Initial results for the application of Statistical-Catch-At-Age methodology to the stock of pollock in Subareas 5 and 6

Doug S. Butterworth and Rebecca A. Rademeyer

Introduction

This paper presents some initial results for the application of Statistical-Catch-at-Age (SCAA) assessment methodology to the pollock population in Subareas 5 and 6. Since it is unclear how best to treat some of the survey indices available for this assessment, the approach taken has been to start minimalistically. Thus the Base Case assessment is fit to the two longest and best understood series only: the NEFSC spring and fall surveys.

Two sets of variants to this Base Case assessment are considered. First the other abundance indices are added to those used for the Base Case, typically one at a time to see their different impacts while maintaining the other assumptions associated with the Base Case. Then those Base Case assumptions are varied, but only for the situation where the NEFSC spring and fall surveys alone are used as input to the assessment.

Data and methodology

The data used and SCAA methodology applied are fully described in Appendices A and B respectively.

Results

Results for the Base Case and variants including additional survey indices are shown in Table 1. For the Base Case, the natural mortality M is fixed at 0.2; the population is assumed to be at unexploited equilibrium level in 1960 (θ=1, ζ=0); and the steepness parameter h is estimated at its upper bound of 0.9. The commercial selectivity for the US fleet is assumed to have changed over the 1985-1988 period (i.e. there are two constant selectivity periods: 1960-1985 and 1988-2009, with linear change between them), as this removed some systematic patterns in the commercial catch-at-age residuals. The NEFSC spring survey is taken to have fixed selectivity for age 8 and above, while for the NEFSC fall survey, the selectivity is assumed flat for age 7 and above.

Spawning biomass trajectories for the Base Case are plotted in Fig. 1, while the estimated survey, commercial, discard and recreational selectivities for this case are shown in Fig. 2. The Beverton-Holt stock-recruitment relationship estimated for the Base Case is shown Fig. 3, together with time-trajectories of recruitment and recruitment residuals. The Base Case fits to the NEFSC spring and fall survey indices are plotted in Fig. 4, while the fits to the commercial and survey CAA information are plotted in Fig. 5.

In addition to the NEFSC spring and fall surveys, Case 2 (Table 1) also fits to the Maine/New Hampshire spring and fall surveys and the Massachusetts inshore survey. These three surveys are treated as indices of recruitment (age 1 only). The fit of Case 2 to the five surveys is shown in Fig. 6. Although the model is not fit to this information, the observed and model predicted survey CAL data are shown in Fig. 7. The purpose is to indicate that the lengths sampled in these surveys correspond mainly to pollock of age 1, hence the decision to treat these as indices of recruitment. Fig. 7 also shows that the length distributions concerned are complex, with a finer structure than that suggested by age alone, which argues against attempting to fit these length distributions closely with simple models based on age-specific selectivities.

Case 3 (Table 1) also includes the larval index as an index of spawning biomass. The fit of this case to the two NEFSC surveys and this larval index is shown in Fig. 8.

For Case 4, all the surveys available, apart from the NEFSC summer survey, are included in the model fit.

Finally Cases 5 and 6 include the NEFSC summer survey, first assuming a uniform selectivity for ages 1 to 3 (Case 5), and then assuming an (estimated) exponential decline from ages 1 to 3. The choice of up to age 3 only was based on the observation of a sudden drop in frequencies for lengths above about 50 cm. The fit to the three surveys is shown in Fig. 9 for Case 5, while the fit to the NEFSC summer CAL information and the length-at-age distribution are plotted in Figs 10 and 11 respectively.

Tables 2 and 3 compare the results for the Base Case and a series of sensitivities which involve different assumptions about selectivities, stock-recruit steepness, natural mortality and the form of the stock-recruitment relationship. Table 4 shows how estimates of current depletion for the Base Case are impacted by alternative specifications (than unexploited equilibrium) for the status of the population at the start of the catch series in 1960.

Fig. 12 compares the US commercial CAA residuals for the Base Case and for Case 9 which does not allow for a change in selectivity over time, to illustrate the lesser patterning (evidence for greater randomness) for the former.

Finally, in Fig. 13, the stock-recruitment relationships and the trajectories of recruitment residuals are plotted for the Base Case and Cases 12a (true Ricker stock-recruitment relationship) and 12b (generalised form of the Ricker stock-recruitment curve).

Discussion

The various assessments uniformly reflect a resource now fairly close to its unexploited level after having been depleted well below that level in 1990. Estimates of MSY are for the most part in the 20-30 thousand ton range. Importantly however, the precision of these estimates is not that high, particularly for MSY.

Of the sensitivities, addition of the larval index raises the scale of typical biomasses. Changing assumptions about selectivities has little impact, while steepness h needs to drop below h = 0.5 before becoming rejected compared to the Base Case in AIC terms. Changing the value of natural mortality M or the form of the stock-recruitment relationship have effects (though not large ones) in the expected directions. Changing the age at which older fish are aggregated for inclusion in catch-at-age likelihood function also makes little impact. Finally estimates of current depletion of the resource are little affected by alternative specifications for the depletion and age structure of the resource in 1960.

Acknowledgments

The data have kindly been provided by Liz Brooks.

Table 1: Estimates of management quantities for the SCAA Base Case and variants including additional survey indices. Biomasses are in thousand tons. Quantities shown in parenthesis are Hessian-based CVs. The Maine/New Hampshire and Massachusetts inshore surveys are taken as indices of recruitment (age 1 only). For case 6, a selectivity function for ages 1-3 is fitted by including the year-averaged length distribution data for the NEFSC summer surveys in the likelihood.

	1.Base Case: fit to NEFSC spring and fall surveys only			2. as 1. incl. Maine/NH and Mass. inshore surveys as recruitment indices			3. as 1. incl. larval index			4. as 1. incl. Maine/NH and Mass. inshore surveys and larval index			5. as 1. incl. NEFSC summer survey (uniform sel, ages 1-3)			6. as 1. incl. NEFSC summer survey (exp sel, ages 1-3)		
'-lnL:overall	-12.6			49.8			-10.3			52.3			-22.0			-22.8		
'-lnL:Survey	-41.7			16.0			-40.2			17.4			-53.4			-54.6		
'-lnL:CAA	-7.9			-6.7			-7.2			-5.8			-7.2			-7.4		
'-lnL:CAAsurv	29.4			29.5			29.9			30.1			29.3			29.1		
'-lnL:CALsurv	-			-			-			-			0.2			0.7		
'-lnL:RecRes	7.6			11.0			7.3			10.6			9.1			9.3		
h	0.90			0.90			0.90			0.90			0.90			0.83		
M	0.2			0.2			0.2			0.2			0.2			0.2		
θ	1.0			1.0			1.0			1.0			1.0			1.0		
ζ	0.0			0.0			0.0			0.0			0.0			0.0		
K^{sp}	432	(0.40)		366	(0.33)		2439	(3.75)		1443	(2.27)		431	(0.40)		434	(0.40)	
B^{sp}_{2009}	356	(0.48)		318	(0.40)		2229	(3.87)		1395	(2.39)		383	(0.47)		376	(0.47)	
B^{sp}_{2009}/K^{sp}	0.83	(0.13)		0.87	(0.12)		0.91	(0.15)		0.97	(0.15)		0.89	(0.12)		0.87	(0.15)	
$MSYL^{sp}$	0.19			0.19			0.18			0.18			0.19			0.22		
B^{sp}_{MSY}	81	(0.40)		69	(0.33)		442	(3.75)		261	(2.27)		81	(0.40)		95	(0.69)	
$B^{sp}_{2009}/MSYL^{sp}$	4.4	(0.13)		4.6	(0.12)		5.0	(0.15)		5.3	(0.15)		4.8	(0.13)		4.0	(0.57)	
MSY	28	(0.40)		24	(0.33)		153	(3.75)		90	(2.27)		28	(0.40)		25	(0.69)	
com CAA σ	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.
Commercial	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15
Discard	0.27			0.28			0.28			0.29			0.28			0.28		
Recreational	0.26			0.27			0.26			0.27			0.27			0.26		
Survey	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ
NEFSC spring	1.87	0.00	0.27	2.20	0.00	0.26	0.27	0.00	0.27	0.45	0.00	0.26	1.90	0.00	0.27	1.91	0.00	0.27
NEFSC fall	1.13	0.00	0.28	1.34	0.00	0.29	0.20	0.00	0.28	0.33	0.00	0.29	1.12	0.00	0.28	1.14	0.00	0.27
NEFSC summer	-	-	-	-	-	-	-	-	-	-	-	-	1.13	0.00	-	2.66	0.00	-
Maine/NH spring	-	-	-	2.42	0.00	-	-	-	-	0.61	0.00	-	-	-	-	-	-	-
Maine/NH fall	-	-	-	1.43	0.00	-	-	-	-	0.36	0.00	-	-	-	-	-	-	-
Inshore spring	-	-	-	1.62	2.00	-	-	-	-	0.41	2.00	-	-	-	-	-	-	-
Larval Index	-	-	-	-	-	-	8066	0.02	-	13670	0.02	-	-	-	-	-	-	-
σ_R(out)	0.23			0.27			0.22			0.27			0.25			0.25		

Table 2: Estimates of management quantities for the Base Case and some sensitivities. Biomasses are in thousand tons. Quantities shown in parenthesis are Hessian-based CVs.

	1.Base Case: fit to NEFSC spring and fall surveys only			7. as 2. but the recruitment indices are indices of the age 2 as well (S(2)=0.5)			8. as 1. but survey selectivity flat from age 7 instead of age 8			9. as 1. but US commercial selectivity not changing over the years			10a. As 1. but h=0.7			10b. As 1. but h=0.5			10c. As 1. but h=0.4		
'-lnL:overall	-12.6			51.9			-11.5			-4.9			-12.3			-11.6			-10.9		
'-lnL:Survey	-41.7			19.4			-41.7			-41.6			-41.5			-41.2			-41.0		
'-lnL:CAA	-7.9			-6.9			-7.9			0.7			-7.8			-7.7			-7.5		
'-lnL:CAAsurv	29.4			29.3			30.4			29.4			29.3			29.3			29.3		
'-lnL:CALsurv	-			-			-			-			-			-			-		
'-lnL:RecRes	7.6			10.2			7.7			6.7			7.7			8.0			8.3		
h	0.90			0.90			0.90			0.90			0.70			0.50			0.40		
M	0.2			0.2			0.2			0.2			0.2			0.2			0.2		
θ	1.0			1.0			1.0			1.0			1.0			1.0			1.0		
ζ	0.0			0.0			0.0			0.0			0.0			0.0			0.0		
K^{sp}	432	(0.40)		367	(0.32)		406	(0.36)		389	(0.37)		473	(0.41)		629	(0.51)		907	(0.76)	
B^{sp}_{2009}	356	(0.48)		315	(0.40)		334	(0.43)		311	(0.45)		380	(0.50)		499	(0.64)		733	(0.90)	
B^{sp}_{2009}/K^{sp}	0.83	(0.13)		0.86	(0.12)		0.82	(0.12)		0.80	(0.13)		0.80	(0.14)		0.79	(0.16)		0.81	(0.18)	
$MSYL^{sp}$	0.19			0.19			0.19			0.20			0.26			0.32			0.35		
B^{sp}_{MSY}	81	(0.40)		69	(0.32)		77	(0.36)		77	(0.37)		124	(0.41)		203	(0.51)		315	(0.76)	
$B^{sp}_{2009}/MSYL^{sp}$	4.4	(0.13)		4.6	(0.12)		4.3	(0.12)		4.0	(0.13)		3.1	(0.14)		2.5	(0.16)		2.3	(0.18)	
MSY	28	(0.40)		24	(0.32)		27	(0.36)		23	(0.37)		23	(0.41)		20	(0.51)		20	(0.76)	
com CAA σ	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.
Commercial	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.15	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15
Discard	0.27			0.28			0.27			0.27			0.27			0.28			0.28		
Recreational	0.26			0.27			0.26			0.26			0.26			0.26			0.26		
Survey	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ
NEFSC spring	1.87	0.00	0.27	2.20	0.00	0.26	1.83	0.00	0.27	2.15	0.00	0.27	1.74	0.00	0.27	1.29	0.00	0.27	0.86	0.00	0.27
NEFSC fall	1.13	0.00	0.28	1.33	0.00	0.28	1.21	0.00	0.28	1.26	0.00	0.28	1.06	0.00	0.28	0.83	0.00	0.28	0.58	0.00	0.28
NEFSC summer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine/NH spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine/NH fall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inshore spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Larval Index	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
σ_R(out)	0.23			0.26			0.23			0.21			0.23			0.23			0.23		

Table 3: Estimates of management quantities for the Base Case and some sensitivities. Biomasses are in thousand tons. Quantities shown in parenthesis are Hessian-based CVs.

	1.Base Case: fit to NEFSC spring and fall surveys only			11a. As 1. with M=0.25			11b. As 1. with M=0.3			12a. As 1. with Ricker SR instead of Beverton-Holt			12b. As 1. with generalised Ricker instead of BH			13. As 1. with plus-groups of 10+ and 8+ for the NEFSC spring and fall surveys		
'-lnL:overall	-12.6			-12.6			-12.4			-13.0			-13.2			-8.2		
'-lnL:Survey	-41.7			-41.6			-41.6			-42.1			-42.2			-41.8		
'-lnL:CAA	-7.9			-7.9			-7.8			-7.9			-7.7			-7.8		
'-lnL:CAAsurv	29.4			29.4			29.5			29.6			29.4			33.7		
'-lnL:CALsurv	-			-			-			-			-			-		
'-lnL:RecRes	7.6			7.6			7.5			7.5			7.4			7.7		
h	0.90			0.90			0.90			0.71			0.46			0.90		
M	0.2			0.25			0.30			0.2			0.2			0.2		
θ	1.0			1.0			1.0			1.0			1.0			1.0		
ζ	0.0			0.0			0.0			0.0			0.0			0.0		
K^{sp}	432	(0.40)		363	(0.43)		327	(0.47)		355	(0.43)		320	(0.46)		439	(0.40)	
B^{sp}_{2009}	356	(0.48)		297	(0.51)		264	(0.55)		319	(0.47)		312	(0.49)		365	(0.48)	
B^{sp}_{2009}/K^{sp}	0.83	(0.13)		0.82	(0.13)		0.81	(0.13)		0.90	(0.12)		0.97	(0.12)		0.83	(0.12)	
$MSYL^{sp}$	0.19			0.19			0.19			0.40			0.60			0.19		
B^{sp}_{MSY}	81	(0.40)		68	(0.43)		62	(0.47)		141	(0.42)		193	(0.29)		83	(0.40)	
$B^{sp}_{2009}/MSYL^{sp}$	4.4	(0.13)		4.3	(0.13)		4.3	(0.13)		2.3	(0.32)		1.6	(0.40)		4.4	(0.12)	
MSY	28	(0.40)		30	(0.43)		32	(0.47)		22	(0.42)		19	(0.29)		29	(0.40)	
com CAA σ	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.	US	Can	Dist.F.
Commercial	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15	0.11	0.17	0.15
Discard	0.27			0.27			0.27			0.27			0.28			0.27		
Recreational	0.26			0.26			0.26			0.26			0.26			0.26		
Survey	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ	q'sx10^9	σ_{add}	CAA σ
NEFSC spring	1.87	0.00	0.27	1.90	0.00	0.27	1.88	0.00	0.27	2.10	0.00	0.27	2.13	0.00	0.27	1.81	0.00	0.26
NEFSC fall	1.13	0.00	0.28	1.05	0.00	0.28	0.97	0.00	0.28	1.27	0.00	0.28	1.29	0.00	0.28	1.09	0.00	0.27
NEFSC summer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine/NH spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine/NH fall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inshore spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Larval Index	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
σ_R(out)	0.23			0.22			0.22			0.22			0.22			0.23		

Table 4: Total negative log-likelihood and current depletion for alternative specifications of starting conditions in 1960. θ is the starting value of B/K and ζ the average fishing mortality over immediately preceding years (the Base Case has θ=1 and ζ=0). Cases for which the -lnL is worse by more than 1 likelihood point are shaded.

		θ=1	θ=0.75	θ=0.5	θ=0.25	θ=0.15
ζ=0	'-lnL:overall	-12.55	-12.56	-12.44	-11.63	-10.85
	B^{sp}_{2009}/K^{sp}	0.83	0.81	0.73	0.77	0.77
ζ=0.2	'-lnL:overall	-11.96	-12.44	-12.65	-12.30	-11.49
	B^{sp}_{2009}/K^{sp}	0.87	0.84	0.82	0.67	0.78
ζ=0.4	'-lnL:overall	-9.89	-11.08	-12.16	-12.70	-12.30
	B^{sp}_{2009}/K^{sp}	0.93	0.90	0.86	0.80	0.79
ζ=0.6	'-lnL:overall	-6.30	-8.18	-10.26	-12.32	-12.75
	B^{sp}_{2009}/K^{sp}	0.99	0.95	0.91	0.85	0.80

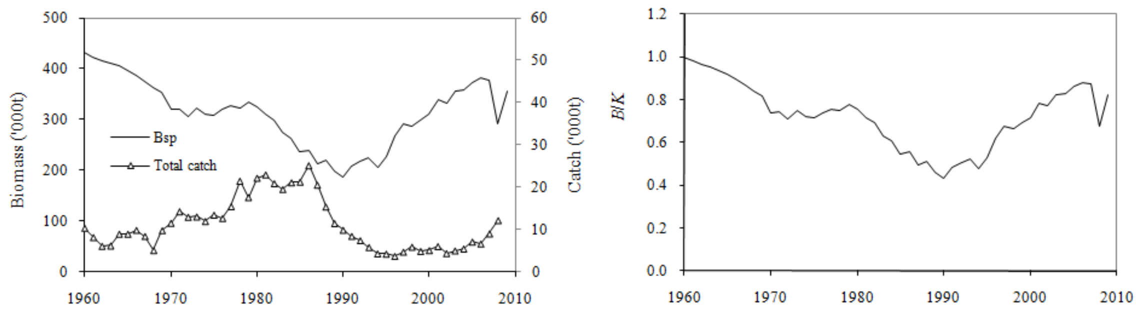

Fig. 1: Spawning biomass trajectories, in absolute terms and in terms of pre-exploitation levels, for the Base Case. The total catch is also shown.

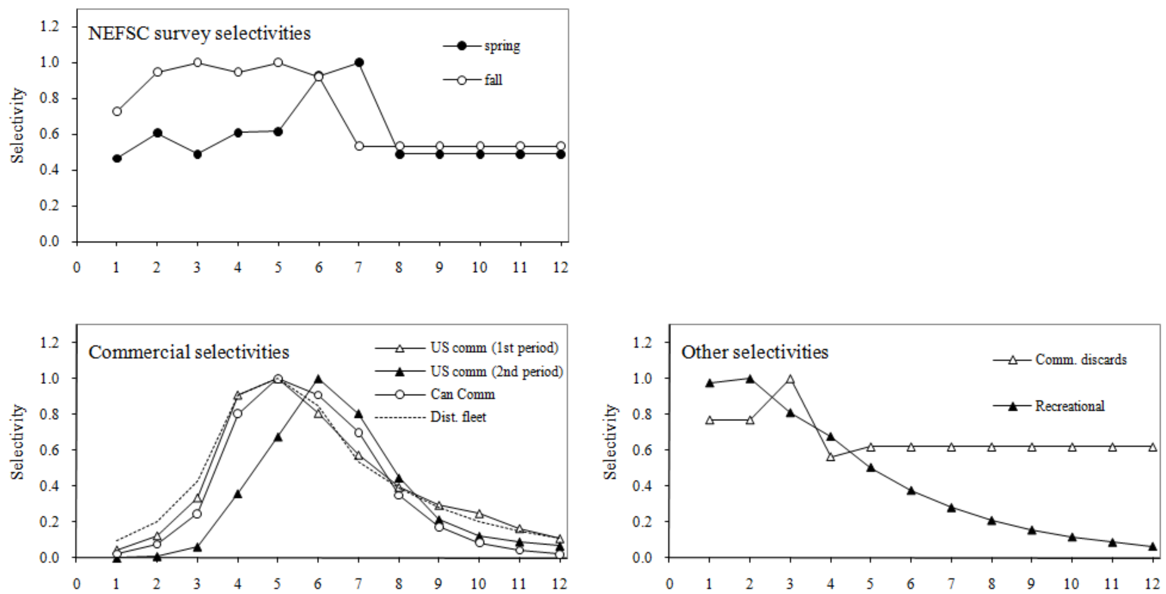

Fig. 2: Estimated survey, commercial, discard and recreational selectivities for the Base Case. The two selectivity periods for the US commercial are 1960-1985 and 1988-2009 with a linear change in between these periods.

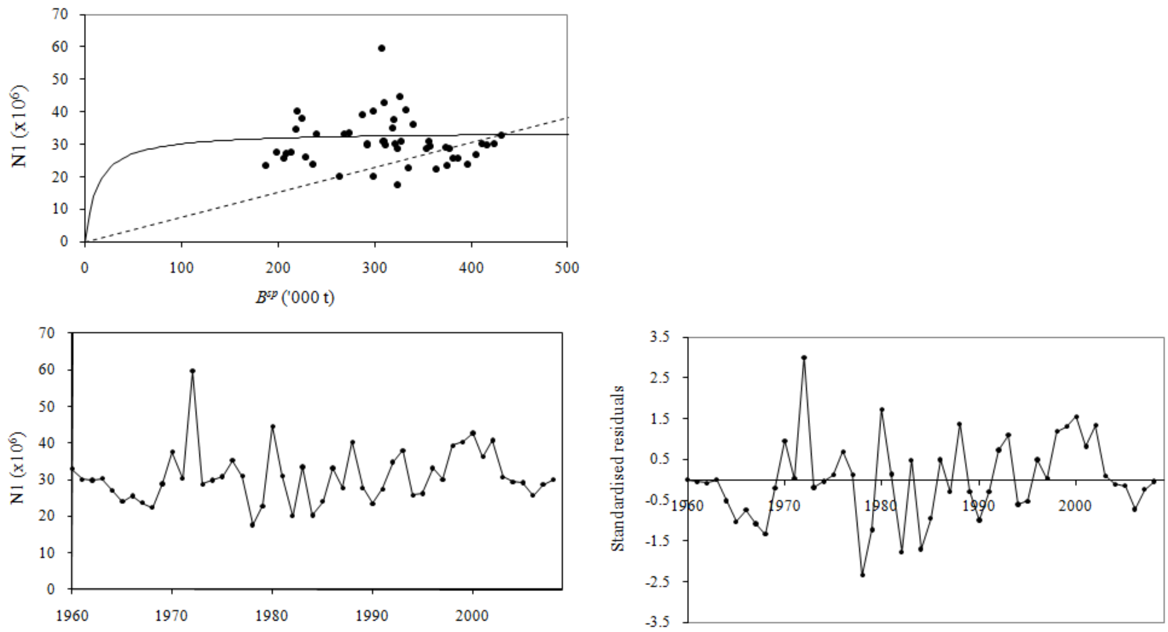

Fig. 3: Stock-recruitment curve (with the replacement line shown dashed) and time series of recruitment and standardised stock-recruitment residuals for the Base Case (Beverton-Holt, h=0.9, σ_R=0.4).

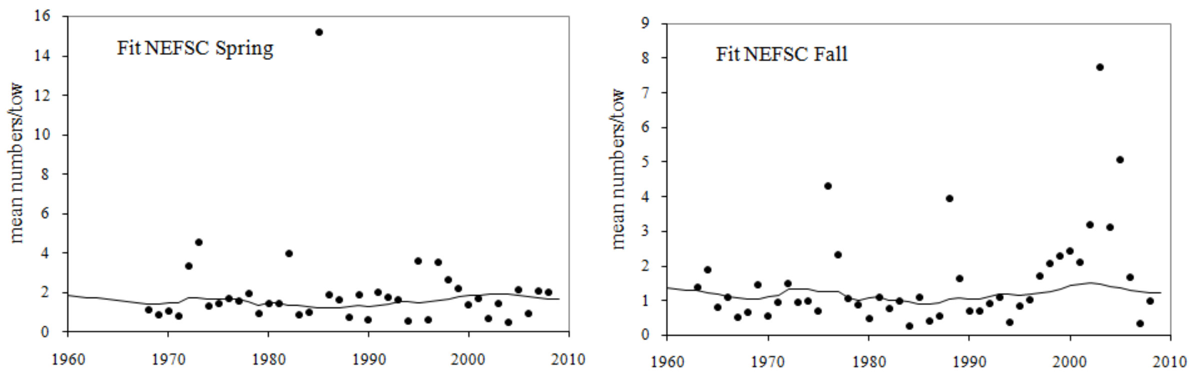

Fig. 4: Fit of the Base Case to the NEFSC spring and fall survey indices.

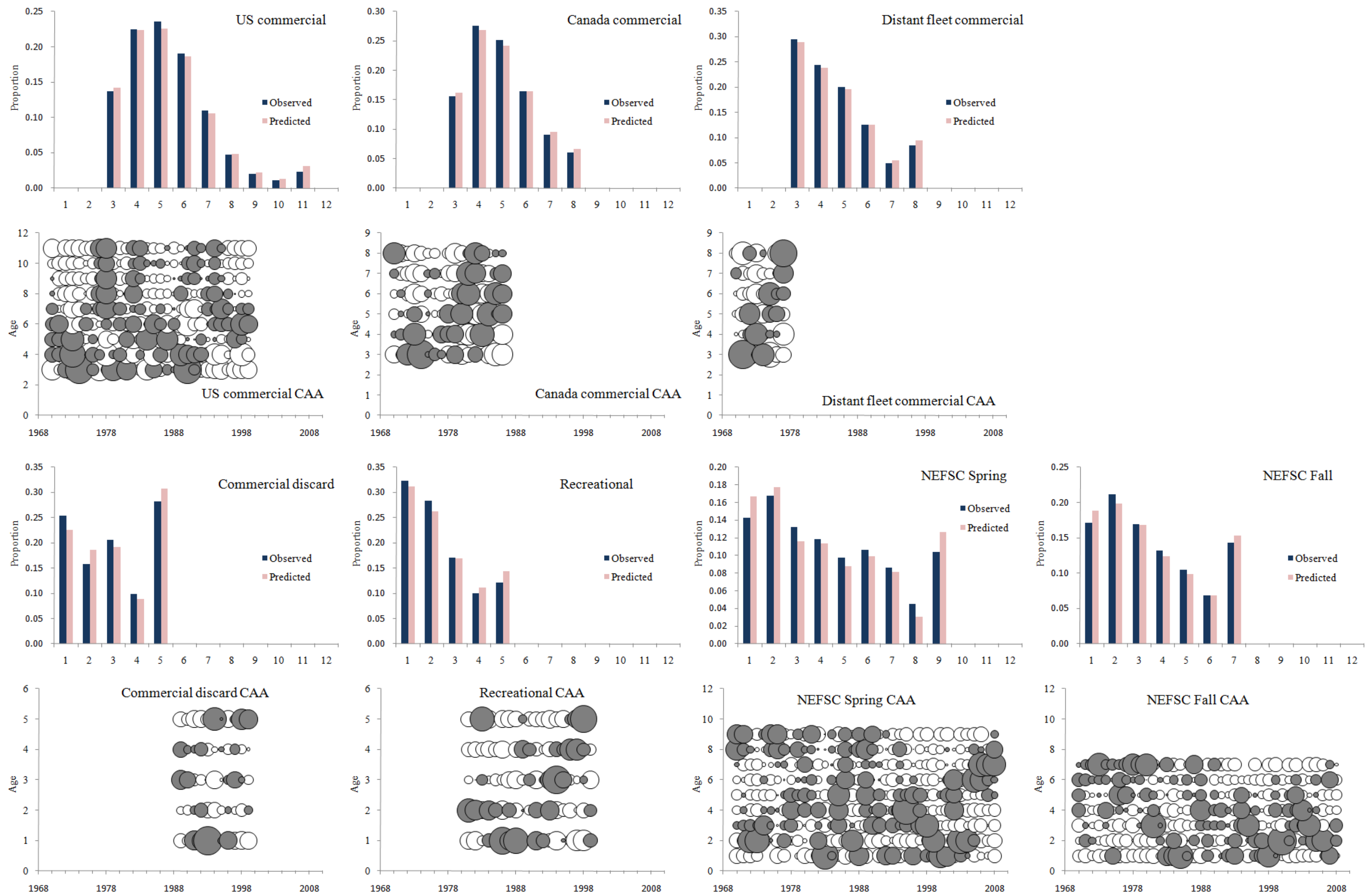

Fig. 5: Fit to the commercial and survey CAA information for the Base Case. The "bubble" plots show the residuals. The size (radius) of the bubble is proportional to the standardised residuals (white for positive residuals and gray for negative residuals).

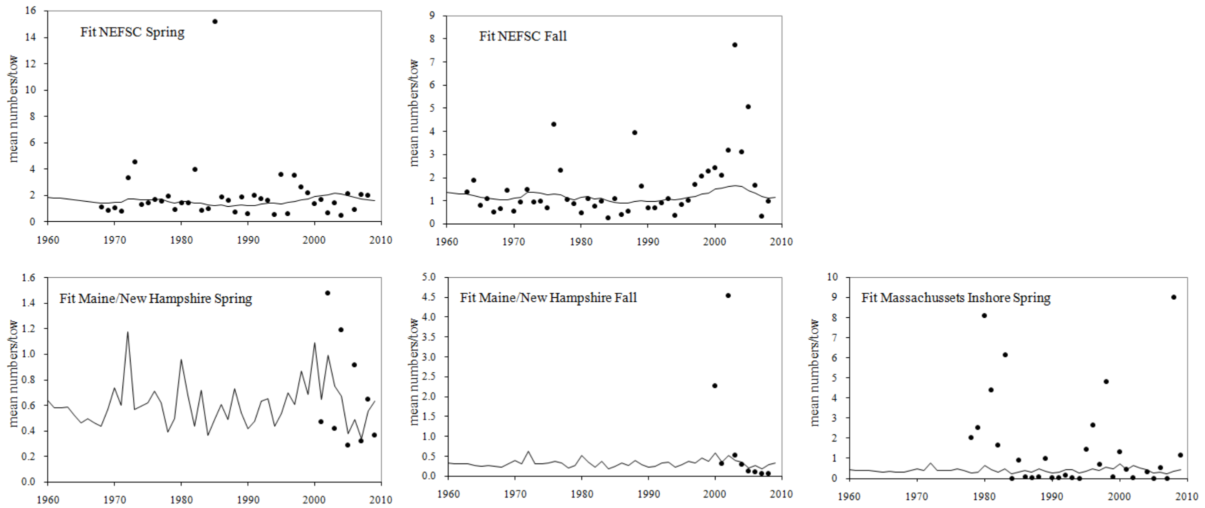

Fig. 6: Fit of the Case 2 to the NEFSC spring and fall, Main/New Hampshire spring and fall and Massachusetts inshore survey indices.

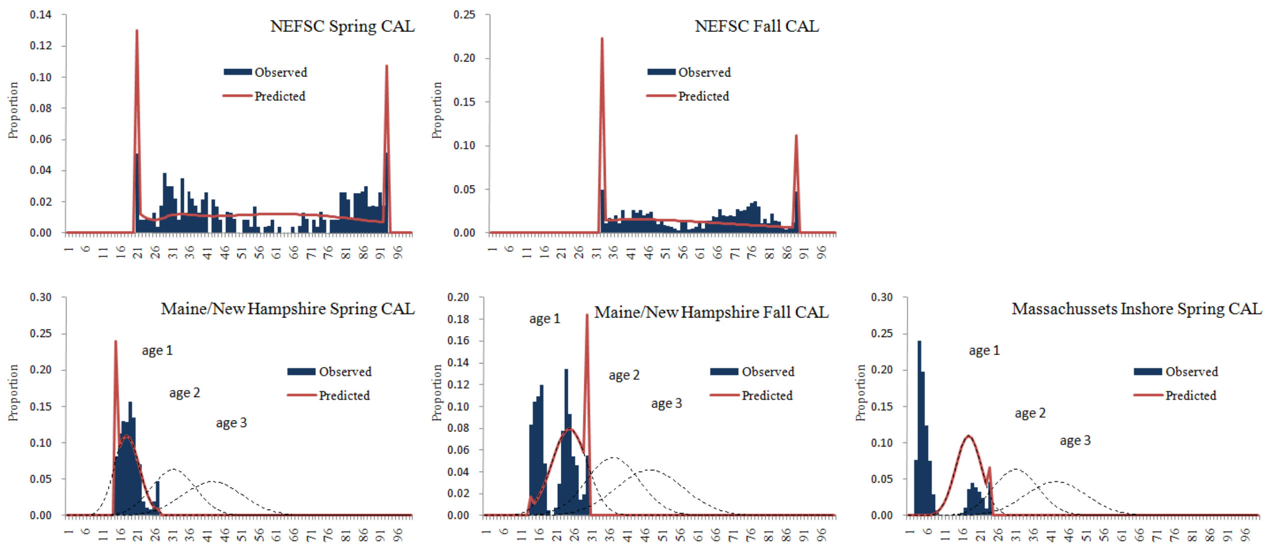

Fig. 7: Observed and predicted CAL distributions for Case 2 for the NEFSC spring and fall, Main/New Hampshire spring and fall and Massachusetts inshore surveys as averaged over all the years available. For the three surveys taken as recruitment indices (bottom row), the assumed length-at-age distributions for ages 1 to 3 are also shown. Note that this information is not included in the negative log-likelihood function.

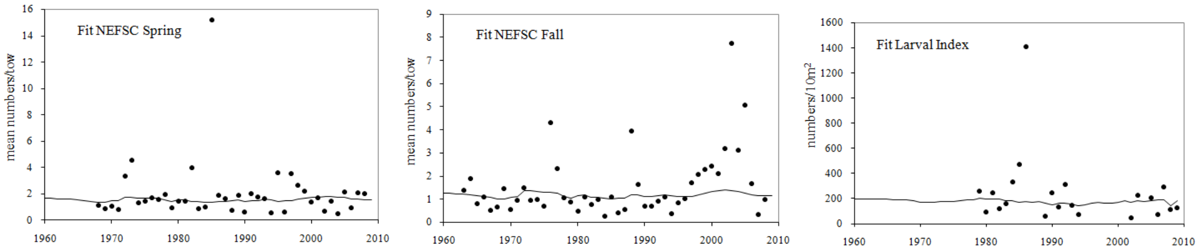

Fig. 8: Fit of the Case 3 to the NEFSC spring and fall surveys and the larval index.

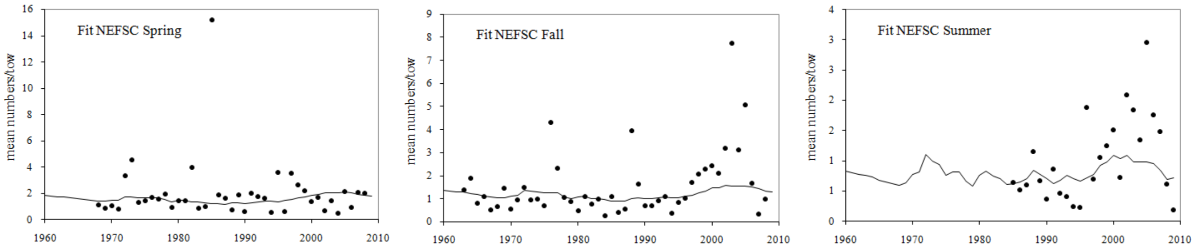

Fig. 9: Fit of the Case 5 to the NEFSC spring, fall and summer surveys indices.

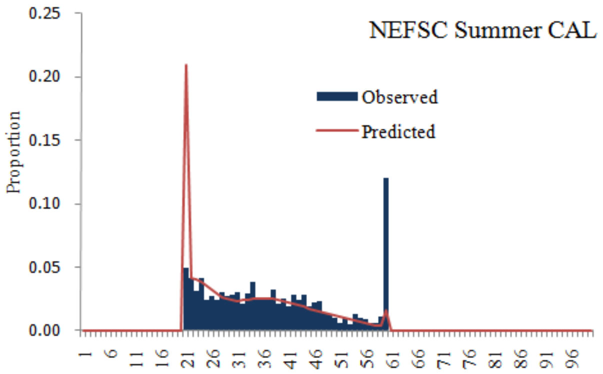

Fig. 10: Fit of Case 5 to the NEFSC summer CAL information, as averaged over all the years with data available.

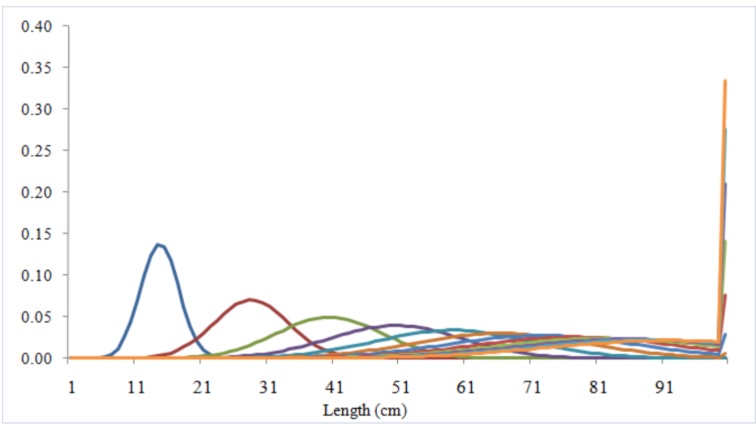

Fig. 11: Estimated length-at-age distributions used for the fit shown in Fig 9.

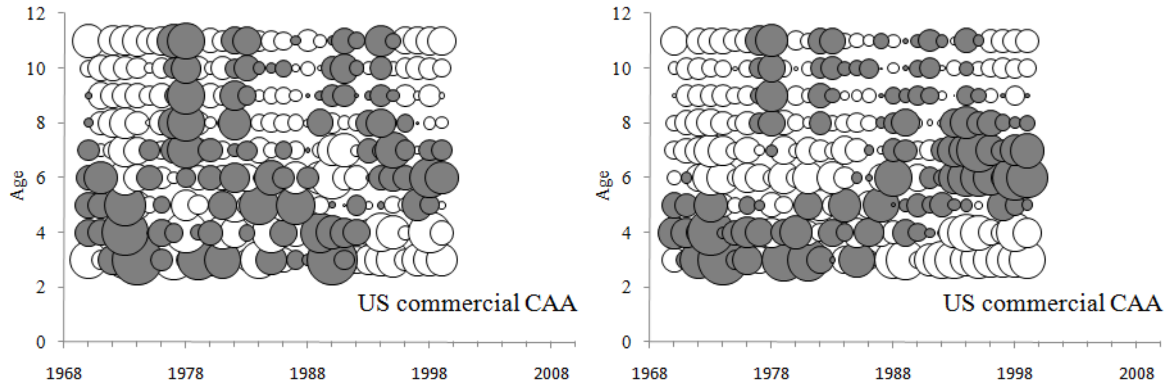

Fig. 12: Bubble plots of the standardised residuals of the US commercial CAA for the Base Case (left plot) and Case 9 with no changes in the US commercial selectivity over time (right plot).

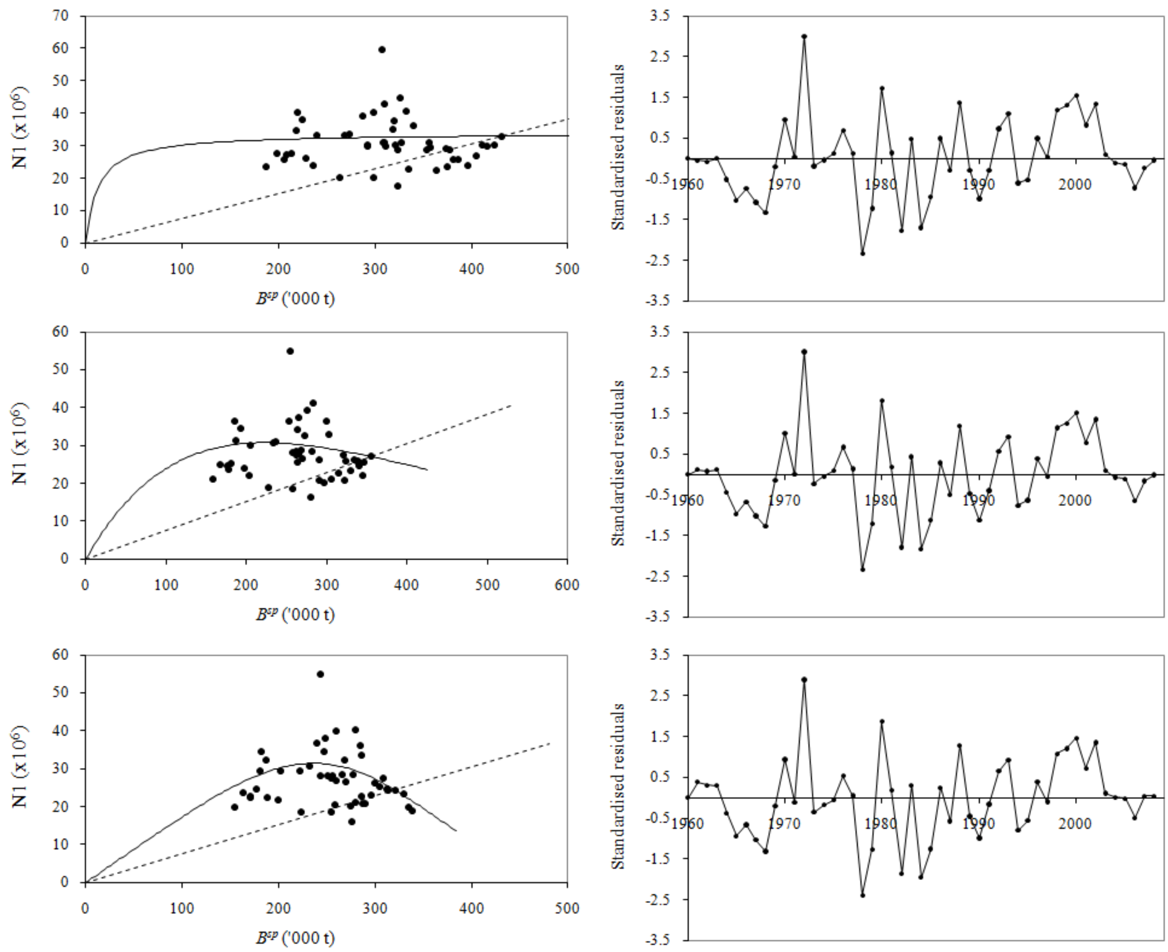

Fig. 13: Stock-recruitment curves (with replacement lines shown dashed) and time-series of standardised residuals for the Base Case (top row), Case 12a (Ricker - middle row) and Case 12b (generalised Ricker - bottom row).

Appendix A - Data used

Catches by fleet are given in Table A1.

Commercial catches-at-age are available for all fleets (Table A2).

Table A3 lists the available survey indices. The NEFSC spring and fall surveys indices for 2009 are available but are not used in the model fitting. These surveys have been conducted with a different vessel and no calibration factor is as yet available. Catches-at-age are available for the NEFSC spring and fall surveys (Table A4).

As the tables for proportions-at-length from each survey are rather large, they have not been included here. The maturity-at-age vector (Table A5) is taken to apply to the whole period.

Begin-year weights-at-age (based on the Rivard procedure) are shown in Table A6 for the period 1970 to 2008. For the period pre-1970, the average weights-at-age over the 1970-1974 period are used. For the projections and in the MSY calculations, the average weights-at-age over the 2004-2008 period are used.

Table A7 gives the mean weights-at-age for the commercial landings for the period 1970 to 1999. For the period pre-1970, the average weights-at-age over the 1970-1974 period are used. For the period post-1999 and in the MSY calculations, the average weights-at-age over the 1995-1999 period are used. These weights are used in the computation of the predicted exploitable biomass for the US commercial, Canadian commercial and distant fleets.

Table A8 gives the mean weights-at-age for the commercial discards for the period 1989 to 1999. For the period post-1999, the average weights-at-age over the 1995-1999 period are used. No assumption needs to be made pre-1989 as the assumption is made that there were no discards in this period.

Table A9 gives the mean weights-at-age for the recreational landings for the period 1981 to 1999. As for the commercial landings and discards, for the period post-1999, the average weights-at-age over the 1995-1999 period are used. No assumption need to be made pre-1981 as the recreational catch series starts in 1981.

Data are missing to compute weights-at-age in Tables A7-A9, particularly at older ages. The values in bold represent the missing data that have been replaced by the average of the closest available cells before and after those missing data.

Table A1: Catches by fleet in metric tons.

Year	US comm.	Canada comm.	Distant fleet	Comm. discard	Total recrea.
1960	8186	2211	0	0	0
1961	7861	359	0	0	0
1962	5550	601	0	0	0
1963	4673	953	615	0	0
1964	4764	1942	2298	0	0
1965	4903	2044	2040	0	0
1966	3232	4012	2664	0	0
1967	2741	5287	449	0	0
1968	2913	1740	499	0	0
1969	3521	2443	3872	0	0
1970	3586	853	7116	0	0
1971	4734	1636	7949	0	0
1972	5248	1366	6381	0	0
1973	5753	1727	5600	0	0
1974	7720	3539	755	0	0
1975	8190	4736	556	0	0
1976	9593	2116	1022	0	0
1977	11999	3413	104	0	0
1978	16758	4754	0	0	0
1979	14613	3032	0	0	0
1980	16567	5634	0	0	0
1981	17766	4050	0	0	1159
1982	13961	5373	1	0	1573
1983	13842	4383	0	0	1313
1984	17657	3290	0	0	180
1985	19192	1764	0	0	317
1986	24339	654	1	0	177
1987	20251	0	0	0	303
1988	14830	0	0	0	573
1989	10553	0	0	473	496
1990	9559	0	0	107	271
1991	7886	0	0	223	389
1992	7184	0	0	196	97
1993	5674	0	0	100	110
1994	3763	0	0	154	455
1995	3352	0	0	192	761
1996	2962	0	0	230	562
1997	4264	0	0	124	368
1998	5572	0	0	68	314
1999	4590	0	0	141	230
2000	4043	0	0	117	976
2001	4109	0	0	73	1921
2002	3580	0	0	68	792
2003	4794	0	0	45	210
2004	5070	0	0	103	354
2005	6509	0	0	100	534
2006	6067	0	0	69	552
2007	8372	0	0	147	568
2008	9965	0	0	362	1880
2009	*9965*	0	0	*362*	959

Table A2a: US commercial catch-at-age in numbers (thousands).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0	5	84	255	235	144	89	47	27	13	3	0
1971	0	72	256	406	372	297	101	44	1	2	0	0
1972	0	141	384	435	282	163	85	19	17	5	11	15
1973	0	15	333	1222	781	104	43	13	14	14	3	1
1974	0	59	1593	724	628	253	80	46	15	16	7	4
1975	0	77	343	1160	440	455	190	61	22	26	18	16
1976	0	51	748	1004	1513	335	237	59	4	1	3	7
1977	0	18	269	867	626	759	300	240	91	57	18	179
1978	0	87	687	520	614	597	885	330	255	127	79	200
1979	0	190	1278	1667	977	470	228	268	107	44	24	105
1980	0	174	377	1772	1410	874	491	177	152	71	33	69
1981	0	582	1414	631	1814	745	364	252	96	120	32	122
1982	0	102	1130	675	288	746	366	290	167	93	92	191
1983	0	29	808	2052	653	191	361	175	127	119	82	204
1984	0	42	507	1848	2944	637	114	160	124	104	42	114
1985	0	196	1835	675	1637	1835	286	81	98	122	52	117
1986	0	54	934	3079	873	1597	1165	176	56	145	87	133
1987	0	81	950	856	2703	546	637	413	94	43	98	161
1988	0	0	360	803	848	1614	441	262	158	26	21	76
1989	0	1	136	1255	776	447	496	186	77	49	18	69
1990	0	0	602	900	1131	371	199	145	67	52	37	68
1991	0	0	142	743	591	654	161	76	69	33	13	79
1992	0	0	32	398	753	440	347	81	27	22	14	37
1993	0	0	25	131	319	546	273	148	28	6	8	21
1994	0	0	2	59	176	274	231	90	36	14	8	27
1995	0	0	7	96	165	225	201	81	24	8	1	19
1996	0	0	19	151	214	251	134	69	20	4	1	3
1997	0	0	8	154	444	359	187	72	30	8	3	2
1998	0	0	10	44	318	689	332	92	16	6	1	2
1999	0	0	17	167	248	392	316	105	34	7	0	2

Table A2b: Canadian commercial catch-at-age in numbers (thousands).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0	1	16	53	46	32	28	21	9	5	2	0
1971	0	25	89	141	129	103	35	15	0	1	0	0
1972	0	37	100	113	73	42	22	5	4	1	3	4
1973	0	12	100	371	228	31	12	4	4	4	1	0
1974	0	26	668	330	297	133	38	20	9	7	5	1
1975	0	29	174	628	326	292	140	23	8	10	6	5
1976	0	11	107	154	280	83	89	17	3	1	1	4
1977	0	5	196	390	240	291	97	54	12	3	3	11
1978	0	4	137	536	527	213	199	43	23	3	3	3
1979	0	10	275	558	334	164	49	25	5	1	1	0
1980	0	20	38	268	779	482	162	42	26	5	1	0
1981	0	4	131	66	201	395	239	70	20	15	3	2
1982	0	18	486	219	78	259	317	148	54	24	12	3
1983	0	7	239	1200	161	31	67	107	55	21	6	7
1984	0	2	67	324	664	59	8	20	19	14	3	2
1985	0	0	18	84	157	208	48	6	7	9	5	2
1986	0	0	6	41	54	52	42	5	1	2	2	1

Table A2c: Distant fleet commercial catch-at-age in numbers (thousands).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0	640	336	681	603	388	276	175	85	48	20	2
1971	0	948	1143	720	518	396	141	58	1	1	0	0
1972	0	108	294	465	391	125	65	15	189	3	8	11
1973	0	539	431	1121	483	68	26	12	99	7	1	1
1974	0	2	153	56	43	25	8	4	3	6	8	6
1975	0	1	13	82	43	44	7	12	2	0	0	0
1976	0	17	50	77	155	49	28	5	1	1	1	3
1977	0	0	6	3	4	8	3	3	3	0	0	0

Table A2d: Commercial discards catch-at-age in numbers (thousands).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1989	53	110	185	97	25	10	8	4	2	1	0	1
1990	13	13	43	11	11	4	2	1	0	0	0	0
1991	152	66	44	55	19	10	3	1	0	0	0	1
1992	197	112	46	61	1	0	0	0	0	0	1	1
1993	413	40	83	5	1	0	0	0	0	0	0	0
1994	8	4	1	3	5	9	9	5	1	0	0	0
1995	21	12	23	11	9	8	7	5	2	1	0	0
1996	96	40	47	15	10	7	7	6	1	1	1	0
1997	1	9	16	6	7	7	6	3	1	0	0	0
1998	1	2	5	1	4	7	3	1	0	0	0	0
1999	1	12	6	4	5	10	10	2	1	0	0	0

Table A2e: Total recreational (including recreational discards) catch-at-age in numbers (thousands).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1981	288	1247	186	23	80	26	5	3	2	1	0	1
1982	65	453	249	16	12	16	7	8	5	6	12	70
1983	104	24	79	35	2	1	1	0	4	5	7	84
1984	126	202	43	13	4	0	0	0	0	0	0	0
1985	88	73	41	8	13	9	3	2	1	5	1	4
1986	327	31	39	7	1	0	0	1	0	3	1	3
1987	337	287	29	0	9	1	0	0	0	0	2	8
1988	1057	183	75	20	1	4	1	1	2	1	2	18
1989	61	106	35	69	11	2	1	1	0	1	1	21
1990	108	91	139	72	26	6	0	0	0	0	0	0
1991	282	190	23	57	23	3	0	2	1	0	0	10
1992	54	25	18	10	6	0	1	0	0	0	3	0
1993	82	144	85	6	6	0	0	0	0	0	0	0
1994	73	147	445	144	40	12	4	0	1	0	0	1
1995	274	152	337	191	33	7	2	0	1	0	0	0
1996	113	51	43	127	56	28	5	1	0	0	0	0
1997	16	66	32	59	59	12	7	2	1	0	0	0
1998	19	22	32	23	35	30	4	1	0	0	0	1
1999	127	101	7	20	15	10	7	1	0	0	0	2

Table A3: Survey indices (all in mean numbers in thousands/tow except for the larval index in numbers/10m^2) with their associated CV in parenthesis. Note the 2009 NEFSC spring and fall surveys are not used in the assessments because they have been carried out on a different vessel and a calibration factor is not as yet available.

year	NEFSC spring	NEFSC fall	NEFSC summer	Maine/New Hampshire spring	Maine/New Hampshire fall	Mass. Inshore spring	Larval index
1960							
1961							
1962							
1963		1.394 (0.20)					
1964		1.897 (0.38)					
1965		0.796 (0.20)					
1966		1.112 (0.46)					
1967		0.535 (0.35)					
1968	1.155 (0.32)	0.659 (0.25)					
1969	0.890 (0.33)	1.448 (0.46)					
1970	1.092 (0.24)	0.551 (0.20)					
1971	0.800 (0.18)	0.949 (0.43)					
1972	3.376 (0.50)	1.483 (0.26)					
1973	4.564 (0.45)	0.969 (0.21)					
1974	1.343 (0.25)	1.007 (0.35)					
1975	1.428 (0.31)	0.704 (0.38)					
1976	1.687 (0.19)	4.296 (0.48)					
1977	1.606 (0.32)	2.342 (0.31)					
1978	1.941 (0.50)	1.062 (0.21)				2.027 (0.75)	
1979	0.945 (0.19)	0.873 (0.19)				2.543 (0.77)	259.9 (3.75)
1980	1.427 (0.31)	0.494 (0.21)				8.101 (0.47)	91.8 (4.64)
1981	1.427 (0.25)	1.100 (0.68)				4.393 (0.55)	249.4 (0.99)
1982	3.960 (0.46)	0.793 (0.36)				1.682 (0.97)	120.3 (1.96)
1983	0.877 (0.33)	1.001 (0.44)				6.169 (0.89)	163.0 (0.20)
1984	1.027 (0.27)	0.280 (0.36)				0.021 (0.71)	334.8 (0.15)
1985	15.202 (0.85)	1.107 (0.35)	0.639 (0.58)			0.926 (0.96)	474.6 (0.10)
1986	1.882 (0.42)	0.424 (0.28)	0.516 (0.50)			0.071 (0.84)	1411.2 (0.38)
1987	1.656 (0.68)	0.541 (0.30)	0.601 (0.25)			0.036 (0.51)	
1988	0.778 (0.23)	3.963 (0.66)	1.152 (0.34)			0.082 (0.56)	
1989	1.900 (0.50)	1.642 (0.63)	0.670 (0.48)			0.998 (0.58)	59.8 (0.77)
1990	0.645 (0.34)	0.699 (0.33)	0.366 (0.26)			0.062 (0.51)	246.2 (0.16)
1991	2.052 (0.26)	0.696 (0.40)	0.862 (0.60)			0.041 (0.58)	134.5 (0.08)
1992	1.753 (0.30)	0.907 (0.53)	0.470 (0.34)			0.177 (0.71)	315.6 (0.15)
1993	1.622 (0.34)	1.096 (0.49)	0.415 (0.54)			0.028 (0.50)	145.8 (0.42)
1994	0.581 (0.20)	0.374 (0.37)	0.238 (0.35)			0.016 (0.74)	76.0 (0.56)
1995	3.582 (0.83)	0.856 (0.41)	0.235 (0.41)			1.436 (0.99)	
1996	0.636 (0.43)	1.011 (0.40)	1.877 (0.59)			2.675 (0.86)	
1997	3.535 (0.40)	1.704 (0.54)	0.700 (0.52)			0.695 (0.72)	
1998	2.657 (0.37)	2.058 (0.66)	1.055 (0.38)			4.827 (0.51)	
1999	2.222 (0.45)	2.282 (0.32)	1.246 (0.33)			0.063 (0.57)	
2000	1.404 (0.38)	2.449 (0.74)	1.514 (0.28)		2.272 (0.54)	1.310 (0.92)	
2001	1.716 (0.31)	2.113 (0.32)	0.726 (0.28)	0.470 (0.41)	0.333 (0.34)	0.447 (0.68)	
2002	0.721 (0.28)	3.179 (0.43)	2.084 (0.34)	1.484 (0.32)	4.538 (0.69)	0.023 (0.61)	45.8 (0.53)
2003	1.443 (0.69)	7.742 (0.66)	1.840 (0.84)	0.418 (0.33)	0.530 (0.38)	30.593 (0.58)	225.1 (0.21)
2004	0.472 (0.40)	3.106 (0.55)	1.349 (0.35)	1.192 (0.30)	0.298 (0.39)	0.331 (0.70)	
2005	2.166 (0.38)	5.064 (0.41)	2.960 (0.68)	0.293 (0.91)	0.128 (0.43)	0.015 (0.61)	206.7 (0.41)
2006	0.944 (0.25)	1.672 (0.66)	1.759 (0.13)	0.920 (0.55)	0.113 (0.50)	0.532 (0.98)	73.6 (0.48)
2007	2.094 (0.24)	0.332 (0.26)	1.476 (0.27)	0.322 (0.53)	0.081 (0.46)	0.006 (1.00)	290.5 (0.55)
2008	2.042 (0.23)	1.010 (0.57)	0.610 (0.22)	0.650 (0.72)	0.072 (0.54)	9.004 (0.95)	115.0 (0.42)
2009			0.186 (0.33)	0.366 (0.36)		1.155 (0.70)	128.2 (0.35)

Table A4a: NEFSC spring survey catches-at-age (proportions).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.0695	0.0346	0.1078	0.0591	0.0333	0.0605	0.0898	0.1625	0.0518	0.0454	0.0388	0.247
1971	0.0443	0.115	0.164	0.1005	0.0751	0.0789	0.01	0.0676	0.0155	0.0549	0.0545	0.22
1972	0.1565	0.4729	0.1925	0.0076	0.018	0.0057	0.0161	0.0347	0.0147	0.0209	0.0039	0.056
1973	0.0013	0.7215	0.1291	0.0367	0.0274	0.0056	0.0033	0.0197	0.0033	0.0329	0.0023	0.017
1974	0	0.0483	0.424	0.1213	0.0418	0.1065	0.0495	0.0162	0	0.0162	0.078	0.098
1975	0	0.1626	0.1204	0.2346	0.0273	0.0514	0.0605	0.0574	0.0252	0.0454	0.0136	0.202
1976	0.029	0.0593	0.0986	0.1016	0.1509	0.0671	0.1018	0.1031	0.0755	0.0194	0.0319	0.162
1977	0.0672	0.2955	0.1363	0.0402	0.0939	0.1708	0.0893	0.0647	0.0072	0.0034	0.0022	0.029
1978	0	0.1391	0.2126	0.2653	0.162	0.0597	0.0449	0.0242	0.0394	0.0189	0.0112	0.023
1979	0.117	0.0536	0.0885	0.0764	0.1425	0.1101	0.0654	0.1459	0.0728	0.0269	0.0317	0.069
1980	0.0696	0.1267	0.0654	0.2055	0.1736	0.1082	0.1656	0.0382	0.0191	0.005	0	0.023
1981	0.0039	0.2627	0.0341	0.0506	0.1139	0.1466	0.0493	0.0425	0.0366	0.0624	0.0382	0.159
1982	0.0271	0.3823	0.2158	0.1852	0.0308	0.0674	0.0285	0.0293	0.0113	0	0.0077	0.015
1983	0.6501	0.067	0.0218	0.0332	0.0023	0	0.0543	0.0299	0.0087	0.0137	0.0189	0.1
1984	0.1669	0.1243	0.1123	0.1189	0.1119	0.0994	0.0438	0.0373	0.0348	0.0384	0.038	0.074
1985	0.001	0.0221	0.2924	0.2362	0.299	0.1167	0.016	0.0011	0.0045	0.0042	0.0004	0.006
1986	0.0261	0.0792	0.0357	0.1047	0.0543	0.2216	0.2025	0.0692	0.0375	0.0136	0.0574	0.098
1987	0.0922	0.5486	0.1212	0.0153	0.0211	0.0218	0.0446	0.0483	0.0302	0.0039	0.0107	0.042
1988	0.5168	0.0305	0.1	0.0181	0	0.0393	0.0279	0.0723	0.0537	0.0483	0.0386	0.054
1989	0.0299	0.0653	0.0551	0.2299	0.2146	0.1488	0.0897	0.076	0.0179	0.0361	0	0.037
1990	0	0.0375	0.369	0.1434	0.0498	0.0798	0.0637	0.0507	0.0634	0.0403	0.0343	0.068
1991	0.0534	0.0368	0.2114	0.2869	0.1512	0.1255	0.077	0.0054	0.0234	0.0045	0.0124	0.012
1992	0.4079	0.1111	0.0834	0.0805	0.0941	0.0466	0.0511	0.0219	0.0065	0.0167	0.0426	0.038
1993	0.3627	0.171	0.2016	0.1207	0.0284	0.0549	0.0298	0.0089	0.0068	0.0107	0.0047	0
1994	0.0053	0.0789	0.1708	0.2197	0.1283	0.1229	0.1474	0.082	0.0119	0.021	0.0059	0.006
1995	0.0012	0.0061	0.2424	0.551	0.143	0.0347	0.0009	0.0138	0.0034	0.0034	0	0
1996	0.3722	0.0327	0.0121	0.1099	0.2405	0.1292	0.0698	0.0338	0	0	0	0
1997	0.145	0.1351	0.2195	0.1677	0.2015	0.0547	0.0545	0.0095	0.0089	0.0036	0	0
1998	0.284	0.0979	0.3665	0.0675	0.0218	0.0646	0.0607	0.0258	0.0113	0	0	0
1999	0.2937	0.5017	0.0814	0.0584	0.0173	0.0231	0.0189	0.0055	0	0	0	0
2000	0.5244	0.0755	0.0843	0.0598	0.1097	0.0759	0.0393	0.0201	0.0109	0	0	0
2001	0.3909	0.0968	0.0692	0.0439	0.1499	0.1425	0.0668	0.0294	0	0.0074	0	0.003
2002	0.0549	0.029	0.0541	0.3033	0.2025	0.2534	0.0794	0.0236	0	0	0	0
2003	0.2097	0.5967	0.0316	0.0513	0.0263	0.0361	0.0278	0.0114	0	0	0.0091	0
2004	0.141	0.4106	0.0974	0.0195	0.0631	0.1332	0.0616	0.0258	0	0.0479	0	0
2005	0.0028	0.2095	0.0071	0.0144	0.0626	0.4303	0.1731	0.0714	0.0198	0.0091	0	0
2006	0.0914	0.02	0.0228	0.0079	0.0583	0.3305	0.4022	0.0541	0.0062	0.0062	0	0
2007	0.112	0.0671	0.0969	0.0417	0.1517	0.2035	0.316	0.0111	0	0	0	0
2008	0.0485	0.0113	0.003	0.0298	0.1003	0.124	0.3603	0.1211	0.1416	0.042	0.0141	0.004

Table A4b: NEFSC fall survey catches-at-age (proportions).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.1289	0.1616	0.0114	0.1906	0.1678	0.125	0.0814	0.0528	0.0176	0.0221	0.0176	0.023
1971	0.0191	0.3716	0.1807	0.0172	0.0446	0.1179	0.0187	0.0713	0.0403	0.0117	0.0085	0.098
1972	0.2313	0.1982	0.1418	0.062	0.0531	0.0628	0.0567	0.0504	0.0355	0.0175	0.0241	0.066
1973	0.0126	0.2584	0.0788	0.0508	0.0852	0.0725	0.0778	0.0864	0	0.1412	0.0116	0.125
1974	0.0023	0.0771	0.32	0.2338	0.096	0.0841	0.1117	0	0.014	0	0.0306	0.03
1975	0.3413	0.0557	0.0477	0.1723	0.0983	0.068	0.117	0.023	0.0259	0.0253	0.0027	0.023
1976	0.0088	0.0074	0.0394	0.1351	0.4511	0.1515	0.0814	0.0488	0.0125	0.002	0	0.062
1977	0.0219	0.0971	0.118	0.1183	0.2153	0.1685	0.0968	0.0346	0.0439	0.0121	0	0.073
1978	0.0307	0.2068	0.0417	0.0474	0.1032	0.0768	0.1616	0.0755	0.066	0.0369	0.0227	0.131
1979	0.0143	0.0195	0.2091	0.1665	0.093	0.1074	0.0815	0.0989	0.0702	0.0459	0.0132	0.081
1980	0.1153	0.0128	0.0217	0.0997	0.1939	0.0622	0.0958	0.0987	0.0393	0.1141	0.0468	0.1
1981	0.0239	0.161	0.4686	0.1245	0.1176	0.0287	0.0235	0.0025	0	0	0	0.05
1982	0.1038	0.279	0.2805	0.0669	0.0227	0.0719	0.0601	0	0.0305	0	0.022	0.063
1983	0.5054	0.0151	0.0698	0.041	0.0695	0.0165	0.0566	0.0783	0.0332	0.0181	0.0235	0.073
1984	0.3707	0.4395	0.0589	0.0139	0.0093	0.0706	0.0089	0.0089	0.0193	0	0	0
1985	0.6056	0.0436	0.0933	0.071	0.0719	0.045	0.0207	0	0	0.0084	0.0114	0.029
1986	0.319	0.1935	0.0748	0.0911	0.0986	0.1015	0.0908	0.0182	0	0	0.0127	0
1987	0.0776	0.3532	0.1037	0	0.1087	0.0286	0.1235	0.0566	0.1092	0	0.0163	0.023
1988	0.0243	0.0294	0.279	0.3408	0.109	0.1132	0.02	0.0484	0.0215	0.0051	0.0019	0.007
1989	0.2663	0.413	0.2217	0.0806	0	0	0	0	0	0	0.0077	0.011
1990	0.0134	0.1156	0.3181	0.1957	0.1605	0.0116	0.0285	0.0435	0.0298	0.0491	0	0.034
1991	0.198	0.0943	0.2205	0.3282	0.0798	0.0617	0.0175	0	0	0	0	0
1992	0.3339	0.2211	0.1457	0.145	0.125	0.0181	0.0113	0	0	0	0	0
1993	0.4419	0.3641	0.0839	0.0296	0.011	0.0557	0	0	0	0	0	0.014
1994	0	0.1356	0.3659	0.2626	0.1888	0.0471	0	0	0	0	0	0
1995	0.0357	0.1824	0.5466	0.1279	0.0797	0.0274	0	0	0	0	0	0
1996	0.2846	0.3062	0.0454	0.2099	0.1327	0.0151	0.006	0	0	0	0	0
1997	0.3224	0.3721	0.0855	0.0998	0.1009	0.0194	0	0	0	0	0	0
1998	0.6016	0.1588	0.1542	0.0446	0.0133	0.0171	0.0104	0	0	0	0	0
1999	0.2224	0.2349	0.0887	0.2255	0.1162	0.0871	0.0192	0.006	0	0	0	0
2000	0.1427	0.7945	0.0378	0.007	0.0109	0.0071	0	0	0	0	0	0
2001	0.0542	0.286	0.2249	0.2339	0.1271	0.0432	0.0245	0.006	0	0	0	0
2002	0.0638	0.0413	0.2902	0.2174	0.2612	0.1025	0.0235	0	0	0	0	0
2003	0.0393	0.2553	0.2396	0.3899	0.0665	0.0094	0	0	0	0	0	0
2004	0.0373	0.0838	0.5347	0.1346	0.1162	0.0652	0.028	0	0	0	0	0
2005	0.0064	0.4375	0.0799	0.1774	0.1238	0.1501	0.0224	0.0024	0	0	0	0
2006	0.1676	0.477	0.0686	0.0306	0.0609	0.0921	0.0996	0.0037	0	0	0	0
2007	0.3388	0.0368	0	0.083	0.0462	0.2329	0.1698	0.0416	0.0504	0	0	0.001
2008	0.1512	0.2596	0.2287	0.0794	0.0434	0.0253	0.0471	0.0472	0.0465	0.0345	0.0155	0.022

Table A5: Proportion mature-at-age

1	2	3	4	5	6	7	8	9	10	11	12+
0.020	0.078	0.259	0.592	0.857	0.961	0.990	0.998	0.999	1.000	1.000	1.000

Table A6: Begin-year weights-at-age (kg) (Rivard weights)

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.0359	0.2013	0.8247	1.6169	1.8348	3.5877	3.9641	4.8955	5.1027	5.7444	6.2092	7.3649
1971	0.0375	0.1378	0.5550	1.3269	2.5314	3.2348	4.5305	4.6339	5.4191	5.8672	6.6503	7.8547
1972	0.0300	0.1796	0.4364	1.2992	2.6348	3.8011	4.4251	5.2279	5.4198	5.8354	6.6026	7.4679
1973	0.0321	0.1660	0.5719	1.2786	2.6384	3.7886	4.8846	5.2639	5.5355	5.9787	6.9909	8.4302
1974	0.0174	0.1431	0.4194	1.3803	2.5579	3.8401	4.5224	5.2765	5.9042	6.4463	6.8275	7.7185
1975	0.1569	0.1627	0.5234	0.9280	2.3842	3.5444	4.4632	5.3710	6.3353	6.2064	7.0953	7.6767
1976	0.0394	0.2150	0.5348	1.2247	1.8988	3.3197	4.3746	5.4432	6.1465	6.8830	6.9952	8.0651
1977	0.0448	0.1465	0.4280	1.0711	2.1258	2.8967	4.4300	5.4605	6.9595	6.8342	6.7620	8.3917
1978	0.1209	0.2060	0.5116	1.0444	1.7797	3.2720	4.1688	5.4032	6.4101	7.1499	7.7690	8.1717
1979	0.0690	0.3047	0.6421	1.4129	2.4028	3.2088	4.6359	5.1631	6.1334	7.5522	7.9861	8.7557
1980	0.0477	0.2875	0.7639	1.2738	2.3317	3.3968	4.2224	5.5838	6.5720	7.4782	8.2517	8.1965
1981	0.0829	0.2365	0.8487	1.5588	2.0348	3.0572	4.2602	5.2947	6.2898	7.1684	8.1501	9.0143
1982	0.0398	0.1376	0.7207	1.6918	2.5306	3.1721	3.8017	4.7855	5.7641	6.8929	8.0975	9.7700
1983	0.0311	0.1762	0.4408	0.9705	2.4444	2.7466	4.0464	5.0202	5.9834	6.0252	7.0330	9.4657
1984	0.0218	0.1274	0.5084	1.0837	1.8670	3.3687	3.6185	5.3899	5.2890	7.5490	6.5521	9.2912
1985	0.0343	0.2493	0.5300	1.1462	1.6415	2.8222	4.1813	6.5657	6.4895	6.7231	6.8407	7.9310
1986	0.0347	0.1928	0.8289	1.1862	2.2212	2.9151	3.6980	4.9871	8.8834	7.1651	7.5987	8.6644
1987	0.0579	0.1536	0.3596	0.9970	1.8871	3.3370	4.2503	5.8668	6.8470	8.0686	7.3383	7.5498
1988	0.0373	0.1465	0.4010	0.8626	2.1310	3.0059	4.8964	5.2500	6.6189	7.5915	8.4498	9.5484
1989	0.0393	0.1502	0.5385	1.1252	1.9124	3.0663	3.5704	4.6245	4.7764	6.2580	7.7475	9.4485
1990	0.0371	0.1421	0.3888	0.8384	1.8327	2.8385	3.7172	4.2858	4.7398	6.7701	6.1641	8.5996
1991	0.0356	0.1380	0.5194	0.9986	1.5616	2.5531	3.4507	4.5237	5.7344	5.8742	6.9588	9.9785
1992	0.0316	0.1300	0.4299	1.0689	1.9879	2.9130	4.0486	4.4744	5.2158	5.3269	5.9227	8.8039
1993	0.0226	0.1154	0.4056	0.8549	1.5467	2.8471	4.4176	4.9075	6.2482	6.9827	5.1630	8.0918
1994	0.0226	0.0743	0.3481	0.7397	1.4872	2.6099	3.0668	4.0325	4.1905	5.8283	5.7577	8.0918
1995	0.0370	0.0963	0.3418	0.6893	1.1374	2.3468	3.4747	4.4198	5.5750	6.9489	5.4334	8.0918
1996	0.0277	0.0941	0.4782	0.9422	1.6139	2.2746	3.8398	4.8164	6.4147	8.1025	6.5569	8.0918
1997	0.0350	0.1486	0.3163	0.9028	1.6110	2.8604	3.8036	5.2527	6.7521	7.7886	6.4161	8.0918
1998	0.0300	0.1277	0.4211	0.7401	1.3660	2.5250	3.9238	4.7207	6.1308	7.6851	6.2755	8.0918
1999	0.0237	0.1233	0.3708	0.8716	1.4703	2.4896	3.7518	5.2279	6.0644	7.3003	6.1754	8.0918
2000	0.0275	0.1016	0.3388	0.8962	1.5853	2.4157	4.0141	5.2904	5.7411	7.8256	6.1711	8.0918
2001	0.0289	0.0844	0.3685	0.8160	1.4637	2.3739	3.4853	5.1772	6.1526	6.6410	6.3395	10.6060
2002	0.0333	0.1339	0.2842	0.6458	1.7570	2.8829	4.1356	5.0367	6.1632	7.4317	5.9944	8.0918
2003	0.0498	0.0727	0.2709	0.6326	1.2188	2.9723	4.6391	5.5399	6.2403	7.5277	7.8895	8.0918
2004	0.0186	0.0617	0.2499	0.6506	1.3927	2.4962	4.1971	4.9775	6.3990	8.0918	6.2469	8.0918
2005	0.0298	0.1122	0.3158	0.8075	1.5863	2.5473	3.6926	5.2051	6.4649	7.6704	6.4767	8.0918
2006	0.0478	0.1561	0.4735	1.0330	1.5981	2.5589	3.5260	4.7807	6.8641	7.5741	6.2699	8.0918
2007	0.0468	0.1699	0.4384	1.0642	1.6301	2.5363	3.5891	5.0229	5.7191	6.7757	6.1349	8.0918
2008	0.0262	0.1632	0.5146	1.0009	1.6276	2.2892	3.1253	3.9817	4.9459	5.4831	4.2811	5.3190

Table A7: Mean weights-at-age from commercial landings (kg).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.000	0.970	1.840	2.930	3.790	4.590	5.780	6.410	7.560	6.750	9.290	**9.560**
1971	0.000	1.670	2.320	2.120	3.150	4.000	5.000	6.240	7.250	9.620	**8.050**	**9.560**
1972	0.000	1.060	1.860	2.930	4.440	5.290	5.950	6.520	6.840	7.600	6.810	9.560
1973	0.000	0.950	1.370	1.890	2.630	3.960	4.840	6.070	6.470	7.210	9.330	9.660
1974	0.000	0.850	1.440	2.000	3.040	4.080	4.990	6.000	6.570	7.240	7.940	9.040
1975	0.000	0.860	1.340	2.090	3.080	4.010	5.210	6.500	7.610	7.600	8.470	9.990
1976	0.000	0.630	1.270	1.890	2.670	3.620	4.330	5.260	6.860	6.700	7.240	9.990
1977	0.000	0.910	1.310	1.850	2.920	3.610	4.650	5.980	7.020	7.000	7.260	8.150
1978	0.000	0.770	1.230	1.770	3.070	4.060	4.670	5.630	6.420	6.690	7.400	7.750
1979	0.000	0.710	1.200	1.930	3.050	3.970	5.330	5.750	6.800	7.570	7.840	8.310
1980	0.000	0.880	1.190	1.830	2.830	3.680	4.390	5.750	6.450	7.170	7.740	8.770
1981	0.000	0.590	1.220	2.430	2.990	3.890	4.790	5.590	6.350	7.050	7.840	8.050
1982	0.000	0.390	0.870	2.230	3.490	4.080	4.880	5.580	6.450	6.810	7.600	8.230
1983	0.000	0.670	0.960	1.670	2.950	4.210	4.950	5.660	6.600	7.030	7.540	8.900
1984	0.000	0.830	1.180	1.780	2.550	3.200	4.950	5.480	6.130	6.680	7.460	8.520
1985	0.000	0.710	0.930	1.840	2.800	3.600	4.950	6.350	6.710	7.180	7.360	9.130
1986	0.000	0.820	1.130	1.690	2.850	3.660	4.520	6.000	7.130	7.440	7.890	9.100
1987	0.000	0.730	1.040	1.910	2.710	3.660	4.510	5.350	6.390	7.910	7.920	8.970
1988	0.000	0.000	1.190	1.740	2.750	3.410	4.040	5.150	6.200	7.130	8.370	9.190
1989	0.000	0.840	1.129	1.625	2.708	3.608	4.302	5.019	6.335	6.998	7.068	8.957
1990	0.000	0.644	0.966	1.557	2.594	3.545	4.603	5.289	5.964	6.544	7.856	9.103
1991	0.000	0.000	1.139	1.608	2.486	3.647	4.765	5.292	5.834	7.098	8.057	9.797
1992	0.000	0.000	1.265	1.657	2.643	3.609	4.666	5.862	6.029	7.351	7.661	10.350
1993	0.000	0.000	0.975	1.510	2.514	3.606	4.618	5.947	6.677	8.378	9.131	10.550
1994	0.000	0.000	1.242	1.554	2.351	3.518	4.580	5.784	6.650	8.315	8.205	10.966
1995	0.000	0.000	1.201	1.654	2.388	3.594	4.709	6.215	8.159	9.731	11.457	12.546
1996	0.000	0.000	1.246	1.740	2.642	3.474	4.472	5.825	7.259	9.202	10.787	12.013
1997	0.000	0.000	1.231	1.790	2.400	3.485	4.694	6.008	7.539	8.691	10.057	12.355
1998	0.000	0.000	0.646	1.652	2.504	3.526	4.643	5.657	7.126	8.526	10.517	11.663
1999	0.000	0.000	1.269	1.661	2.464	3.370	4.433	5.928	7.507	8.854	**10.517**	10.990

Table A8: Mean weights-at-age from commercial discards (kg).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1989	0.214	0.358	0.884	1.038	1.811	3.423	4.232	5.062	6.289	6.712	6.031	7.335
1990	0.114	0.366	0.793	0.963	2.485	3.296	3.787	4.363	5.235	5.118	**7.531**	5.755
1991	0.050	0.161	0.865	1.092	1.763	4.255	4.907	5.275	5.236	9.723	**7.531**	12.193
1992	0.058	0.594	0.853	0.985	1.685	4.274	4.456	6.249	6.770	7.484	9.030	10.585
1993	0.031	0.432	0.758	1.029	1.174	1.880	3.684	**6.198**	**6.726**	**7.176**	**8.623**	**10.081**
1994	0.044	0.075	0.935	1.650	2.986	4.249	5.292	6.147	6.682	6.868	8.217	9.578
1995	0.097	0.357	0.804	1.174	2.589	3.961	5.308	7.023	8.146	10.337	8.787	10.315
1996	0.109	0.457	0.761	1.244	2.648	3.759	5.220	6.531	7.708	2.529	11.775	**10.315**
1997	0.162	0.550	0.941	1.419	2.262	4.108	5.099	6.306	7.416	7.801	9.800	**10.315**
1998	0.171	0.297	0.570	1.185	2.788	3.770	5.089	6.662	8.096	7.162	**9.800**	**10.315**
1999	0.244	0.498	0.638	1.582	2.773	3.964	4.841	6.341	8.532	**7.162**	**9.800**	**10.315**

Table A9: Mean weights-at-age from recreational landings (kg). Values shown in bold are interpolated from neighbouring cells because data are missing.

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1981	0.203	0.363	1.105	1.979	2.888	3.857	5.126	5.993	7.363	7.508	**9.523**	8.112
1982	0.172	0.335	0.653	1.807	3.004	3.388	5.308	6.662	8.231	8.467	9.523	11.994
1983	0.177	0.646	0.839	1.426	2.627	3.404	8.885	8.131	9.039	8.966	10.008	11.940
1984	0.210	0.424	0.783	1.843	2.419	2.546	**7.407**	**7.468**	**8.933**	**8.608**	**9.620**	**11.477**
1985	0.139	0.257	0.938	2.275	3.408	4.805	5.930	6.805	8.827	8.250	9.232	11.013
1986	0.162	0.464	0.645	1.210	2.059	2.193	**4.827**	9.907	**8.523**	10.114	9.907	10.784
1987	0.114	0.316	0.525	2.310	3.055	3.724	3.724	**7.557**	**8.523**	11.242	12.591	12.239
1988	0.138	0.370	0.518	0.642	5.207	5.207	5.207	5.207	8.218	9.999	10.501	12.029
1989	0.165	0.313	0.760	1.393	2.107	3.235	3.466	8.405	8.979	10.560	10.900	12.617
1990	0.130	0.280	0.657	1.036	1.798	2.821	**2.830**	**8.120**	**8.407**	**10.560**	**10.899**	**12.838**
1991	0.131	0.235	0.959	1.336	1.706	1.982	2.193	7.836	7.836	**10.560**	**10.899**	13.059
1992	0.142	0.398	0.736	1.249	1.985	2.196	5.853	5.853	5.853	**10.560**	10.897	**12.326**
1993	0.133	0.269	0.479	1.556	1.884	**2.481**	**4.540**	**4.552**	**8.723**	**10.560**	**10.729**	**12.326**
1994	0.151	0.224	0.370	0.788	1.384	2.766	3.227	3.251	11.594	**10.560**	**10.729**	11.594
1995	0.181	0.353	0.886	1.306	1.940	2.587	7.303	**4.413**	7.303	**10.560**	**10.729**	**14.232**
1996	0.160	0.516	1.116	1.598	2.500	3.436	4.762	5.574	**8.371**	**10.560**	**10.729**	**14.232**
1997	0.173	0.389	0.735	1.424	2.111	3.842	5.454	5.972	9.440	10.560	10.560	**14.232**
1998	0.158	0.290	0.822	1.638	2.572	3.779	5.009	7.162	7.836	**10.560**	**10.560**	16.870
1999	0.161	0.329	0.672	1.852	2.420	3.618	4.698	4.895	**7.836**	**10.560**	**10.560**	10.897

Appendix B - Statistical Catch-at-Age Analysis Methodology

The model equations and the general specifications of the SCAA methodology applied 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).

B1. Population dynamics

B1.1 Numbers-at-age

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

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

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - \sum_f C^f_{y,a} \right) e^{-M_a/2} \qquad \text{for } 1 \le a \le m-2 \quad \text{(B2)}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - \sum_f C^f_{y,m-1} \right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - \sum_f C^f_{y,m} \right) e^{-M_m/2} \quad \text{(B3)}$$

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_a denotes the natural mortality rate for fish of age *a*,

$C^f_{y,a}$ is the predicted number of fish of age *a* caught in year *y* by fleet *f*, and

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

B1.2. Recruitment

The number of recruits (1-year olds) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by a Beverton-Holt or a modified (generalised) form of the Ricker stock-recruitment relationship, parameterised in terms of the "steepness" of the stock-recruitment relationship, *h*, and the pre-exploitation equilibrium spawning biomass, SSB_0, and recruitment, R_0 and allowing for annual fluctuation about the deterministic relationship:

$$R_{y+1} = \frac{4hR_0 SSB_y}{SSB_0(1-h) + (5h-1)SSB_y}\, e^{(\varsigma_y - \sigma_R^2/2)} \quad \text{(B4)}$$

for the Beverton-Holt stock-recruitment relationship and

$$R_{y+1} = \alpha SSB_y \exp\left(-\beta \left(SSB_y\right)^\gamma\right) e^{(\varsigma_y - \sigma_R^2/2)} \quad \text{(B5)}$$

with

$$\alpha = R_0 \exp\left(\beta \left(SSB_0\right)^\gamma\right) \qquad \text{and} \qquad \beta = \frac{\ln(5h)}{\left(SSB_0\right)^\gamma \left(1 - 5^{-\gamma}\right)}$$

for the modified Ricker relationship (for the true Ricker, γ=1)

where

ς_y reflects fluctuations about the expected recruitment for year *y*, which are assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

SSB_y is the spawning biomass at the start of year *y*, computed as:

$$SSB_y = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{strt} N_{y,a} \qquad \text{(B6)}$$

where

$w_{y,a}^{strt}$ is the mass of fish of age *a* at the beginning of the year (Table A6), and

$f_{y,a}$ is the proportion of fish of age *a* that are mature (Table A5).

In the fitting procedure, SSB_0 is estimated while *h* can be estimated or fixed. For the Beverton-Holt form, *h* is bounded above by 0.9 to preclude high recruitment at extremely low spawning biomass, whereas for the modified Ricker form, *h* is bounded above by 1.5 to preclude extreme compensatory behaviour.

B1.3. Total catch and catches-at-age

The fleet-disaggregated catch by mass in year *y* is given by:

$$C_y^f = \sum_{a=1}^{m} w_{y,a}^{f,mid} C_{y,a}^f = \sum_{a=1}^{m} w_{y,a}^{f,mid} N_{y,a} e^{-M_a/2} S_{y,a}^f F_y^f \qquad \text{(B7)}$$

where

$w_{y,a}^{f,mid}$ denotes the mass of fish of age *a* landed in year *y* (Tables A7, A8 and A9),

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

$S_{y,a}^f$ is the commercial selectivity of fleet *f* (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^f is the proportion of a fully selected age class that is fished, for fleet *f*.

B1.4. Initial conditions

For the first year (y_0) considered in the model, the stock is assumed to be at a fraction (θ) of its pre-exploitation biomass, i.e.:

$$SSB_{y_0} = \theta \cdot SSB_0 \qquad \text{(B8)}$$

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

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

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

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

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

B2. The (penalised) likelihood function

The model can be fit to survey indices and catch-at-age as well as commercial catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell\text{n}L$) are as follows.

B2.1 Survey relative abundance data

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

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

where

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

$\hat{I}_y^i = \hat{q}^i \hat{B}_y^{surv}$ is the corresponding model estimate, where

$$\hat{B}_y^{surv} = \sum_{a=1}^{m} S_a^{surv} N_{y,a} e^{-\frac{M_a}{4}} \left(1 - \sum_f S_{y,a}^f F_y^f \Big/ 4\right) \quad \text{(B14)}$$

for spring surveys,

$$\hat{B}_y^{surv} = \sum_{a=1}^{m} S_a^{surv} N_{y,a} e^{-\frac{M_a}{2}} \left(1 - \sum_f S_{y,a}^f F_y^f \Big/ 2\right) \quad \text{(B15)}$$

for summer surveys,

$$\hat{B}_y^{surv} = \sum_{a=1}^{m} S_a^{surv} N_{y,a} e^{-\frac{3M_a}{4}} \left(1 - 3\sum_f S_{y,a}^f F_y^f \Big/ 4\right) \quad \text{(B16)}$$

for fall surveys,

$$\hat{B}_y^{surv} = B_y^{sp} \quad \text{(B17)}$$

for the larval index, and

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

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

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

$$-\ell\text{n}\, L^{surv} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \quad \text{(B18)}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*, taken to be given by the survey CV.

The estimated CVs likely fail to include all sources of variability, and unrealistically high precision could hence be accorded to these indices. The procedure adopted takes account of an additional variance $\left(\sigma_A^i\right)^2$ which is treated as another estimable parameter in the minimisation process, and included by replacing σ_y^i by $\sqrt{\left(\sigma_y^i\right)^2+\left(\sigma_A^i\right)^2}$ in equation B18. This procedure is carried out enforcing the constraint that $0 \le \left(\sigma_A^i\right)^2 \le 2$.

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

$$\ell n\, \hat{q}^i = \frac{\sum_y \left(\ln I_y^i - \ln \hat{B}_y^{surv}\right) \Big/ \left(\left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2\right)}{\sum_y 1 \Big/ \left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2} \qquad \text{(B19)}$$

B2.3.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:

$$-\ell \text{n}\, L^{CAA} = \sum_f w_{CAA} \sum_y \sum_a \left[\ell n\left(\sigma_{com}^f / \sqrt{p_{y,a}^f}\right) + p_{y,a}^f \left(\ell n\, p_{y,a}^f - \ell n\, \hat{p}_{y,a}^f\right)^2 / 2\left(\sigma_{com}^f\right)^2\right] \qquad \text{(B20)}$$

where

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

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

where

$$\hat{C}_{y,a}^f = N_{y,a}\, e^{-M_a/2}\, S_{y,a}^f\, F_y^f \qquad \text{(B21)}$$

and

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

$$\sigma_{com}^f = \sqrt{\sum_y \sum_a p_{y,a}^f \left(\ell n\, p_{y,a}^f - \ell n\, \hat{p}_{y,a}^f\right)^2 / \sum_y \sum_a 1} \qquad \text{(B22)}$$

w_{CAA} is input (this allows for the contribution from these data to be up-or downweighted compared to that from the survey indices).

The log-normal error distribution underlying equation (B20) is chosen on the grounds that (assuming no ageing error) variability is likely dominated by a combination of interannual variation in the distribution of fishing effort, and fluctuations (partly as a consequence of such variations) in selectivity-at-age, which suggests that the assumption of a constant coefficient of variation is appropriate. However, for ages poorly represented in the sample, sampling variability considerations must at some stage start to dominate the variance. To take this into account in a simple manner, motivated by binomial distribution properties, the observed proportions are used for weighting so that undue importance is not attached to data based upon a few samples only.

Commercial catches-at-age are incorporated in the likelihood function using equation (B20), for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

B2.4.Survey catches-at-age

The survey catches-at-age are incorporated into the negative log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation B20) where:

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

$\hat{p}_{y,a}^{surv}$ is the expected proportion of fish of age *a* in year *y* in the survey *surv*, given by:

$$\hat{p}_{y,a}^{surv} = \frac{S_a^{surv} N_{y,a} e^{-\frac{M_a}{4}} \left(1 - \sum_f S_{y,a}^f F_y^f \Big/ 4\right)}{\sum_{a'} S_{a'}^{surv} N_{y,a'} e^{-\frac{M_{a'}}{4}} \left(1 - \sum_f S_{y,a'}^f F_y^f \Big/ 4\right)} \tag{B23}$$

for spring surveys, and

$$\hat{p}_{y,a}^{surv} = \frac{S_a^{surv} N_{y,a} e^{-\frac{3M_a}{4}} \left(1 - 3\sum_f S_{y,a}^f F_y^f \Big/ 4\right)}{\sum_{a'} S_{a'}^{surv} N_{y,a'} e^{-\frac{3M_{a'}}{4}} \left(1 - 3\sum_f S_{y,a'}^f F_y^f \Big/ 4\right)} \tag{B24}$$

for fall surveys.

B2.5. Survey catches-at-length

The predicted proportions-at-age from equations B23 and B24, or similar equations for other surveys, may be converted into proportions-at-length using the von Bertalanffy growth equation, assuming that the length-at-age distribution remains constant over time:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{surv} \tag{B25}$$

where

$A_{a,l}^{surv}$ is the proportion of fish of age *a* that fall in the length group *l* for survey *surv* (i.e. $\sum_l A_{a,l}^{surv} = 1$ for all ages *a* for survey *surv*).

The matrix *A* is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a \sim N\left[L_\infty\left(1 - e^{-\kappa(a-t_0)}\right); \theta_a^2\right] \tag{B26}$$

where

N is the normal distribution, and

θ_a is the standard deviation of length-at-age *a*, which is modelled to be proportional to the expected length at age *a*, i.e.:

$$\theta_a = \beta L_\infty\left(1 - e^{-\kappa(a-t_0)}\right) \tag{B27}$$

where β can be fixed or estimated in the model fitting process.

The following term is then added to the negative log-likelihood:

$$-\ell\text{n}\, L^{\text{CAL}} = \sum_{surv} w_{CAL} \sum_{y} \sum_{l} \left[\ell n \left(\sigma_{len}^{surv} / \sqrt{\hat{p}_{y,l}^{surv}} \right) + \hat{p}_{y,l}^{surv} \left(\ell n p_{y,l}^{surv} - \ell n\, \hat{p}_{y,l}^{surv} \right)^2 / 2 \left(\sigma_{len}^{surv} \right)^2 \right] \quad \text{(B28)}$$

where

$p_{y,l}^{surv}$ is the observed proportion (by number) in length group *l* in the catch in year *y* for survey *surv*, and

σ_{len}^{surv} is the standard deviation associated with the length-at-age data for survey *surv*, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{len}^{surv} = \sqrt{\sum_{y} \sum_{l} \hat{p}_{y,l}^{surv} \left(\ln\, p_{y,l}^{surv} - \ln\, \hat{p}_{y,l}^{surv} \right)^2 / \sum_{y} \sum_{l} 1} \quad \text{(B29)}$$

The w_{CAL} weighting factor may be set at a value less than 1 to downweight the contribution of the catch-at-length data to the overall negative log-likelihood compared to that of the survey or catch-at-age data. The reason that this factor is introduced is that the $p_{y,l}^{surv}$ data for a given year frequently show evidence of strong positive correlation, and so are not as informative as the independence assumption underlying the form of equation B28 would otherwise suggest.

B2.6. 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:

$$-\ell n L^{SRpen} = \sum_{y=y1}^{y2} \left[\varepsilon_y^2 \big/ 2\sigma_R^2 \right] \quad \text{(B30)}$$

where

ε_y from $N\left(0, (\sigma_R)^2\right)$, which is estimated for year *y*1 to *y*2 (see equation (B4)), and

σ_R is the standard deviation of the log-residuals, which is input (a value of 0.4 is used for the Base Case assessment).

B3. Model parameters

B3.1. Commercial fishing selectivity-at-age

The commercial fleet-specific fishing selectivity, S_a^f, is estimated directly for each age from age '*minus*' to age '*plus*'. The estimated decreases from ages *minus*+1 to *minus* and ages *plu*s-1 to *plus* are either assumed to continue exponentially to ages 0 and *m* (maximum age considered) respectively.

Time dependence may be incorporated into these specifications by estimating different selectivity parameters for specific time periods, so that $S_a^f \rightarrow S_{y,a}^f$.

B3.2. Survey fishing selectivity-at-age

For the NEFSC spring and fall surveys, the fishing selectivity, S_a^{surv}, is estimated directly for each age from age 1 to age 8. The selectivity is assumed to remain constant at the level estimated for age 8 for ages 9 and above.

For the NEFSC summer survey, the selectivity is assumed to take the form of an exponential decline up to some maximum age specified, after which it becomes zero:

$$S_a^{surv} = e^{-\lambda(a-1)} \qquad \text{(B31)}$$

The Maine/New Hampshire spring and fall surveys, as well as the Massachusetts inshore surveys are taken as indices of recruitment for the Base Case as their catch-at-length distributions are dominated by lengths corresponding to 1-year-old fish, i.e.:

$$S_a^{surv} = \begin{cases} 1 & \text{for } a = 1 \\ 0 & \text{for } a \neq 1 \end{cases} \qquad \text{(B32)}$$

B3.3. Natural mortality-at-age

$$M_a = 0.2 \qquad \text{(B33)}$$