1 0.67	-500.6 0.64	-501.2 0.65	-500.2 0.66
	0.4	-497.6 0.66	-499.6 0.64	-501.1 0.65	-500.8 0.66

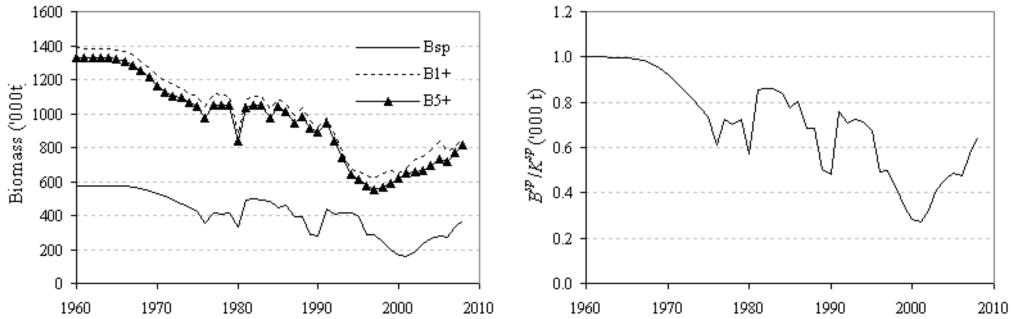

Fig. 1: Spawning (10+) biomass trajectories (in absolute terms and relative to pre-exploitation level) and B1+ and B5+ biomasses for the updated Baseline B2.

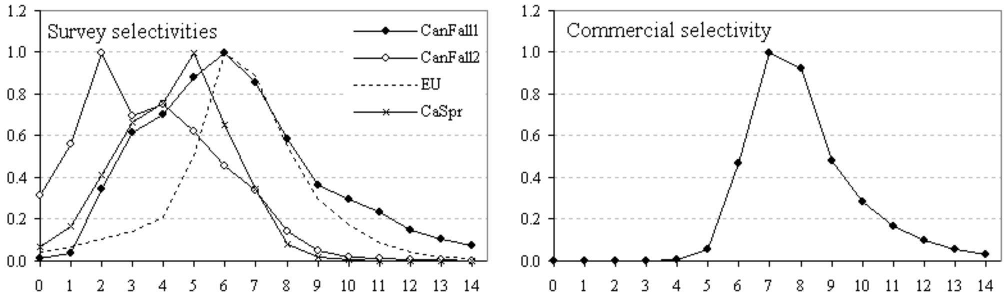

Fig. 2: Survey and commercial fishing selectivities-at-age estimated for the updated Baseline B2.

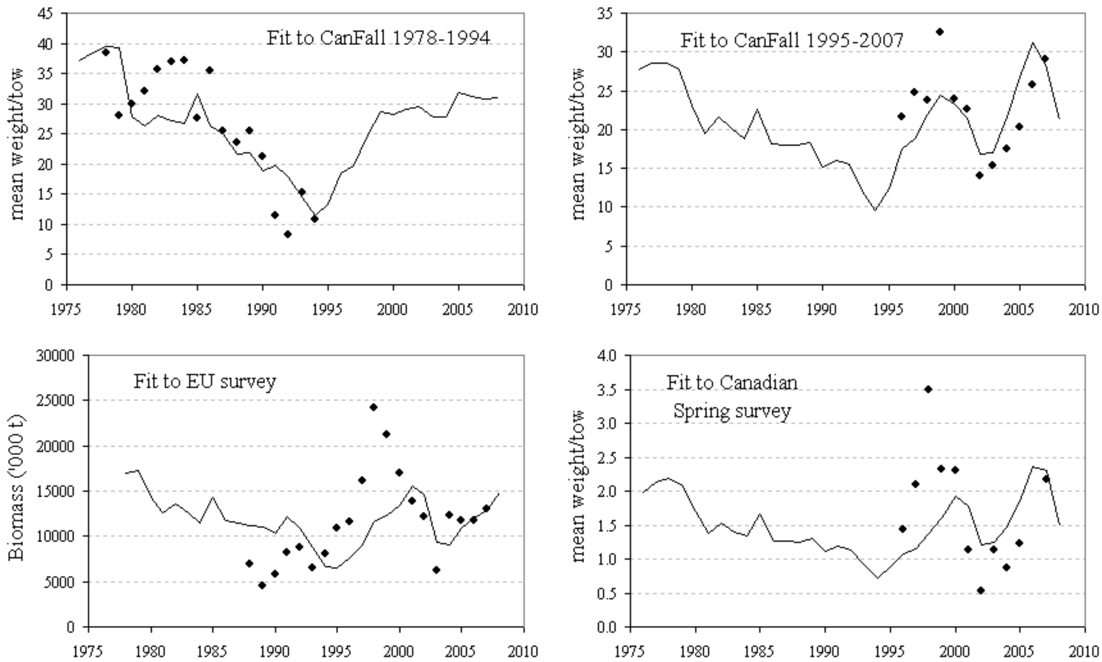

Fig. 3: Fits of the updated Baseline B2 to the abundance indices provided by the survey series.

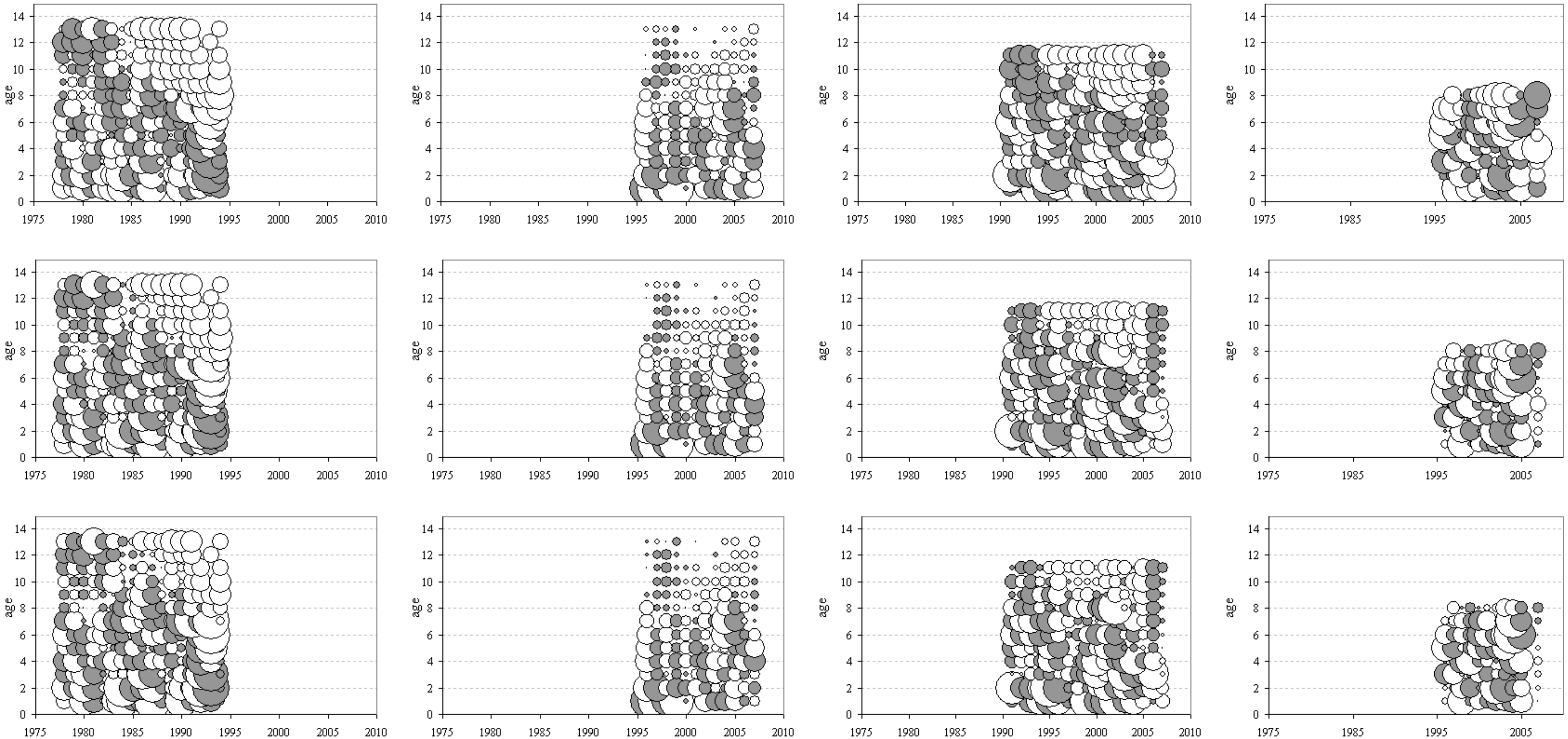

Fig. 4: Standardised residual plots for the survey proportions-at-age data for the updated Baseline B2 (top row) and for variants 1 and 2 with the extent of variation in survey selectivities (in 2 year periods) increased to σ_{Ω} =1.0 (middle row) and 2.0 (bottom row).

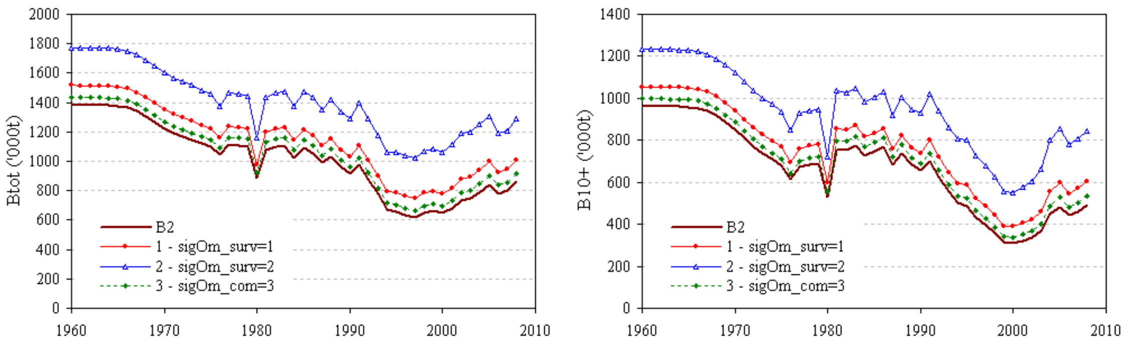

Fig. 5: Comparison of total (1+) and spawning (10+) biomass trajectories for the updated Baseline B2 and alternative specification for the extent of temporal variation in either survey or commercial selectivity at age σ_Ω (see also Table 1). .

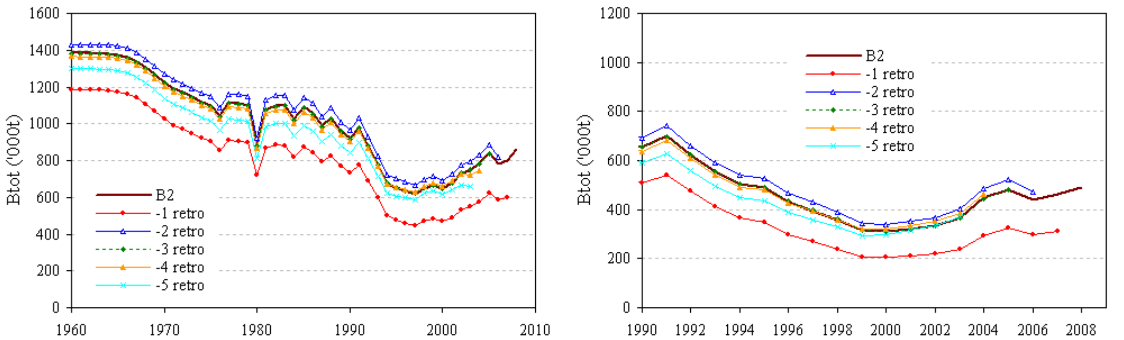

Fig. 6: Comparison of total (1+) biomass trajectories for the updated Baseline B2 and retrospectives from 1 to 5 years (see also Table 2)..

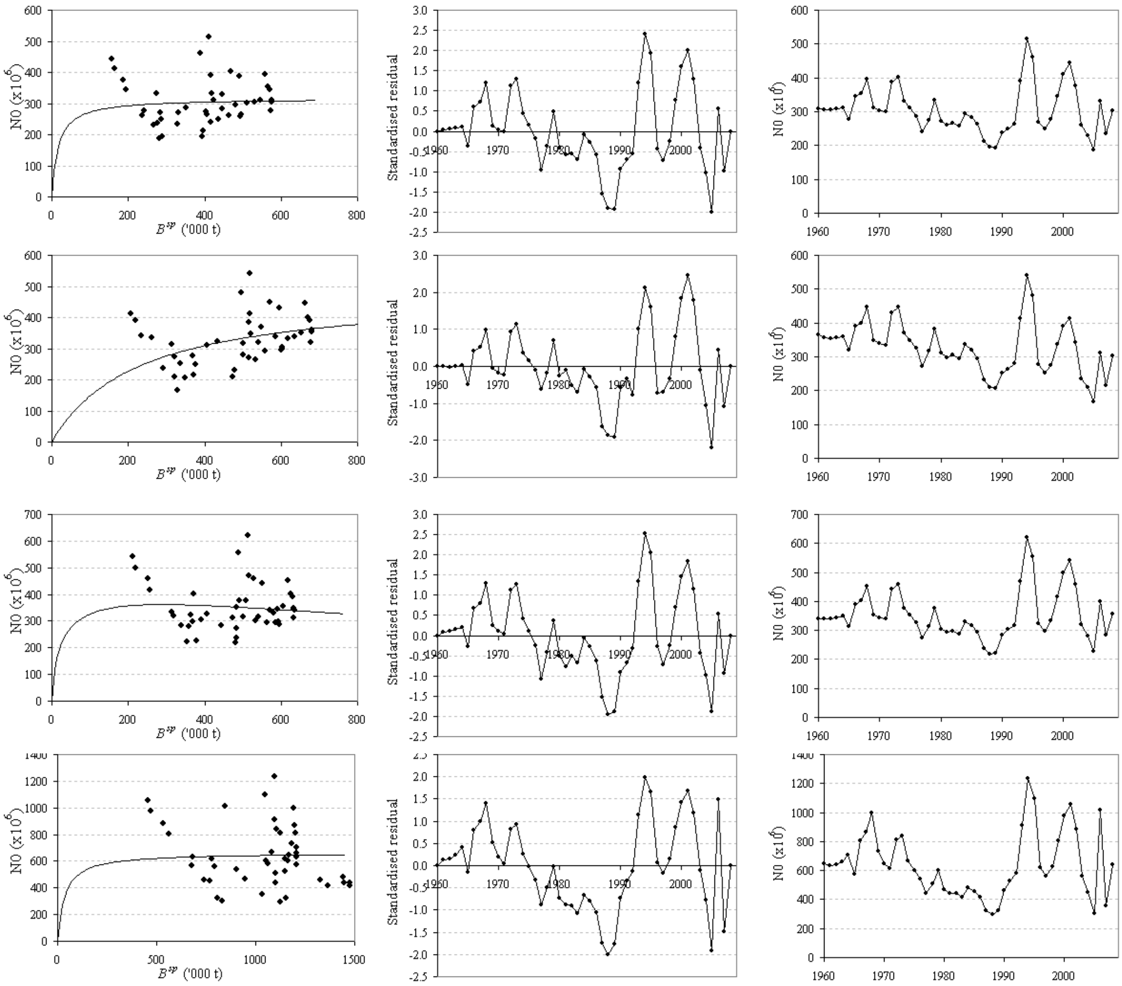

Fig. 7: Stock-recruitment curve and time series of recruitment and standardised stock-recruitment residuals for the updated Baseline B2 model (σ_R=0.25, h=0.9, top row), variant 5 (h=0.5, second row), variant 6 (Ricker-type, third row) and variant 7 (σ_R=0.35, bottom row) (see also Table 3).

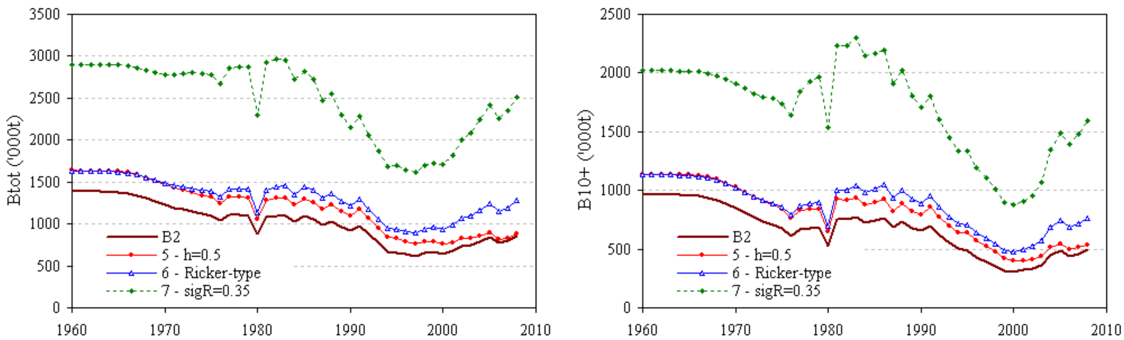

Fig. 8: Comparison of total (1+)and spawning (10+) biomass trajectories for the updated baseline B2 and alternative assumptions regarding the stock-recruitment relationship (see also Table 3).

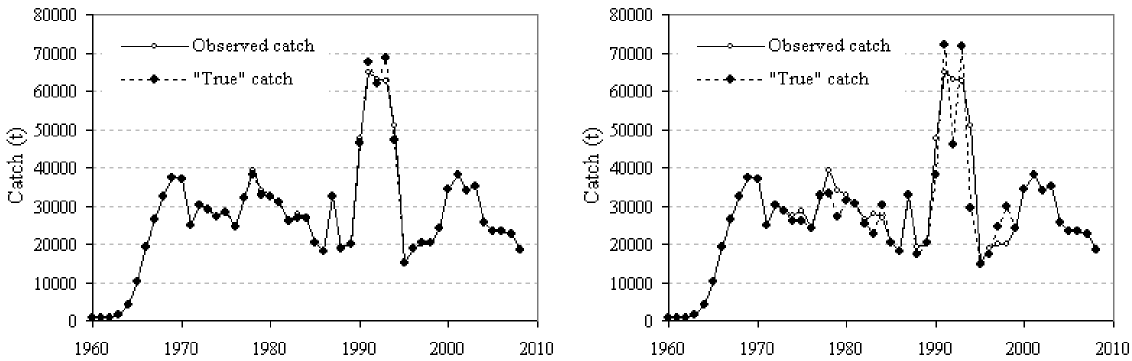

Fig. 9: Comparison of observed and "true" catch for variants 8 (σ_C=0.1, left) and 9 (σ_C=0.2, right) (see also Table 4).

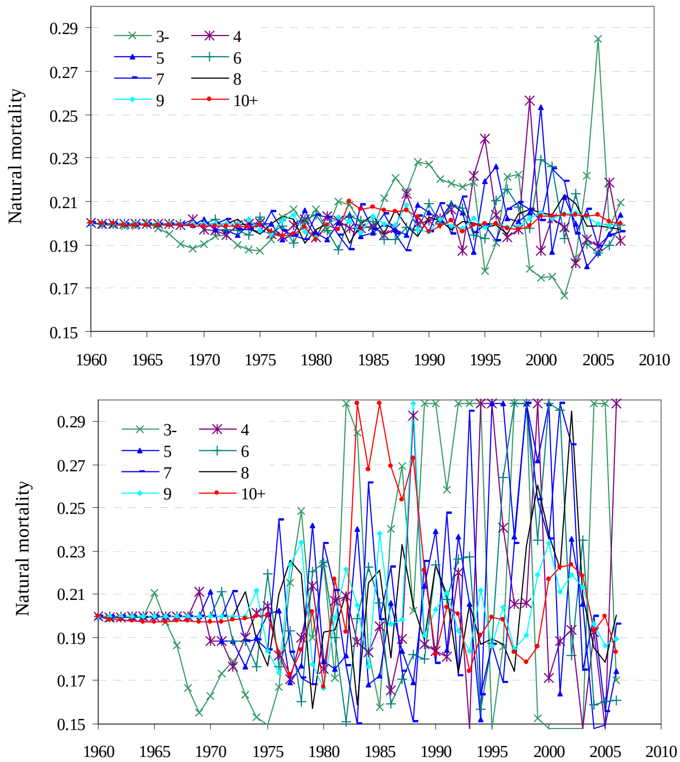

Fig. 10: Time series of natural mortality at age for variants 10 (σ_M=0.2, top) and 11 (σ_M=0.4, bottom) (see also Table 4).

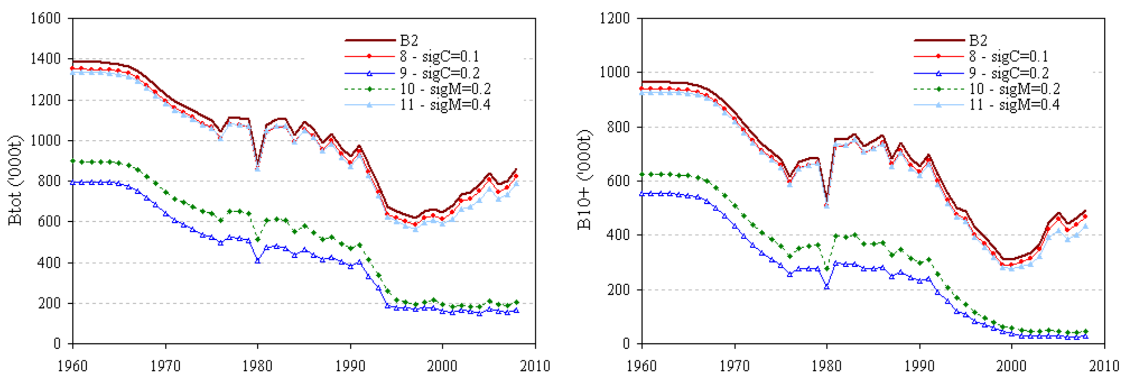

Fig.11: Comparison of total (1+) and spawning (10+) biomass trajectories for the updated Baseline B2 and variants allowing for errors in annual reported catches or natural mortality in time and age (see also Table 4).

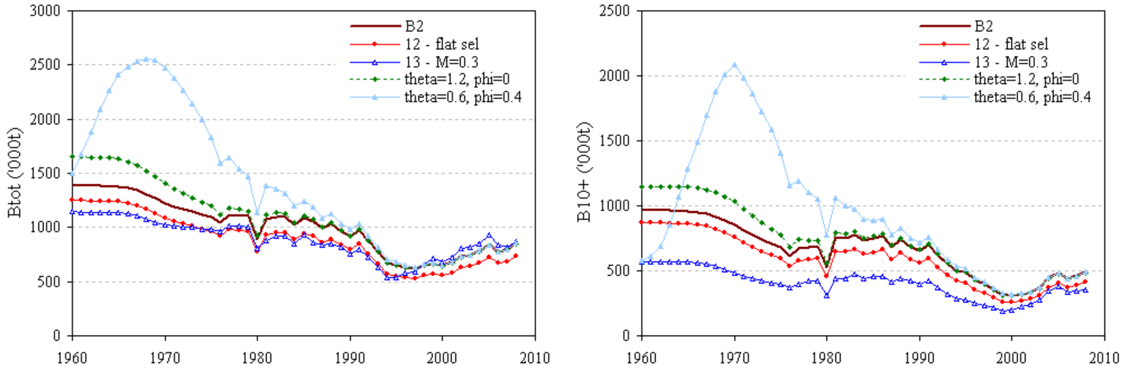

Fig.12: Comparison of total (1+) and spawning (10+) biomass trajectories for the updated Baseline B2, flat selectivity at large ages and higher natural mortality (see alsoTable 4), and two extreme cases of non-equilibrium starting conditions in 1960 (see also Table 6).

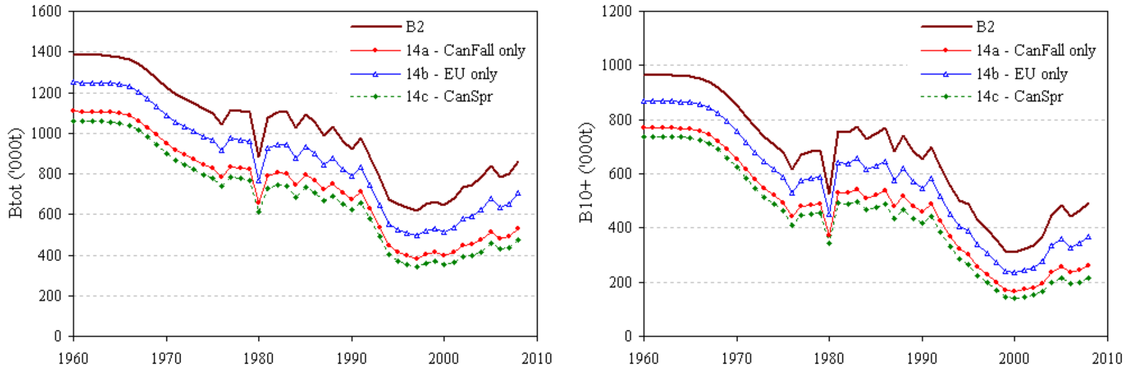

Fig.13: Comparison of total (1+) and spawning (10+) biomass for the updated Baseline B2, and variants 14a-c which fit to one survey series only, rather than all three simultaneously as for B2 (see also Table 5).

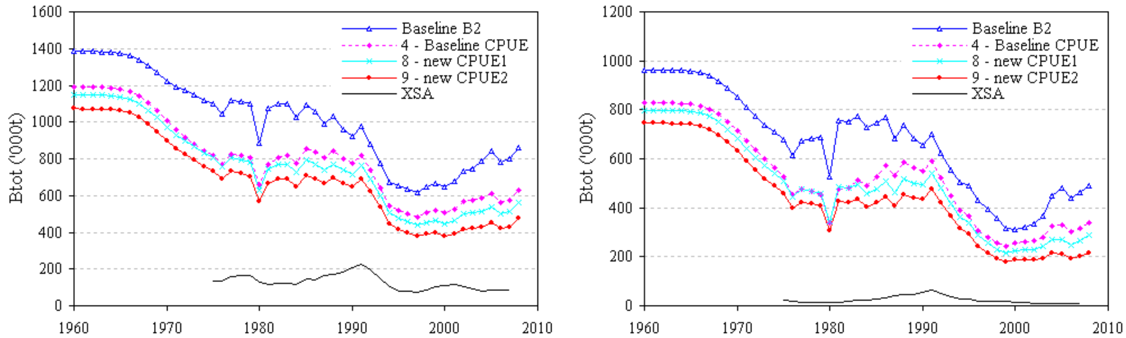

Fig.14: Comparison of total (1+) and spawning (10+) biomass for the Baseline CPUE, variants 8 and 9 with the new CPUE (Butterworth and Rademeyer, 2009b), the updated Baseline B2 based on surveys and the XSA assessment of Healey and Mahé (2008).