Further Statistical Catch-at-Age Assessment Results together with Biological Reference Point estimates for Gulf of Maine cod, October 2012

Doug S. Butterworth and Rebecca A. Rademeyer

October 2012

Summary

The Statistical Catch-at-Age assessments of the Gulf of Maine cod stock by Butterworth and Rademeyer (2012) are extended, with a particular focus on the estimation of Biological Reference Points (BRPs). The analysis supports starting these assessments from an early year to provide precise estimates of these BRPs, and the estimation n of the Ricker form of the stock –recruitment relationship within the assessment is found to be preferred. Across a wide range of sensitivity tests the 2011 spawning biomass is robustly estimated at about 14 thousand tons with specific estimates ranging from about 12.5 to 16 thousand tons. When starting the assessments in the 1960s or earlier with a Ricker stock-recruitment function, most estimates of the spawning biomass which provides MSY are around 25 thousand tons for the *M* = 0.2 scenario, and around 13 thousand tons for the *M* increasing scenario; the corresponding estimates of MSY itself are about 13 and 6 thousand tons respectively. The AIC selection criterion and a reduced retrospective pattern suggest that greater weight should be accorded to results for the *M* increasing compared to the *M* = 0.2 scenario.

Introduction

This paper continues from that (Butterworth and Rademeyer, 2012) submitted to the earlier SAW/SARC 55 Modeling Meeting. Taking account of advances made and some agreements reached at that meeting, it extends SCAA assessment analyses for Gulf of Maine cod, now particularly focusing also on the estimation of MSY-related biological reference points. (BRPs)

Data and Methodology

The catch and survey based data (including catch-at-length information) and some biological data used for the analyses are listed in Tables in Appendix A. These have been updated in a few respects in the light of discussions at the earlier Modeling Meeting; the consequent changes are indicates through highlighting.

The details of the SCAA assessment methodology are provided in Appendix B. As in Appendix A, there are some recent changes which are highlighted.

Results

Results are first given for variants on an assessment run which incorporates the following choices, based primarily on those made for a comparison exercise with ASAP outputs run during the Modeling Meeting. These include:

- Use the sqrt(p) formulation of equation B.21 to describe the distribution of proportions-at-age (in relation to numbers of fish).
- No refinement of the *Bigelow-Albatross* calibration function within the assessment.
- Force flat selectivity at ages of 5/6 and above for the NEFSC autumn/spring surveys (though estimation of a common doming trend in the commercial selectivities is allowed – see Section B.4.1).
- Make allowance for additional variance when fitting to time series of abundance indices
- Fit to the aggregated abundance indices as expressed in terms of numbers (equation B10) rather than biomass.
- Where pertinent given the starting year, incorporate data on NEFSC survey length compositions from the 1960s when catches from these surveys were not aged.

The first sensitivity exercise conducted is run conduct assessments comprising a full cross of the following factors:

a) Start in 1963 (estimating the first three numbers-at-age in the starting vector and then the parameter ϕ) *vs* start in 1982 (estimating all elements of the starting numbers at age vector).
b) M = 0.2 *vs* M increasing linearly from 0.2 prior to 1989 to 0.4 from 2003
c) Internal (equation B31) *vs* external (equation B39) estimation of the stock-recruitment relationship; note that with external estimation, the assessment shrinks only the last two recruitment estimates as detailed in section B.2.6
d) Use of a Ricker (equation B4 with γ= 1) *vs* a Beverton Holt (equation B5) stock-recruitment relationship.

Tables 1 and 2 list the results of this examination, showing log likelihood contributions and model parameter estimates, and also now estimates of BRPs.

For the purpose of further evaluation, a Reference Case (RC) is selected from the cases considered above, with the same specifications for each of the M = 0.2 and M increasing scenarios. This RC starts the assessment in 1963, and estimates a Ricker stock-recruitment curve internally.

Table 3 shows results for sensitivities to the RC for M = 0.2. First sensitivities to different starting years are shown, and then some other factors investigated. For the different starting years, the numbers of ages which are estimated individually in the starting vector are (1, 3, 3, 4, 5, all, all) for the years (1934, 1963, 1964, 1965, 1967, 1970 and 1982) respectively. These choices were made on an AIC basis. Table 4 is similar to Table 3, but for the RC with *M* increasing and with somewhat fewer sensitivities.

Table 5 gives results for the authors' "preferred" runs for the two different *M* scenarios. These "preferred" runs differ from the RC only in starting in 1934 rather than 1963, and in incorporating refinement of the *Bigelow-Albatross* calibration function within the assessment. The reasons for the various choices made for these "preferred" runs are given in the Discussion section following.

Figs 1-7 are constructed to illustrate some of the sensitivities associated with different choices for a number of the factors requiring specification in the assessment. Figs 1-3 show various trajectory plots for spawning biomass and recruitment, some of which also show approximate Hessian-based 95% CIs, and Fig. 1 also shows the total catch trajectory. Fig. 4 plots some of the selectivity functions that differ across the sensitivities investigated, while Fig. 5 compares spawning biomass trajectories for the two different *M* scenarios for the RC. Figs 6-7 compare different estimated stock recruitment functions.

Figs 8-13 show diagnostic plots for the "preferred" case with *M* = 0.2. These include spawning biomass and recruitment trajectories showing approximate 95% CIs, selectivity-at-age plots, fits/residuals to abundance indices and proportions-at-age and -at-length data, refined *Bigelow-Albatross* calibration functions, and retrospective analyses. Figs 14-19 repeat these same plots for the other "preferred" case with *M* increasing. Fig. 20 shows the fitted stock-recruiment relationships for each case.

Discussion

Several features are evident from the exploratory results in Tables 1 and 2:

- Starting the assessment in 1982 provides no basis to discriminate alternative stock-recruitment relations, and the estimates of spawning biomass at MSY are hopelessly imprecise for the *M* = 0.2 case.
- For a 1963 start to the assessment, the Ricker form is preferred over the Beverton-Holt form in terms of AIC, particularly for the *M* increasing scenario. For *M*=0.2, the Beverton-Holt estimate of spawning biomass at MSY is appreciably larger than its Ricker counterpart.
- Internal estimates of the spawning biomass at MSY for a 1963 start to the assessment are both somewhat higher and less precise than their external estimation counterparts, but this last result is not unexpected since the internal estimates take account of errors in estimates of spawning biomass and correlations amongst estimates over time, unlike the external estimates.

- Estimates of current (2011) spawning biomass are typically 1000 tons lower without internal estimation of the stock-recruitment function.

With BRP estimation in mind, and given the results summarised in the first three bullets above, preference is indicated for internal estimation using a Ricker form for the stock-recruitment relationship, and for starting the assessment in an early year. Hence the Reference Case (RC) was selected to include these specifications, and with a 1963 start because that corresponded to the beginning of the NEFSC survey time series.

Further results shown in Table 3 and plotted in Figs 1-7 suggest little sensitivity of recruitment estimates to most of the assessment options examined, and also of the spawning biomass trajectory except for some variability in the early years depending on the 1960s starting year chosen (Figs 1-3). However when the starting year is taken back to 1934, this results in a clear and relatively precise trend in spawning biomass of an increase over the 1950s and early 1960s co-incident with the low catches over that period (Fig. 2). The survey CAL data from the 1960s also support this trend (lowest left plot in Fig. 3). Another feature of the results for BRPs is that once the contrast provided by the assessment estimates from the 1960s is lost, the ability for precise estimation of the stock-recruitment relationship, and hence of BRPs such as the spawning biomass at MSY, is lost with it (Table 3 and Fig. 7). Comparison of relationships found by internal and external stock-recruit function estimation shows little difference (Fig. 6).

The above points towards preferring an earlier start to the assessment than the 1963 of the RC, as the combination of the data and the stock-recruit relationship assumption inform the overall BRP estimation process further through providing meaningful information on stock dynamics back into the 1950s at least.

Regarding the other sensitivity tests for M = 0.2, alternative assumptions about selectivity-at-age pre-1982 make little difference to results (Table 3 and Fig.3, third row). Fitting to abundance indices in terms of biomass rather than numbers decreases the current spawning biomass estimate slightly, but makes little difference otherwise (Table 3, and Fig. 3, second row). Use of the adjusted log-normal form for the proportions data appreciably increases the variance of the BRP estimates (Table 3). A domed survey selectivity is preferred under AIC, but trends into the 1960s (Fig. 3, second row) seem at variance with the pattern suggested by Fig. 1 when earlier years are included in the assessment. Inclusion of the *Bigelow* calibration refinement has little impact on results (Table 3).

Where examined, these same features seem broadly present for the increasing M case, though to lesser extents. Unsurprisingly once M becomes higher, both spawning biomass and recruitment estimates increase (Fig. 5).

Based on these results, the authors' preference is to leave the RC specifications unchanged except to move to a 1934 starting year to make maximal use of data contrast in estimating BRPs, and to include the *Bigelow* calibration refinement because of its in principle desirability.

In broad terms the diagnostics for both the consequent "preferred" cases in Figs 8-19 are satisfactory. The *M* increasing scenario shows an appreciably reduced retrospective pattern compared to the *M* = 0.2 case (Fig. 19 compared to Fig. 13), and further is preferred in AIC terms (Table 5). Accordingly it would seem that more weight should be placed on the results provided by the *M* increasing scenario.

Conclusions

Key conclusions from these results are:

- Assessments should start from as early a year as possible to maximise the contrast in data required to provide BRP estimates with better precision.
- Internal over external estimation of stock-recruitment functions is preferred to best take the variance-covariance of spawning biomass and recruitment estimates into account. The Ricker form for this relationship is AIC preferred to the Beverton-Holt form.
- Across a wide range of sensitivity tests (including treatment of the stock-recruitment relationship), the 2011 spawning biomass is robustly estimated at about 14 thousand tons with specific estimates ranging from about 12.5 to 16 thousand tons.
- Given a start to the assessments in the 1960s or earlier, with internal estimation of a Ricker stock-recruitment function, most estimates of the spawning biomass which provides MSY are around 25 thousand tons for the *M* = 0.2 scenario, and around 13 thousand tons for the *M* increasing scenario; the corresponding estimates of MSY itself are about 13 and 6 thousand tons respectively.
- The AIC selection criterion and a reduced retrospective pattern suggest that greater weight should be accorded to results for the *M* increasing compared to the *M* = 0.2 scenario.

Acknowledgements

We thank Michael Palmer and Tim Miller for provision of the data and/or parameter estimates upon which the analyses reported in this paper are based.

References

Butterworth DS and Rademeyer RA. 2012 Applications of Statistical Catch-at-Age Assessment Methodology to Gulf of Maine cod, October 2012.Document presented to SAW/SARC 55 Working Group on Gulf of Maine and Georges Bank cod Modeling Meeting, 15-19 October, 2012. 40pp.

Miller TJ, Das, C, Politis PJ, Miller AS, Lucey SM, Legault CM, Brown RW and Rago PJ. 2010. Estimation of *Albatross IV* to *Henry B. Bigelow* Calibration Factors. U.S. Depart. of Commerce, Northeast Fisheries Science Center Ref. Doc. 10-05; 233 pp

Table 1: Estimates of abundance, MSY-related biological reference points (BRPs), and related quantities for the Gulf of Maine cod for a comparative exercise across four assessments factors: start date, internal or external estimation of the stock-recruitment relationship, the form of the stock-recruitment relationship, and the time dependence of natural mortality *M* (see text for further details). Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood values shown in square parentheses denote non-comparability with values given in adjacent columns. Mass units are '000 tons. *y*1 refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

	Start in y1=1963												Start in y1=1982											
	M =0.2						*M* increasing						*M* =0.2						*M* increasing					
	Ricker internal		BH internal		No SR		Ricker internal		BH internal		No SR		Ricker internal		BH internal		No SR		Ricker internal		BH internal		No SR	
-lnL: overall	-2765		-2763		-[2797]		-2774		-2769		-[2801]		-2128		-2128		-[2145]		-2137		-2137		-[2151]	
-lnL: survey	-24.2		-24.0		-25.4		-30.2		-30.6		-31.4		-15.5		-15.5		-17.0		-24.1		-24.3		-25.5	
-lnL: comCAA	-787.0		-786.9		-785.6		-783.9		-785.6		-782.4		-793.8		-793.8		-792.3		-791.1		-791.2		-790.1	
-lnL: survCAA	-1819		-1819		-1821		-1819		-1818		-1821		-1329		-1329		-1330		-1329		-1329		-1330	
-lnL: survCAL	-160.5		-160.4		-161.0		-161.0		-160.8		-161.5		-		-		0.0		-		-		0.0	
-lnL: RecRes	29.3		31.9		[0.0]		24.4		28.6		[0.0]		15.2		15.2		[0.0]		13.1		13.1		[0.0]	
-lnL: Catch	3.1		3.0		2.1		3.2		3.8		2.5		1.4		1.4		1.2		1.1		1.1		1.1	
-lnL: calibration	-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	0.000		0.000		0.000		0.000		0.000		0.000		2.600*		2.589*		1.073*		0.000		0.000		0.000	
$N_{y1,0}$	15.10	(0.14)	15.88	(0.14)	15.18	(0.14)	15.10	(0.14)	15.91	(0.14)	15.51	(0.14)	13.30	(0.07)	13.30	(0.07)	13.27	(0.07)	13.52	(0.07)	13.52	(0.07)	13.50	(0.07)
ϕ	0.09	(1.06)	0.19	(0.58)	0.16	(0.64)	0.08	(0.86)	0.16	(0.62)	0.16	(0.63)	-		-		-		-		-		-	
B^{sp}_{2011}	14.51	(0.16)	14.26	(0.16)	13.13	(0.17)	13.57	(0.14)	13.18	(0.14)	12.57	(0.15)	13.51	(0.16)	13.52	(0.16)	12.59	(0.17)	13.54	(0.14)	13.40	(0.14)	12.67	(0.15)
B^{sp}_{1982}	22.83	(0.05)	22.93	(0.05)	22.53	(0.05)	22.27	(0.05)	22.51	(0.05)	22.15	(0.05)	26.37	(0.04)	26.36	(0.04)	26.27	(0.04)	26.08	(0.04)	26.10	(0.04)	26.09	(0.04)
B^{sp}_{y1}	43.41	(0.28)	29.78	(0.34)	33.38	(0.31)	42.90	(0.22)	32.49	(0.31)	32.76	(0.31)	26.37	(0.04)	26.36	(0.04)	26.27	(0.04)	26.08	(0.04)	26.10	(0.04)	26.09	(0.04)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	0.84	0.16	0.84	0.16	0.79	0.11	0.79	0.11	0.78	0.11	0.96	0.18	0.96	0.18	0.96	0.18	0.83	0.12	0.83	0.12	0.83	0.11
NEFSC fall	0.67	0.10	0.68	0.10	0.68	0.10	0.64	0.12	0.64	0.12	0.64	0.12	0.54	0.06	0.54	0.06	0.54	0.05	0.47	0.06	0.47	0.06	0.47	0.05
MADMF spring	0.22	0.30	0.22	0.30	0.22	0.30	0.15	0.24	0.15	0.24	0.15	0.24	0.22	0.30	0.22	0.30	0.23	0.30	0.15	0.24	0.15	0.24	0.15	0.24
K	70.79	(0.13)	245.16	(0.26)			31.22	(0.08)	36.39	(0.09)			157.95	(1.35)	625.38	(1.47)			31.26	(0.26)	43.49	(0.35)		
h	2.44	(0.14)	0.88	(0.05)			1.00	(0.16)	0.98+	(0.00)			1.79	(0.25)	0.80	(0.08)			0.94	(0.29)	0.82	(0.39)		
MSY	13.48	(0.10)	15.27	(0.22)			6.31	(0.16)	5.83	(0.09)			23.77	(1.17)	36.66	(1.40)			5.88	(0.17)	5.76	(0.23)		
F_{MSY}	0.59		0.27				0.67		0.95				0.42		0.22				0.60		0.86			
B^{sp}_{MSY}	23.88	(0.10)	57.05	(0.23)			11.54	(0.16)	8.27	(0.10)			58.07	(1.17)	168.72	(1.40)			11.80	(0.17)	8.79	(0.23)		
B^{sp}_{MSY}/K^{sp}	0.34	(0.11)	0.23	(0.06)			0.37	(0.17)	0.23	(0.03)			0.37	(0.20)	0.27	(0.08)			0.38	(0.32)	0.20	(0.50)		
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.61	(0.10)	0.25	(0.23)			1.18	(0.16)	1.59	(0.10)			0.23	(1.17)	0.08	(1.40)			1.15	(0.17)	1.53	(0.23)		

* This applies to the gradient for the age 4 parameter for selectivity in the first 1982-1988 block. All other estimated parameters have gradient <10^{-3}.

+ Estimate on bound of *h*=0.98 imposed on Beverton-Holt stock-recruitment curve fits.

Table 2: An extension of Table 1 which provides BRP values for external estimation of the stock-recruitment functions.

	Start in 1963								Start in 1982							
	M =0.2				*M* increasing				*M* =0.2				*M* increasing			
	Ricker		Beverton-Holt		Ricker		Beverton-Holt		Ricker		Beverton-Holt		Ricker		Beverton-Holt	
-lnL	8.7		11.4		1.5		6.1		2.8		2.7		-1.9		-1.8	
h	2.65	(0.14)	0.91	(0.05)	1.14	(0.16)	1.00	(0.00)	2.16	(0.24)	0.86	(0.08)	1.18	(0.29)	1.00	(0.00)
K^{sp}	66.41	(0.13)	220.04	(0.22)	29.83	(0.06)	36.86	(0.09)	89.51	(0.65)	324.35	(0.76)	27.22	(0.17)	39.44	(0.11)
F_{MSY}	0.87		0.38		1.11		5.00*		0.67		0.31		1.20		5.00*	
$MSYL^{sp}$	0.33	(0.11)	0.22	(0.05)	0.36	(0.16)	0.11	(0.00)	0.35	(0.18)	0.26	(0.07)	0.36	(0.29)	0.11	(0.00)
B^{sp}_{MSY}	21.94	(0.09)	49.41	(0.18)	10.88	(0.15)	3.87	(0.09)	31.57	(0.50)	83.96	(0.69)	9.86	(0.18)	4.15	(0.11)
MSY	13.55	(0.09)	14.32	(0.18)	7.01	(0.15)	6.59	(0.09)	15.62	(0.50)	20.36	(0.69)	6.65	(0.18)	7.05	(0.11)
B^{sp}_{2011}	13.11	(0.17)	13.11	(0.17)	12.57	(0.15)	12.57	(0.15)	12.59	(0.17)	12.59	(0.17)	12.67	(0.17)	12.67	(0.15)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.60	(0.09)	0.27	(0.18)	1.16	(0.15)	3.25	(0.09)	0.40	(0.50)	0.15	(0.69)	1.29	(0.18)	3.05	(0.11)
B^{sp}_{2011}/K^{sp}	0.20	(0.13)	0.06	(0.22)	0.42	(0.06)	0.34	(0.09)	0.14	(0.65)	0.04	(0.76)	0.47	(0.17)	0.32	(0.11)

* Estimate on upper bound of F=5.00 imposed on the search for F_{MSY}, which may occur in the limit of h=1 for the Beverton-Holt form. (Note that unlike for the internal estimation where a bound of h=0.98 is imposed, the bound imposed here is h=1.)

Table 3: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for different sensitivities about the Reference Case (start in 1963 with a Ricker stock-recruitment curve estimated internally) with M=0.2, which is shown in **bold**. Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood overall values shown in square parentheses denote non-comparability with values of all likelihood components given in adjacent columns. Mass units are '000 tons. $y1$ refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

	Different start year														Adjusted log-normal CAA error		Fit to biomass instead of numbers		Domed NEFSC survey selectivity		Alternative pre-1982 commercial selectivities				Bigelow internal calibration		No CAL data	
			Reference Case																		Same as 82-88		Shifted 2yrs left					
Start year y1=	1934		1963		1964		1965		1967		1970		1982		1963		1963		1963		1963		1963		1963		1963	
-lnL: overall	-[2762]		**-2765**		-[2748]		-[2732]		-[2697]		-[2610]		-[2128]		-[298]		-[2777]		-2781		-2768		-2761		-2766		-[2605]	
-lnL: survey	-24.5		**-24.2**		-25.4		-25.1		-23.2		-19.4		-15.5		-24.2		-37.5		-25.3		-24.7		-23.8		-25.3		-24.1	
-lnL: comCAA	-787.0		**-787.0**		-787.0		-786.8		-786.6		-787.2		-793.8		-177.8		-786.3		-786.7		-790.6		-788.6		-787.0		-787.2	
-lnL: survCAA	-1819		**-1819**		-1819		-1820		-1820		-1820		-1329		-134		-1818		-1828		-1817		-1815		-1821		-1819	
-lnL: survCAL	-160.0		**-160.5**		-141.6		-126.1		-89.3		-		-		16.6		-160.3		-162.1		-160.6		-160.2		-160.6		0.0	
-lnL: RecRes	[31.9]		**29.3**		[29.1]		[29.7]		[26.4]		[21.3]		[15.2]		[25.0]		[29.9]		26.0		27.9		30.1		29.6		[28.7]	
-lnL: Catch	3.2		**3.1**		3.0		2.9		2.4		1.9		1.4		2.9		2.5		2.5		3.1		3.3		3.2		3.1	
-lnL: calibration	-6.7		**-6.7**		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7		-5.4		-6.7	
Maximum gradient	0.000		**0.000**		0.000		0.000		0.000		0.000		2.600*		0.000		0.000		0.000		0.000		30.774		18.6[&]		0.000	
$N_{y1,0}$	9.52	(76.22)	**15.10**	**(0.14)**	8.56	(0.17)	4.65	(0.20)	3.25	(0.21)	4.84	(0.19)	13.30	(0.07)	16.02	(0.11)	15.41	(0.14)	16.29	(0.14)	14.08	(0.14)	15.41	(0.15)	15.09	(0.14)	15.17	(0.16)
ϕ	0.25	(152.54)	**0.09**	**(1.06)**	0.04	(2.05)	0.14	(0.78)	0.16	(0.73)	-		-		0.21	(0.35)	0.09	(0.91)	0.01	(0.08)	0.09	(0.97)	0.08	(1.08)	0.09	(1.05)	0.01	(0.02)
B^{sp}_{2011}	14.25	(0.16)	**14.51**	**(0.16)**	14.42	(0.16)	14.33	(0.16)	14.35	(0.16)	14.22	(0.16)	13.51	(0.16)	16.04	(0.17)	13.59	(0.15)	15.30	(0.17)	14.30	(0.16)	14.39	(0.16)	14.67	(0.16)	14.50	(0.16)
B^{sp}_{1982}	22.92	(0.05)	**22.83**	**(0.05)**	22.84	(0.05)	22.96	(0.05)	22.99	(0.05)	22.94	(0.05)	26.37	(0.04)	26.19	(0.05)	22.94	(0.05)	28.63	(0.09)	22.37	(0.05)	23.29	(0.05)	22.81	(0.05)	22.94	(0.05)
B^{sp}_{y1}	41.17	(140.75)	**43.41**	**(0.28)**	46.74	(0.24)	34.80	(0.27)	38.66	(0.13)	34.58	(0.10)	26.37	(0.04)	28.24	(0.23)	39.48	(0.23)	102.12	(0.17)	44.22	(0.26)	41.24	(0.32)	43.30	(0.28)	51.87	(0.13)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	**0.84**	**0.16**	0.84	0.16	0.84	0.16	0.84	0.16	0.84	0.17	0.96	0.18	0.89	0.16	0.83	0.15	0.86	0.16	0.84	0.16	0.85	0.16	0.84	0.16	0.84	0.16
NEFSC fall	0.67	0.10	**0.67**	**0.10**	0.66	0.09	0.65	0.09	0.64	0.10	0.64	0.11	0.54	0.06	0.79	0.11	0.66	0.07	0.69	0.09	0.66	0.10	0.68	0.10	0.67	0.10	0.66	0.10
MADMF spring	0.22	0.30	**0.22**	**0.30**	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.20	0.29	0.19	0.18	0.21	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.22	0.30
K	74.78	(0.19)	**70.79**	**(0.13)**	70.11	(0.14)	75.18	(0.19)	94.80	(0.27)	383.89	(1.81)	157.95	(1.35)	95.45	(0.29)	71.39	(0.15)	97.48	(0.12)	66.28	(0.12)	75.81	(0.16)	70.73	(0.14)	73.03	(0.13)
h	2.24	(0.15)	**2.44**	**(0.14)**	2.46	(0.14)	2.32	(0.16)	2.11	(0.16)	1.65	(0.18)	1.79	(0.25)	1.99	(0.18)	2.39	(0.15)	2.03	(0.12)	2.45	(0.14)	2.41	(0.14)	2.43	(0.14)	2.40	(0.13)
MSY	13.34	(0.12)	**13.48**	**(0.10)**	13.44	(0.10)	13.75	(0.12)	16.09	(0.19)	53.41	(1.69)	23.77	(1.17)	15.26	(0.18)	13.39	(0.10)	15.69	(0.10)	12.69	(0.09)	14.35	(0.10)	13.46	(0.10)	13.76	(0.10)
F_{MSY}	0.53		**0.59**		0.59		0.56		0.50		0.38		0.42		0.48		0.58		0.53		0.60		0.57		0.59		0.58	
B^{sp}_{MSY}	25.73	(0.12)	**23.88**	**(0.10)**	23.59	(0.10)	25.61	(0.12)	32.96	(0.19)	140.96	(1.69)	58.07	(1.17)	32.92	(0.19)	24.14	(0.10)	32.85	(0.12)	22.41	(0.10)	25.88	(0.11)	23.87	(0.10)	24.70	(0.10)
B^{sp}_{MSY}/K^{sp}	0.34	(0.12)	**0.34**	**(0.11)**	0.34	(0.11)	0.34	(0.13)	0.35	(0.13)	0.37	(0.15)	0.37	(0.20)	0.34	(0.15)	0.34	(0.12)	0.34	(0.11)	0.34	(0.11)	0.34	(0.12)	0.34	(0.11)	0.34	(0.11)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.55	(0.12)	**0.61**	**(0.10)**	0.61	(0.10)	0.56	(0.12)	0.44	(0.19)	0.10	(1.69)	0.23	(1.17)	0.49	(0.19)	0.56	(0.10)	0.47	(0.12)	0.64	(0.10)	0.56	(0.11)	0.61	(0.10)	0.59	(0.10)

Table 4: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for different sensitivities about the Reference Case (start in 1963 with a Ricker stock-recruitment curve estimated internally) with *M* increasing from 0.2 until 1988 to 0.4 in 2003 and constant at 0.4 thereafter. This case is shown in **bold.** Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Negative log-likelihood overall values shown in square parentheses denote non-comparability with values given for all likelihood components in adjacent columns. Mass units are '000 tons. *y*1 refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used.

	Different start year														Adjusted log-normal CAA error	
Start year y1=	1934		**1963**		1964		1965		1967		1970		1982		1963	
-lnL: overall	-[2772]		**-[2774]**		-[2757]		-[2740]		-[2705]		-[2615]		-[2137]		-[311]	
-lnL: survey	-30.1		**-30.2**		-31.4		-31.1		-29.9		-26.4		-24.1		-29.3	
-lnL: comCAA	-785.1		**-783.9**		-785.9		-785.8		-784.5		-785.8		-791.1		-176.2	
-lnL: survCAA	-1818		**-1819**		-1818		-1818		-1820		-1819		-1329		-139	
-lnL: survCAL	-160.9		**-161.0**		-142.1		-126.1		-89.3		0.0		0.0		16.0	
-lnL: RecRes	[25.8]		**[24.4]**		[23.8]		[24.4]		[22.7]		[20.1]		[13.1]		[21.0]	
-lnL: Catch	3.4		**3.2**		3.1		3.1		2.7		2.0		1.1		3.5	
-lnL: calibration	-6.7		**-6.7**		-6.7		-6.7		-6.7		-6.7		-6.7		-6.7	
Maximum gradient	0.000		**0.000**		0.000		0.000		0.000		0.000		0.000		0.000	
$N_{y1,0}$	10.74	(1.98)	**15.10**	**(0.14)**	8.70	(0.17)	4.79	(0.20)	3.56	(0.21)	5.23	(0.19)	13.52	(0.07)	15.93	(0.11)
ϕ	0.33	(2.15)	**0.08**	**(0.86)**	0.03	(2.09)	0.08	(1.02)	0.13	(0.84)	-		-		0.18	(0.40)
B^{sp}_{2011}	13.64	(0.15)	**13.57**	**(0.14)**	13.54	(0.14)	13.55	(0.14)	13.57	(0.14)	13.58	(0.15)	13.54	(0.14)	15.07	(0.15)
B^{sp}_{1982}	22.17	(0.05)	**22.27**	**(0.05)**	22.38	(0.05)	22.46	(0.05)	22.33	(0.05)	22.54	(0.05)	26.08	(0.04)	25.71	(0.05)
B^{sp}_{y1}	25.81	(2.11)	**42.90**	**(0.22)**	46.72	(0.19)	38.85	(0.21)	38.64	(0.13)	33.05	(0.10)	26.08	(0.04)	32.43	(0.20)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.80	0.11	**0.79**	**0.11**	0.79	0.11	0.79	0.11	0.79	0.11	0.78	0.11	0.83	0.12	0.78	0.11
NEFSC fall	0.64	0.12	**0.64**	**0.12**	0.63	0.11	0.62	0.11	0.61	0.11	0.59	0.12	0.47	0.06	0.70	0.13
MADMF spring	0.15	0.24	**0.15**	**0.24**	0.15	0.24	0.15	0.24	0.15	0.24	0.15	0.24	0.15	0.24	0.13	0.24
K	31.64	(0.08)	**31.22**	**(0.08)**	31.26	(0.08)	31.03	(0.08)	33.59	(0.11)	44.77	(0.27)	31.26	(0.26)	32.72	(0.09)
h	1.02	(0.16)	**1.00**	**(0.16)**	1.01	(0.16)	1.01	(0.17)	0.91	(0.18)	0.72	(0.21)	0.94	(0.29)	0.95	(0.20)
MSY	6.50	(0.15)	**6.31**	**(0.16)**	6.37	(0.15)	6.32	(0.16)	6.16	(0.15)	6.27	(0.16)	5.88	(0.17)	6.24	(0.18)
F_{MSY}	0.69		**0.67**		0.68		0.68		0.58		0.39		0.60		0.57	
B^{sp}_{MSY}	11.66	(0.15)	**11.54**	**(0.16)**	11.54	(0.16)	11.46	(0.16)	12.72	(0.16)	17.95	(0.16)	11.80	(0.17)	12.22	(0.18)
B^{sp}_{MSY}/K^{sp}	0.37	(0.18)	**0.37**	**(0.17)**	0.37	(0.17)	0.37	(0.18)	0.38	(0.20)	0.40	(0.25)	0.38	(0.32)	0.37	(0.22)
$B^{sp}_{2011}/B^{sp}_{MSY}$	1.17	(0.15)	**1.18**	**(0.16)**	1.17	(0.16)	1.18	(0.16)	1.07	(0.16)	0.76	(0.16)	1.15	(0.17)	1.23	(0.18)

Table 5: Estimates of abundance, MSY-related BRPs, and related quantities for the Gulf of Maine cod for the preferred cases for the two different *M* scenarios. Values in round parentheses are Hessian based CV's, while maximum gradient refers to the quantity reported with the ADMB estimation results. Mass units are '000 tons. *y*1 refers to the start year for the assessment. Recruitment $N_{y1,0}$ is in millions. Refer to Appendix B for definitions of some of the symbols used.

	M =0.2		*M* increasing	
Start year y1=	1934		1934	
-lnL: overall	-2764		-2773	
-lnL: survey	-25.4		-30.8	
-lnL: comCAA	-787.0		-785.2	
-lnL: survCAA	-1821		-1820	
-lnL: survCAL	-160.1		-161.0	
-lnL: RecRes	32.1		26.0	
-lnL: Catch	3.2		3.4	
-lnL: calibration	-5.4		-5.6	
Maximum gradient	18.5*		15.5	
$N_{y1,0}$	11.21	(175.51)	10.78	(1.97)
ϕ	0.32	(231.12)	0.33	(2.14)
B^{sp}_{2011}	14.49	(0.05)	13.79	(0.05)
B^{sp}_{1982}	22.90	(0.16)	22.15	(0.15)
B^{sp}_{y1}	32.69	(222.39)	25.73	(2.10)
	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.84	0.16	0.80	0.11
NEFSC fall	0.67	0.10	0.65	0.12
MADMF spring	0.22	0.30	0.15	0.24
K	74.70	(0.19)	31.58	(0.08)
h	2.24	(0.15)	1.02	(0.16)
MSY	13.33	(0.12)	6.49	(0.15)
F_{MSY}	0.53		0.69	
B^{sp}_{MSY}	25.70	(0.12)	11.64	(0.15)
B^{sp}_{MSY}/K^{sp}	0.34	(0.12)	0.37	(0.18)
$B^{sp}_{2011}/B^{sp}_{MSY}$	0.56	(0.12)	1.18	(0.15)

* This applies to the gradient for the third calibration parameter F2. All other estimated parameters have gradient $<10^{-5}$.

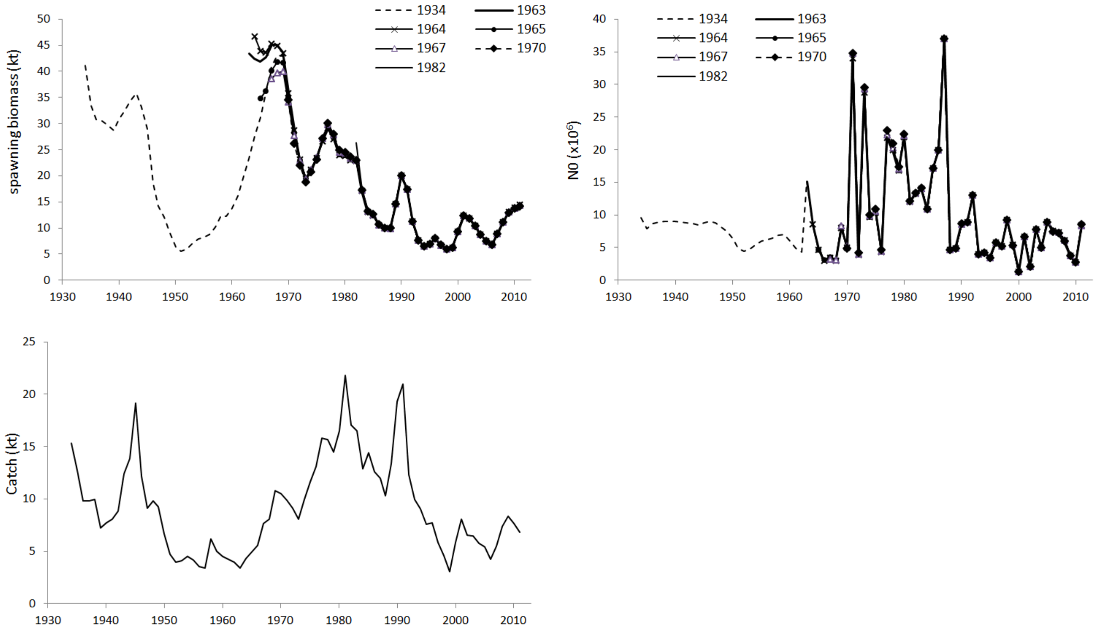

Fig. 1: Spawning biomass and recruitment trajectories for the Ricker internal case with *M*=0.2 and different starting years. The time series of catches is also shown (including the 32% increase pre-1982 to take account of discards).

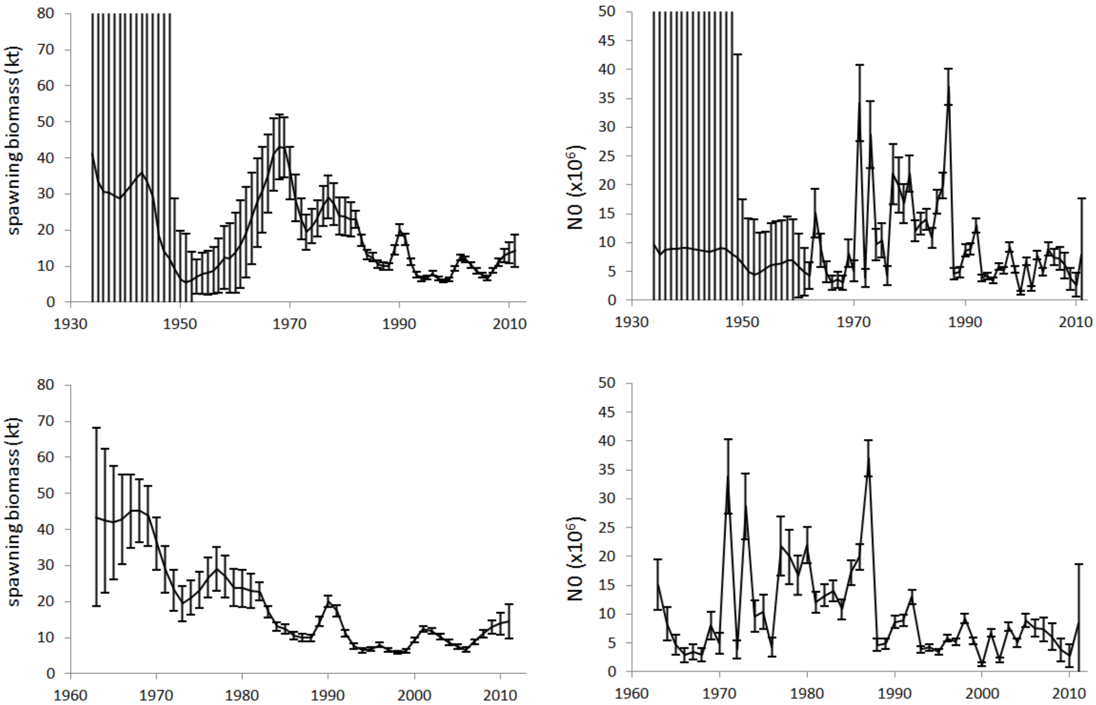

Fig. 2: Spawning biomass and recruitment trajectories for the Ricker internal case with *M*=0.2, start in 1934 (top row) and start in 1963 (bottom row) with ±2 se's shown to reflect approximate 95% CIs.

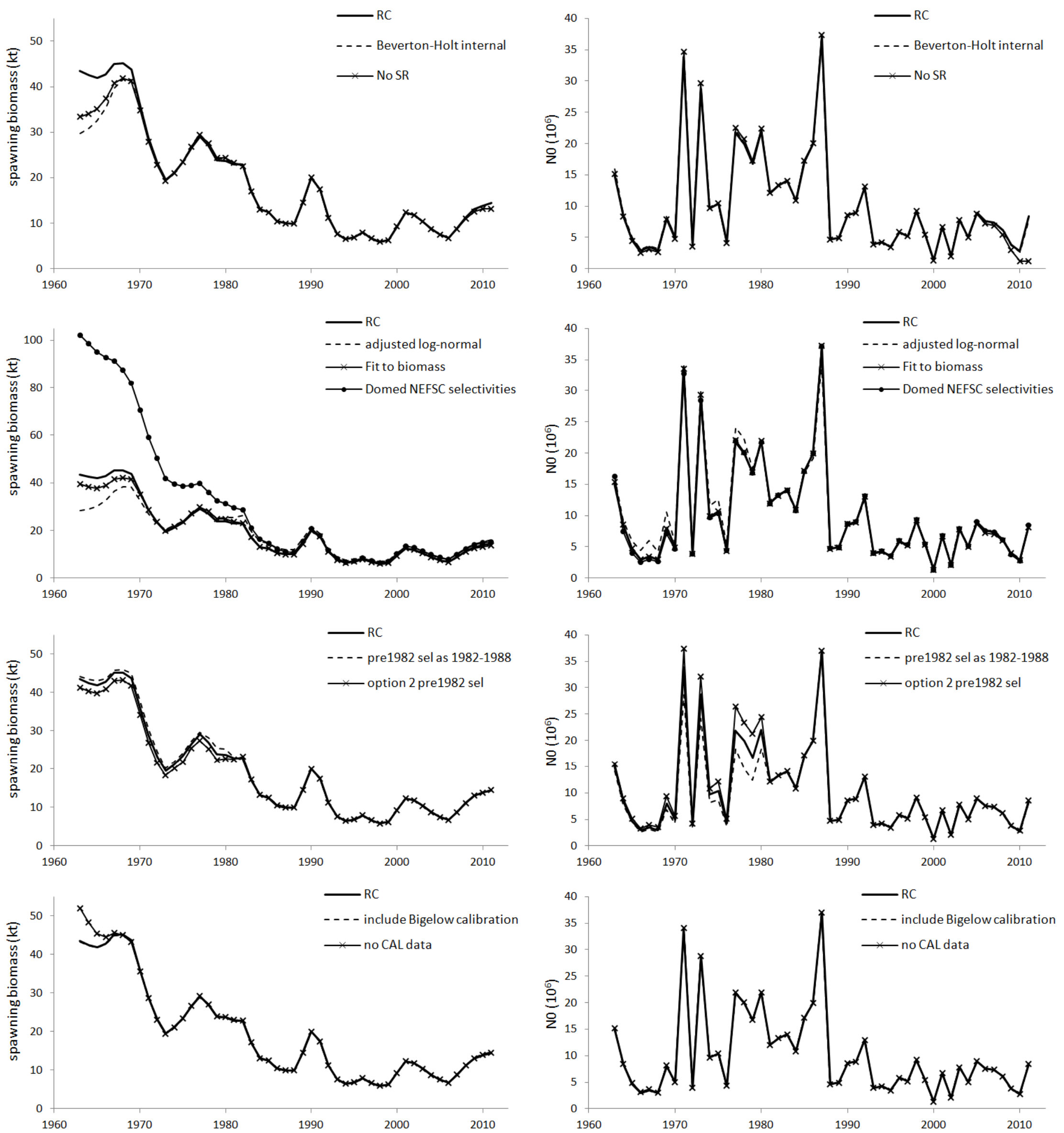

Fig. 3: Spawning biomass and recruitment trajectories for various sensitivities about the Reference Case (RC - Ricker internal start in 1963) for M = 0.2.

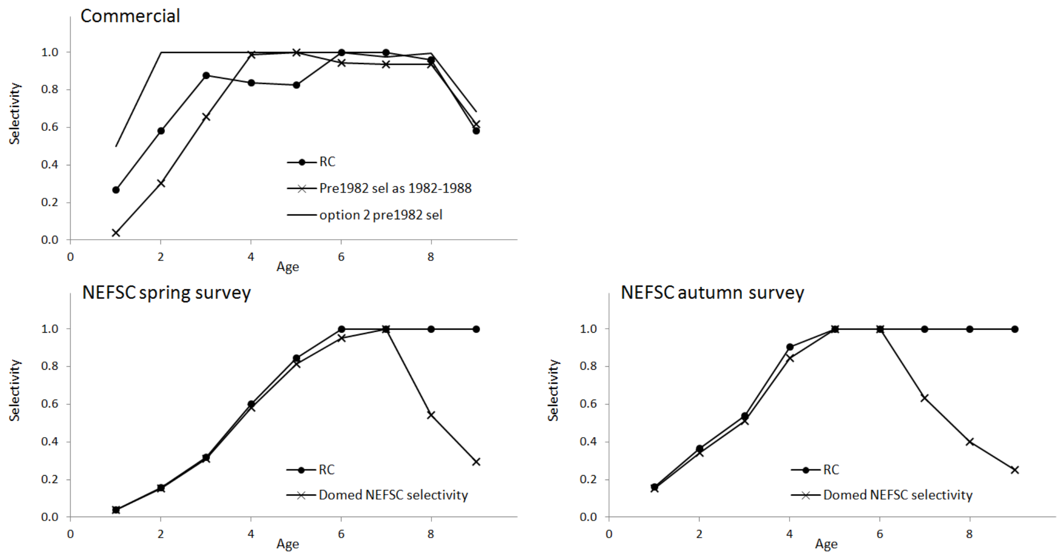

Fig. 4: Pre-1982 commercial selectivities for the RC for *M* = 0.2and the two sensitivities relating to the pre-1982 commercial selectivity, and then for the NEFSC survey selectivities for the RC (flat) and the domed selectivity sensitivity.

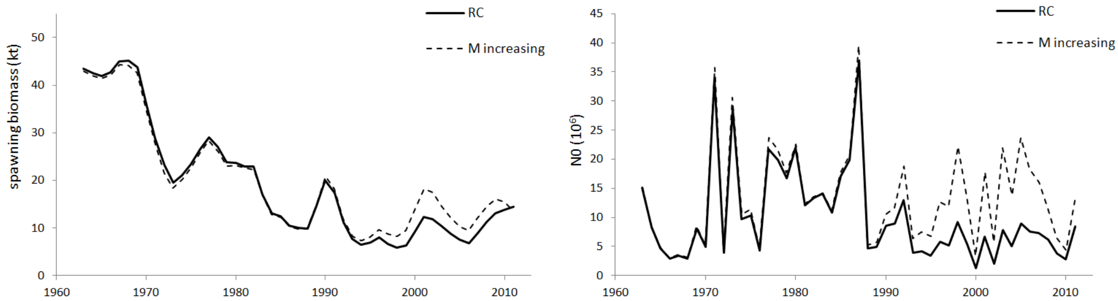

Fig. 5: Spawning biomass and recruitment trajectories for the Reference Case with *M* = 0.2 and the corresponding case with *M* increasing.

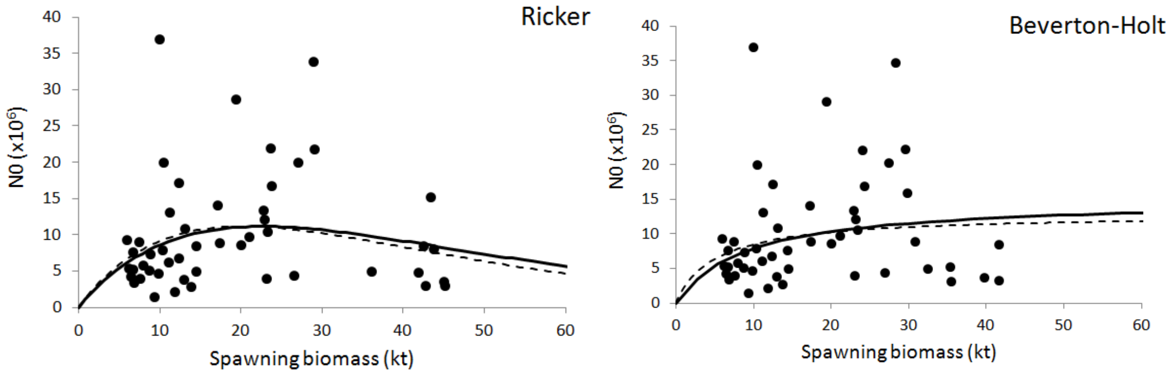

Fig. 6: Stock-recruitment curve and "observed" recruitment for the Ricker and Beverton-Holt relationships estimated internally for the RC choice of a 1963 start year. The dashed lines show the corresponding estimated curves for external estimation.

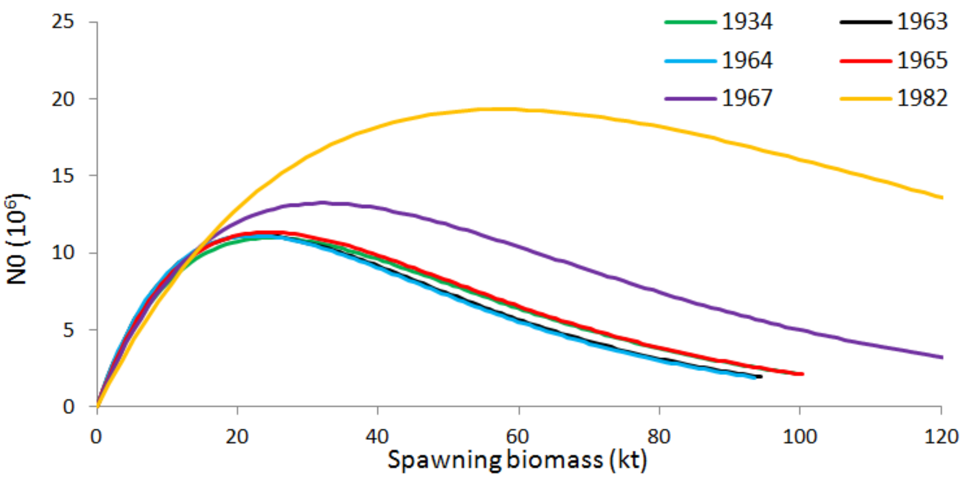

Fig. 7: Stock-recruit relationship for the Reference Case with M = 0.2 and the cases with different start year. To improve discrimination, the very imprecisely estimated 1970 curve which goes to much higher levels than these others is omitted.

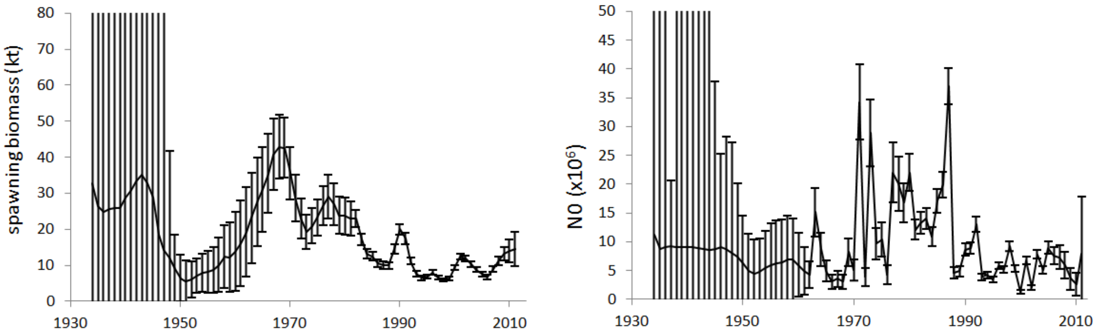

Fig. 8. Spawning biomass and recruitment trajectories (with ±2 se's to reflect approximate 95% CIs) for the "preferred" run, *M*=0.2.

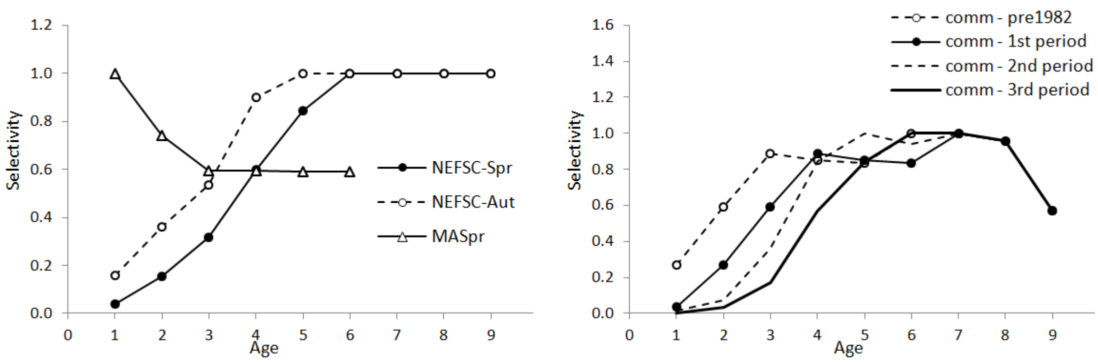

Fig. 9. Survey and commercial selectivities estimated for the "preferred" run, *M*=0.2.

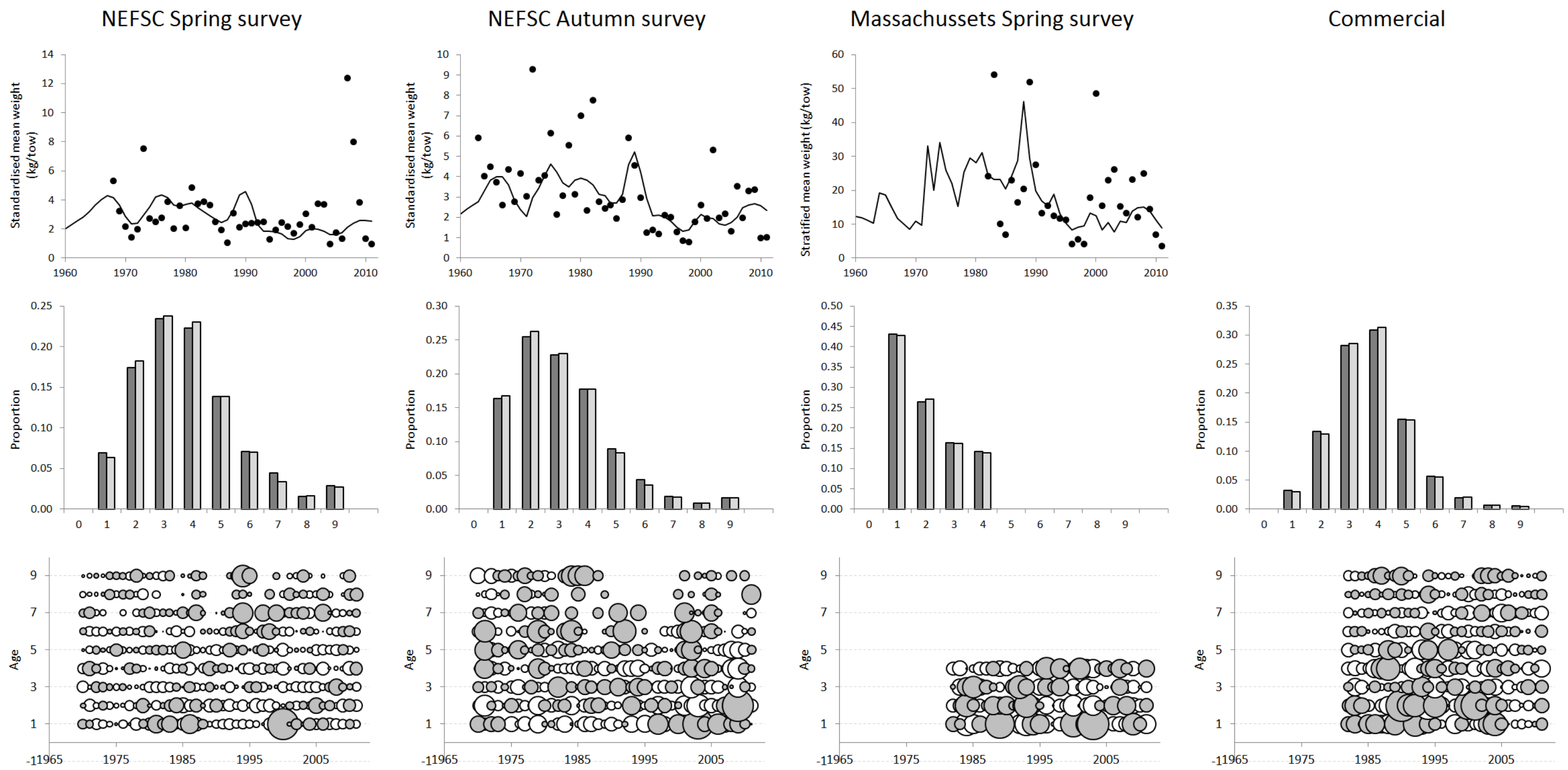

Fig. 10: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the "preferred" run, *M*=0.2. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, 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.

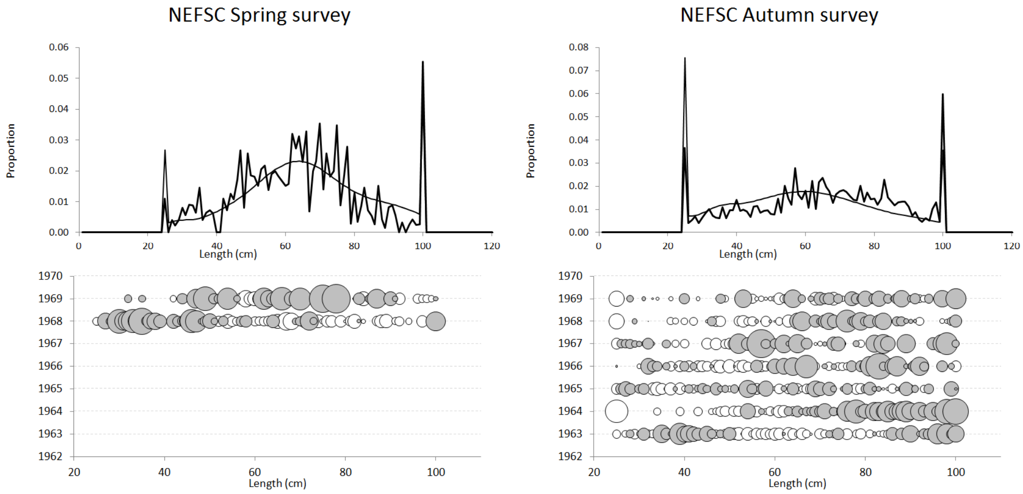

Fig. 11: Fits to the survey catch-at-length data for the "preferred" run, *M*=0.2. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

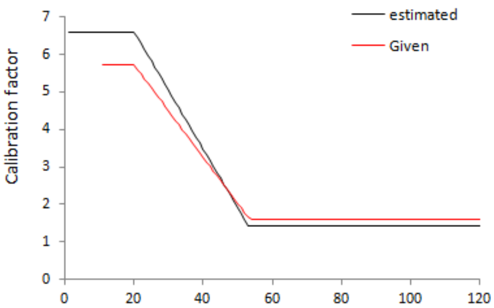

Fig. 12: Comparison of *Bigelow-Albatross* calibration function estimated within the assessment ("preferred" run, *M*=0.2) and calibration function given.

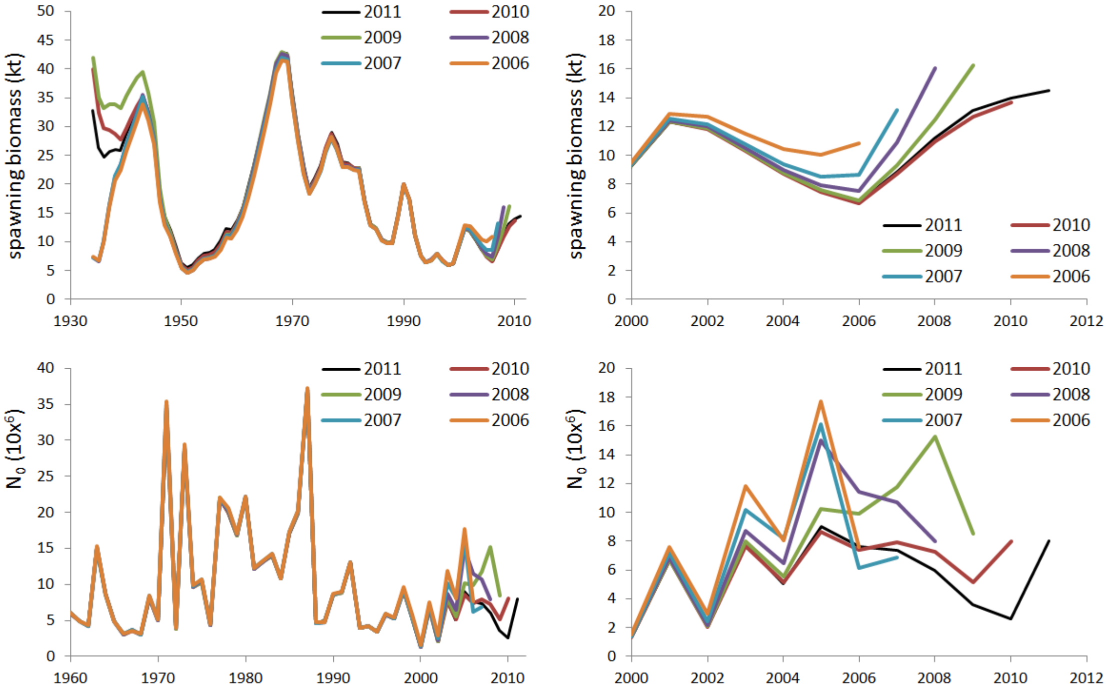

Fig. 13: Retrospective analysis for the "preferred" run, *M*=0.2.

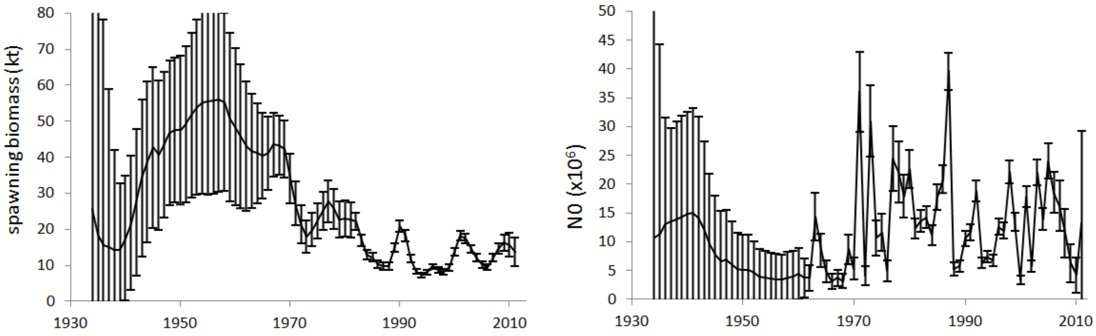

Fig. 14. Spawning biomass and recruitment trajectories (with ±2 se's to reflect approximate 95% CIs) for the "preferred" run, *M* increasing.

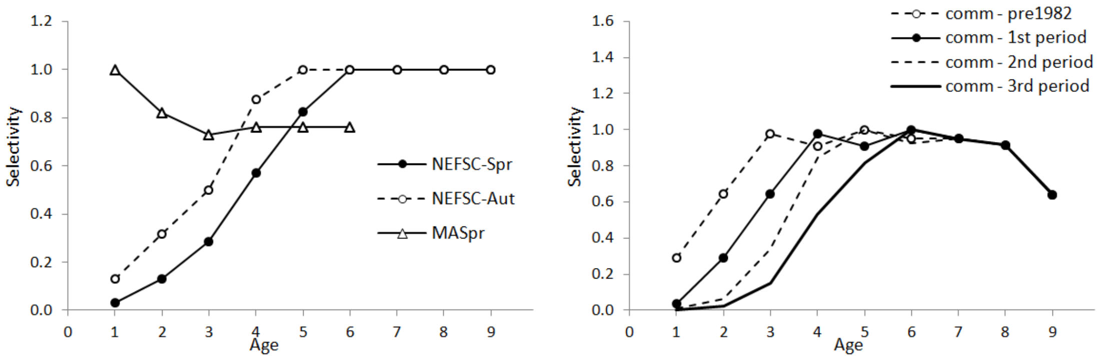

Fig. 15. Survey and commercial selectivities estimated for the "preferred" run, *M* increasing. Note that for the Massachusetts survey as the age 4 selectivity is estimated to be greater than that for age 3, the selectivities for ages 5 and 6 are set equal to those for age 4 rather than continuing the trend from age 3 to age 4.

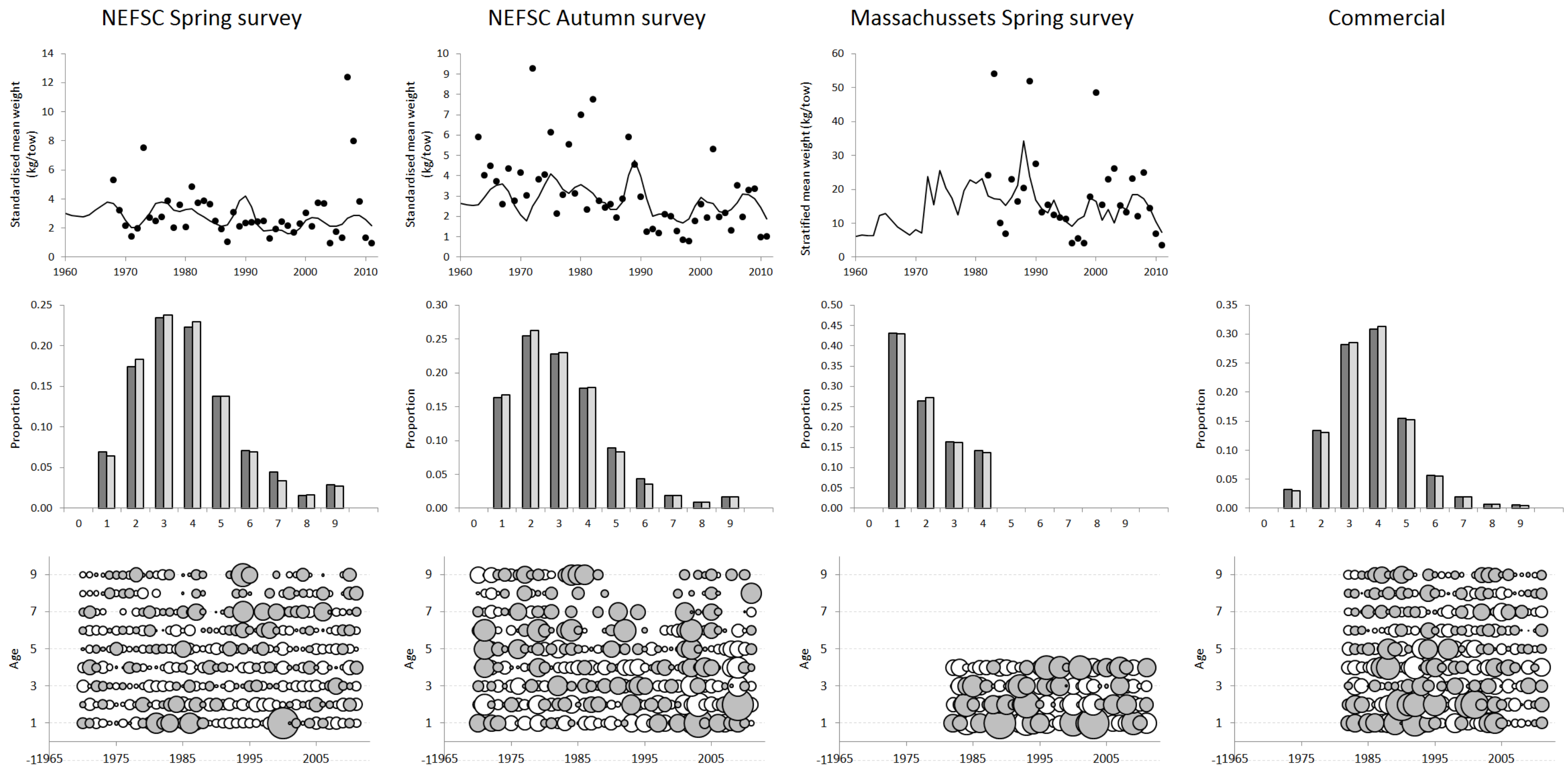

Fig. 16: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the "preferred" run, *M* increasing. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised 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.

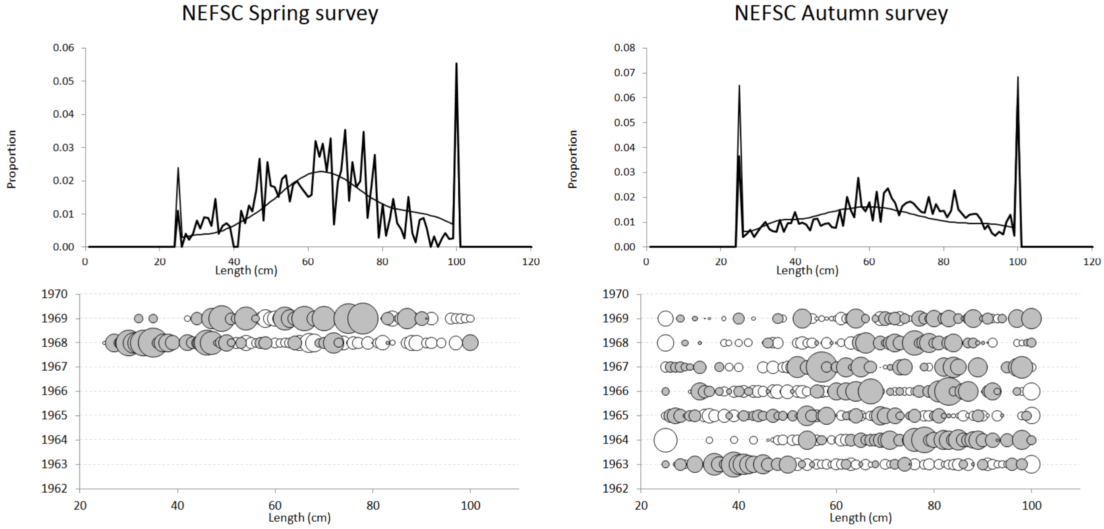

Fig. 17: Fits to the survey catch-at-length data for the "preferred" run, *M* increasing. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles 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.

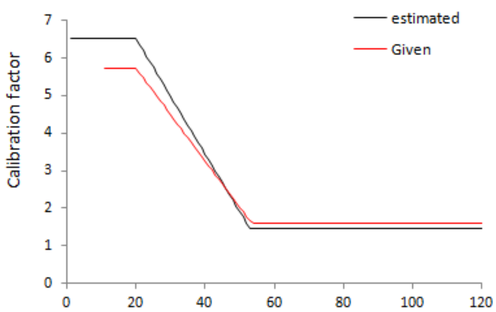

Fig. 18: Comparison of *Bigelow-Albatross* calibration function estimated within the assessment ("preferred" run, *M* increasing) and calibration function given.

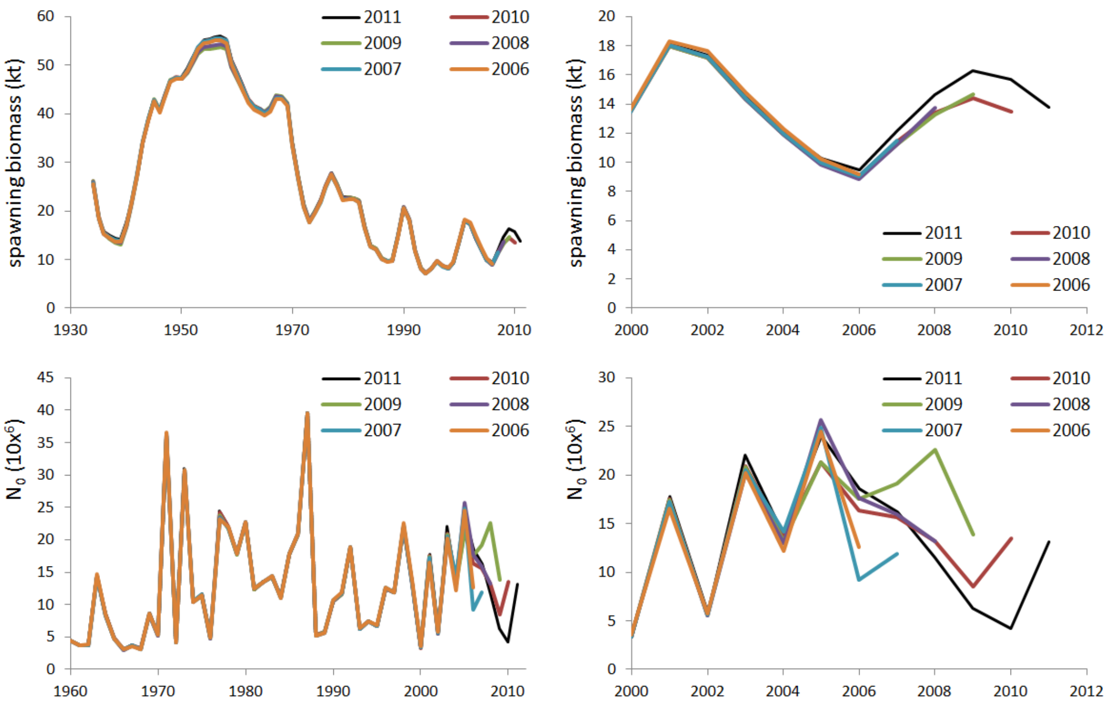

Fig. 19: Retrospective analysis for "preferred" run, *M* increasing.

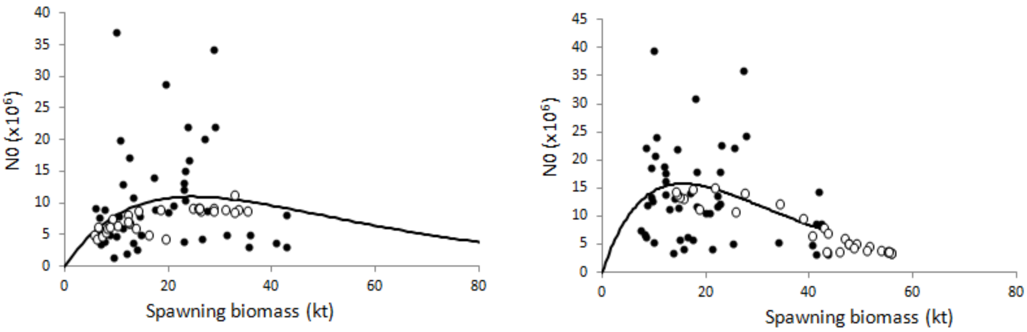

Fig. 20: Stock-recruitment curves and "observed" recruitment (pre-1963 data are shown as open circles) for the "preferred" runs *M*=0.2 (left-hand plot) and *M* increasing (right-hand plot).

APPENDIX A – Data

Note that the tables following, and the analyses reported in the main text, now exclude any 2012 data.

Table A1: Total catch (incl. USA, DWF and recreational landings, and discards) (thousand metric tons) of Atlantic cod from the Gulf of Maine (NAFO Division 5Y), 1964-2012 (Michael Palmer, pers. commn). The revised discard mortality assumptions have been applied. Note that pre-1982 catches have been increased by 32% in the Base Case to allow for levels of discards suggested by recent analyses by the NEFSC.

Year	Total catch	Year	Total catch	Year	Total catch	Year	Total catch
1934	11.619	1954	3.411	1974	7.550	1994	9.060
1935	9.679	1955	3.171	1975	8.788	1995	7.566
1936	7.442	1956	2.693	1976	9.894	1996	7.757
1937	7.432	1957	2.562	1977	11.993	1997	5.814
1938	7.547	1958	4.670	1978	11.890	1998	4.578
1939	5.504	1959	3.795	1979	10.972	1999	3.078
1940	5.836	1960	3.448	1980	12.515	2000	5.823
1941	6.124	1961	3.216	1981	16.512	2001	8.055
1942	6.679	1962	2.989	1982	17.096	2002	6.509
1943	9.397	1963	2.595	1983	16.487	2003	6.497
1944	10.516	1964	3.242	1984	12.868	2004	5.766
1945	14.532	1965	3.759	1985	14.391	2005	5.441
1946	9.248	1966	4.225	1986	12.572	2006	4.268
1947	6.916	1967	5.824	1987	12.005	2007	5.527
1948	7.462	1968	6.137	1988	10.333	2008	7.375
1949	7.033	1969	8.155	1989	13.371	2009	8.355
1950	5.062	1970	7.961	1990	19.314	2010	7.670
1951	3.567	1971	7.475	1991	20.978	2011	6.830
1952	3.011	1972	6.927	1992	12.347		
1953	3.121	1973	6.138	1993	9.960		

Table A2: Mean weight-at-age (kg) at the beginning of the year for the Gulf of Maine cod stock. Values derived from aggregated commercial landings and discard mean weight-at-age data (mid-year) using procedures described by Rivard (1980) (Michael Palmer, pers. commn) and applying the revised mortality assumptions. Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9+
1982	0.0024	0.241	0.594	1.165	2.127	4.635	7.622	9.289	9.695	15.664
1983	0.0077	0.050	0.501	1.114	1.894	3.136	5.539	6.549	9.962	13.325
1984	0.0001	0.075	0.372	1.019	2.021	2.952	4.593	7.118	7.845	14.828
1985	0.0146	0.014	0.403	0.910	2.013	3.532	4.608	6.863	9.700	13.676
1986	0.0009	0.104	0.316	1.077	1.917	3.670	5.504	6.908	9.315	14.646
1987	0.0007	0.028	0.406	0.777	2.273	3.574	5.889	8.079	9.487	14.582
1988	0.0003	0.022	0.293	0.980	1.709	4.010	4.927	6.705	10.069	12.993
1989	0.0223	0.027	0.292	0.887	2.179	3.172	5.578	6.945	8.799	20.913
1990	0.0063	0.095	0.431	0.937	1.742	3.627	5.750	8.043	10.440	18.718
1991	0.0069	0.071	0.450	1.083	1.689	2.846	5.654	8.972	11.518	14.060
1992	0.0116	0.028	0.476	1.215	2.026	2.564	4.629	8.832	10.453	14.483
1993	0.0116	0.046	0.191	1.254	1.702	3.449	4.083	7.388	12.219	15.708
1994	0.0095	0.038	0.236	1.003	2.244	2.571	5.294	6.601	11.095	11.846
1995	0.0122	0.051	0.275	0.946	2.021	3.934	4.722	8.526	10.045	22.443
1996	0.0223	0.060	0.356	1.462	1.784	2.971	6.185	8.967	12.844	16.357
1997	0.0049	0.049	0.391	1.466	2.407	2.571	3.973	8.245	11.940	16.938
1998	0.0015	0.059	0.256	1.445	2.245	3.423	3.558	5.739	10.442	16.676
1999	0.0224	0.044	0.343	1.196	2.237	3.139	4.752	5.301	8.351	12.279
2000	0.0092	0.120	0.461	1.063	2.257	3.422	4.773	5.508	7.882	12.661
2001	0.0229	0.097	0.456	1.305	2.420	3.851	5.091	6.513	6.912	9.538
2002	0.0115	0.089	0.465	1.050	2.249	3.247	5.296	6.514	7.924	12.152
2003	0.0217	0.089	0.346	1.053	1.742	2.977	4.118	6.837	8.011	12.023
2004	0.0105	0.066	0.351	0.971	2.110	2.620	4.199	5.908	8.627	13.288
2005	0.0082	0.060	0.248	0.821	1.654	3.338	3.841	5.758	7.593	12.546
2006	0.0428	0.089	0.295	0.808	1.890	2.467	4.076	4.912	6.744	12.137
2007	0.0086	0.124	0.450	0.925	1.771	3.005	3.723	5.020	6.329	12.394
2008	0.0464	0.085	0.420	1.117	1.888	2.892	3.630	5.147	6.803	12.040
2009	0.0137	0.171	0.480	1.248	2.283	2.908	3.658	4.735	6.735	12.878
2010	0.0061	0.100	0.589	1.168	2.328	3.198	3.685	4.778	7.153	11.612
2011	0.0836	0.087	0.492	1.353	1.972	3.262	4.114	4.788	5.751	12.995

Table A3: Mean weight-at-age (kg) of landings for the Gulf of Maine cod stock applying the revised mortality assumptions (Michael Palmer, pers. commn). Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9+
1982	0.012	0.356	0.858	1.514	2.606	5.067	7.065	9.620	9.771	15.664
1983	0.024	0.224	0.768	1.542	2.418	3.808	6.055	6.071	10.317	13.325
1984	0.001	0.234	0.653	1.478	2.678	3.609	5.540	8.368	10.138	14.828
1985	0.039	0.206	0.733	1.404	2.819	4.658	5.884	8.502	11.244	13.676
1986	0.005	0.277	0.501	1.698	2.774	4.778	6.504	8.109	10.206	14.646
1987	0.004	0.154	0.642	1.323	3.090	4.668	7.259	10.036	11.099	14.582
1988	0.003	0.122	0.577	1.666	2.360	5.205	5.200	6.193	10.103	12.993
1989	0.046	0.236	0.752	1.518	2.959	4.282	5.980	9.276	12.519	20.913
1990	0.021	0.193	0.811	1.349	2.141	4.474	7.721	10.820	11.750	18.718
1991	0.014	0.236	1.113	1.601	2.281	3.894	7.144	10.429	12.261	14.031
1992	0.023	0.055	1.033	1.530	2.747	2.976	5.587	10.921	10.483	14.483
1993	0.021	0.081	0.690	1.748	2.150	4.420	5.670	9.817	13.673	15.701
1994	0.022	0.058	0.730	1.712	3.085	3.251	6.335	7.684	12.542	11.846
1995	0.027	0.103	1.288	1.591	2.649	5.090	6.865	11.466	13.128	22.443
1996	0.033	0.100	1.293	2.096	2.260	3.462	7.558	11.728	14.455	16.269
1997	0.017	0.064	1.351	2.128	3.022	3.074	4.699	9.000	12.156	16.938
1998	0.008	0.202	1.071	1.931	2.633	3.972	4.255	7.122	12.118	16.676
1999	0.052	0.222	0.635	1.723	2.777	3.892	5.670	6.704	9.811	12.279
2000	0.030	0.282	1.081	2.150	3.316	4.325	5.898	5.352	9.331	12.680
2001	0.045	0.316	0.890	2.176	3.144	4.666	6.140	7.273	9.072	9.559
2002	0.032	0.185	0.795	1.797	2.906	3.792	6.132	6.969	8.808	12.205
2003	0.038	0.202	0.809	1.843	2.378	3.654	5.112	7.649	9.191	12.058
2004	0.025	0.111	0.483	1.606	2.965	3.547	5.350	7.220	9.764	13.303
2005	0.027	0.126	0.558	1.625	2.401	4.233	4.502	6.349	8.002	12.549
2006	0.071	0.289	0.648	1.493	2.932	3.357	4.463	5.562	7.430	12.146
2007	0.025	0.220	0.744	1.731	2.922	3.735	4.771	6.167	7.302	12.394
2008	0.085	0.247	0.862	2.179	2.818	3.530	3.988	5.819	7.528	12.044
2009	0.032	0.337	0.911	2.153	3.126	3.575	4.368	5.959	8.000	12.887
2010	0.023	0.264	1.200	1.995	3.203	3.914	4.447	5.708	8.730	11.612
2011	0.0856	0.3289	0.9331	2.0561	2.874	3.8696	4.839	5.7166	5.9528	12.984

Table A4: Total (commercial and recreational landings and discards) catches-at-age for the Gulf of Maine cod stock, applying the revised mortality assumptions (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+
1982	448849	2926542	2287192	1430682	748755	65880	94051	72553	90055
1983	597496	2462037	2913215	1201593	704010	452680	50022	62542	56198
1984	370324	2129556	1675931	1643588	437453	219625	105649	9495	53395
1985	505660	1944327	2405137	1151815	738096	161362	107192	48359	33213
1986	760701	1747046	2747811	991982	279282	202725	48016	38188	47527
1987	281794	2018317	1568334	1574499	345353	89415	81032	14459	37549
1988	415081	1542790	2086633	1156925	447729	67430	25560	26247	9267
1989	166436	1247203	2385088	1651856	521108	87147	70289	9369	19564
1990	65527	812544	5547767	2717623	541353	189069	29703	36417	43315
1991	121627	499588	942731	5561272	1037852	150670	55540	25983	15805
1992	370302	830147	867564	502084	2189957	226167	80181	6044	5530
1993	105929	512307	2149041	944709	103328	497117	41561	11264	0
1994	123996	201923	1525603	1294203	266291	66224	74158	28714	7870
1995	78932	319462	1321833	1260435	221653	29931	6521	18184	2808
1996	37536	111569	627693	2003886	405881	36651	4039	491	1623
1997	69144	137484	519557	467768	869161	72472	5523	2272	1029
1998	5941	171062	492301	628941	152820	205873	28696	5168	2257
1999	73948	90853	347840	336596	172344	53699	59469	12388	1067
2000	24758	485043	556537	813684	176640	85157	12485	10521	0
2001	584	393951	1163770	684449	385530	106600	57232	8262	11577
2002	16831	41591	374949	912638	323797	163476	66392	28087	20263
2003	44899	125587	167812	582079	706098	186022	75694	29224	26844
2004	149420	105917	609344	259720	407447	251632	68378	33017	27442
2005	23545	180064	159581	945815	89223	246596	109148	28457	31674
2006	19249	59082	426566	290132	461742	30341	79655	39016	27343
2007	12171	108471	299416	976424	137404	230163	7947	19244	21999
2008	12156	130508	598424	707392	780450	86355	110576	4041	16558
2009	10651	101492	622453	1093273	477852	304754	20896	30506	9646
2010	8159	83580	394486	888549	668256	164291	71683	11213	7611
2011	8683	60526	322164	589583	573856	339910	34926	38408	9433

Table A5: Standardized stratified mean numbers per tow at age and standardized mean numbers and mean weight (kg) per tow for ages 1+ of Atlantic cod in NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine, 1968-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+	Stratified mean numbers/ tow	CV	Stratified mean wt/tow (kg)	CV
1968										5.329*	(0.127)	17.480*	(0.153)
1969										3.215*	(0.328)	13.100*	(0.329)
1970	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.330	2.191	(0.214)	11.089	(0.237)
1971	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.204	1.429	(0.190)	7.004	(0.211)
1972	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.386	2.004	(0.208)	8.031	(0.233)
1973	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.848	7.525	(0.328)	18.807	(0.415)
1974	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.258	2.738	(0.188)	7.417	(0.199)
1975	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.140	2.500	(0.222)	6.039	(0.249)
1976	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.117	2.782	(0.181)	7.555	(0.166)
1977	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.038	3.872	(0.269)	8.541	(0.208)
1978	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.131	2.050	(0.191)	7.697	(0.207)
1979	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.064	3.599	(0.234)	7.555	(0.176)
1980	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.132	2.084	(0.171)	6.231	(0.182)
1981	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	4.832	(0.194)	10.651	(0.205)
1982	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.050	3.749	(0.219)	8.616	(0.223)
1983	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.181	3.900	(0.263)	10.962	(0.225)
1984	0.151	1.309	0.987	0.853	0.229	0.047	0.090	0.000	0.000	3.667	(0.443)	6.143	(0.324)
1985	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	2.517	(0.202)	7.645	(0.223)
1986	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.018	1.957	(0.314)	3.476	(0.197)
1987	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.015	1.082	(0.257)	1.976	(0.314)
1988	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	3.099	(0.211)	3.603	(0.281)
1989	0.025	0.609	0.712	0.630	0.069	0.068	0.000	0.000	0.000	2.112	(0.184)	2.424	(0.207)
1990	0.009	0.233	1.325	0.669	0.076	0.032	0.018	0.000	0.000	2.362	(0.249)	3.077	(0.280)
1991	0.028	0.077	0.233	1.750	0.247	0.041	0.018	0.000	0.000	2.393	(0.251)	2.891	(0.240)
1992	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	2.435	(0.317)	8.627	(0.374)
1993	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.023	2.507	(0.223)	5.875	(0.347)
1994	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.045	1.271	(0.223)	2.428	(0.216)
1995	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.028	1.930	(0.273)	2.432	(0.257)
1996	0.057	0.022	0.586	1.355	0.385	0.060	0.000	0.000	0.000	2.465	(0.240)	5.427	(0.275)
1997	0.159	0.139	0.390	0.271	0.874	0.244	0.115	0.000	0.000	2.192	(0.168)	5.615	(0.192)
1998	0.018	0.228	0.359	0.513	0.143	0.408	0.021	0.020	0.000	1.711	(0.344)	4.180	(0.324)
1999	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.011	2.301	(0.242)	5.090	(0.320)
2000	1.173	0.737	0.438	0.485	0.099	0.092	0.011	0.022	0.000	3.057	(0.221)	3.211	(0.155)
2001	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.011	2.147	(0.311)	6.215	(0.327)
2002	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	3.724	(0.203)	10.934	(0.215)
2003	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.122	3.677	(0.223)	9.494	(0.368)
2004	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.981	(0.256)	2.412	(0.293)
2005	0.029	0.739	0.081	0.623	0.011	0.138	0.128	0.015	0.000	1.764	(0.241)	2.701	(0.248)
2006	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.015	1.334	(0.203)	2.702	(0.249)
2007	0.100	3.422	3.077	4.446	0.437	0.796	0.075	0.041	0.000	12.393	(0.665)	15.811	(0.540)
2008	0.079	1.165	3.930	1.582	1.099	0.053	0.082	0.000	0.000	7.990	(0.716)	10.824	(0.609)
2009	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.004	3.599	(0.531)	7.161	(0.491)
2010	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.025	1.296	(0.243)	3.336	(0.264)
2011	0.005	0.024	0.140	0.383	0.189	0.086	0.033	0.035	0.000	0.894	(0.279)	2.133	(0.201)

* Aggregate index for ages 0+ as numbers-at-age and biomasses-at-age are not available pre-1970.

Table A6: Standardized stratified mean numbers per tow at age and standardized mean numbers and mean weight (kg) per tow for ages 1+ of Atlantic cod in NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine, 1963-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	7	8	9+	Stratified mean numbers/ tow	CV	Stratified mean wt/tow (kg)	CV
1963										5.914*	(0.250)	17.950*	(0.391)
1964										4.015*	(0.412)	22.799*	(0.496)
1965										4.500*	(0.274)	12.089*	(0.273)
1966										3.720*	(0.217)	12.838*	(0.227)
1967										2.602*	(0.223)	9.313*	(0.219)
1968										4.374*	(0.181)	19.437*	(0.198)
1969										2.758*	(0.152)	15.154*	(0.217)
1970	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.237	4.162	(0.318)	16.437	(0.248)
1971	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.345	3.027	(0.205)	16.196	(0.307)
1972	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.367	9.269	(0.535)	12.988	(0.199)
1973	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.320	3.814	(0.151)	8.758	(0.267)
1974	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.255	4.063	(0.260)	8.959	(0.201)
1975	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.018	6.137	(0.226)	8.619	(0.153)
1976	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.063	2.148	(0.197)	6.740	(0.214)
1977	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.130	3.073	(0.124)	10.199	(0.126)
1978	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.129	5.531	(0.188)	12.895	(0.151)
1979	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.071	3.142	(0.112)	13.927	(0.128)
1980	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.097	7.007	(0.261)	14.202	(0.153)
1981	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.028	2.339	(0.224)	7.533	(0.233)
1982	0.835	3.264	2.476	0.971	0.222	0.000	0.000	0.000	0.000	7.769	(0.636)	15.919	(0.670)
1983	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.083	2.786	(0.170)	8.416	(0.188)
1984	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.096	2.449	(0.220)	8.735	(0.334)
1985	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	2.604	(0.176)	8.261	(0.354)
1986	0.394	0.404	0.626	0.368	0.073	0.041	0.000	0.000	0.045	1.950	(0.230)	4.715	(0.228)
1987	0.570	1.388	0.586	0.198	0.125	0.000	0.000	0.000	0.000	2.868	(0.308)	3.393	(0.234)
1988	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.022	5.903	(0.349)	6.616	(0.232)
1989	0.145	2.468	1.458	0.283	0.138	0.053	0.000	0.009	0.000	4.553	(0.223)	4.535	(0.181)
1990	0.057	0.218	1.788	0.611	0.255	0.048	0.010	0.000	0.000	2.986	(0.190)	4.912	(0.204)
1991	0.144	0.151	0.230	0.621	0.075	0.000	0.023	0.000	0.000	1.243	(0.267)	2.782	(0.246)
1992	0.289	0.448	0.144	0.041	0.327	0.126	0.000	0.000	0.000	1.375	(0.213)	2.447	(0.243)
1993	0.210	0.575	0.361	0.017	0.000	0.038	0.000	0.000	0.000	1.201	(0.259)	1.002	(0.263)
1994	0.184	0.909	0.816	0.093	0.051	0.000	0.045	0.000	0.000	2.098	(0.309)	2.736	(0.292)
1995	0.068	0.308	1.226	0.304	0.082	0.011	0.000	0.000	0.000	2.000	(0.301)	3.664	(0.325)
1996	0.122	0.379	0.231	0.516	0.050	0.000	0.000	0.000	0.000	1.299	(0.254)	2.351	(0.249)
1997	0.297	0.091	0.165	0.168	0.151	0.000	0.000	0.000	0.000	0.872	(0.299)	1.872	(0.307)
1998	0.085	0.342	0.110	0.185	0.041	0.031	0.000	0.000	0.000	0.793	(0.346)	1.499	(0.287)
1999	0.432	0.375	0.590	0.244	0.122	0.019	0.000	0.000	0.000	1.782	(0.181)	3.504	(0.193)
2000	0.540	0.981	0.399	0.492	0.140	0.010	0.000	0.034	0.000	2.596	(0.306)	4.652	(0.332)
2001	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	1.963	(0.271)	7.323	(0.279)
2002	0.269	0.104	0.333	2.683	1.070	0.750	0.077	0.043	0.000	5.328	(0.578)	24.659	(0.686)
2003	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.022	1.988	(0.307)	5.974	(0.251)
2004	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.021	2.165	(0.327)	4.903	(0.214)
2005	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	1.304	(0.065)	2.896	(0.228)
2006	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.014	3.531	(0.301)	4.229	(0.188)
2007	0.136	0.863	0.395	0.496	0.023	0.067	0.000	0.000	0.000	1.981	(0.368)	2.714	(0.277)
2008	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.031	3.295	(0.389)	5.292	(0.285)
2009	0.660	2.096	0.314	0.277	0.045	0.035	0.000	0.000	0.000	3.427	(0.535)	5.844	(0.429)
2010	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.006	0.940	(0.233)	2.571	(0.304)
2011	0.060	0.091	0.210	0.304	0.175	0.078	0.005	0.031	0.000	0.954	(0.304)	2.647	(0.336)

* Aggregate index for ages 0+ as numbers-at-age and biomasses-at-age are not available pre-1970.

Table A7: Stratified mean numbers at age per tow and mean number and mean weight (kg) for ages 1 to 6 of Atlantic cod in State of Massachusetts inshore spring bottom trawl surveys in territorial waters adjacent to the Gulf of Maine (Mass. Regions 4-5), 1982-2011 (Michael Palmer, pers. commn).

	1	2	3	4	5	6	Stratified mean numbers /tow	CV	Stratified mean wt/tow (kg)	CV
1982	13.218	6.649	2.921	1.024	0.216	0.049	24.078	(0.221)	9.783	(0.175)
1983	30.253	17.570	4.710	0.347	1.121	0.075	54.076	(0.166)	15.639	(0.153)
1984	1.898	5.090	2.101	0.751	0.147	0.086	10.073	(0.289)	7.042	(0.259)
1985	1.670	2.695	2.024	0.498	0.000	0.000	6.886	(0.206)	4.535	(0.194)
1986	18.031	3.376	0.903	0.582	0.100	0.023	23.014	(0.552)	4.778	(0.354)
1987	8.622	5.376	2.045	0.168	0.147	0.053	16.411	(0.221)	6.305	(0.271)
1988	10.409	6.750	1.927	1.211	0.016	0.033	20.347	(0.206)	7.389	(0.237)
1989	21.463	22.947	6.868	0.513	0.108	0.048	51.946	(0.268)	15.801	(0.342)
1990	4.972	5.938	14.182	2.149	0.155	0.083	27.479	(0.288)	15.612	(0.341)
1991	5.331	2.295	1.801	3.669	0.249	0.000	13.344	(0.219)	8.123	(0.122)
1992	4.379	5.699	3.444	0.484	1.301	0.066	15.374	(0.287)	8.417	(0.321)
1993	2.842	6.100	2.509	0.879	0.166	0.074	12.569	(0.340)	5.666	(0.270)
1994	5.406	3.883	1.703	0.608	0.131	0.000	11.731	(0.227)	3.908	(0.241)
1995	5.985	2.420	2.408	0.525	0.028	0.000	11.366	(0.262)	3.695	(0.225)
1996	0.777	0.497	0.955	1.590	0.299	0.000	4.119	(0.218)	3.086	(0.305)
1997	2.910	1.035	0.920	0.190	0.383	0.018	5.456	(0.240)	2.281	(0.250)
1998	1.487	0.924	0.779	0.637	0.034	0.211	4.072	(0.261)	3.098	(0.468)
1999	11.832	2.407	2.275	0.735	0.630	0.036	17.914	(0.369)	7.219	(0.261)
2000	35.360	6.995	2.371	2.316	0.784	0.663	48.488	(0.391)	16.294	(0.459)
2001	0.084	4.998	4.710	3.448	1.961	0.323	15.524	(0.435)	24.860	(0.536)
2002	19.340	0.220	1.379	1.145	0.561	0.318	22.964	(0.096)	6.924	(0.390)
2003	17.109	5.496	0.439	1.938	0.937	0.221	26.139	(0.507)	8.674	(0.219)
2004	8.927	1.882	2.627	0.361	1.083	0.455	15.335	(0.459)	7.044	(0.278)
2005	5.524	4.141	0.795	1.955	0.263	0.663	13.342	(0.223)	7.798	(0.197)
2006	9.992	7.139	3.930	0.525	1.532	0.109	23.227	(0.337)	7.001	(0.181)
2007	3.776	3.078	2.303	2.163	0.343	0.519	12.181	(0.274)	7.937	(0.251)
2008	7.275	10.336	3.242	2.287	1.695	0.155	24.991	(0.204)	10.673	(0.215)
2009	8.907	2.350	1.654	1.045	0.348	0.112	14.417	(0.352)	3.839	(0.187)
2010	2.415	1.393	1.423	0.819	0.678	0.129	6.858	(0.234)	4.953	(0.456)
2011	0.326	1.001	0.621	0.933	0.558	0.139	3.579	(0.534)	4.027	(0.424)

Table A8: Percentage of mature females for each age for the Gulf of Maine cod stock (Michael Palmer, pers. commn).

1	2	3	4	5	6	7	8	9+
0.092	0.287	0.613	0.862	0.961	0.990	0.997	0.999	1.000

Table A9: Length frequency distributions for NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC spring survey			NEFSC call survey		
Year	2009	2010	2011	2009	2010	2011
-25cm	0.5634	0.4138	0.0286	0.3967	0.0605	0.2489
26cm	0.0496	0.0189	0.0000	0.1330	0.0283	0.0850
27cm	0.0425	0.0756	0.0000	0.1731	0.0142	0.0283
28cm	0.0638	0.1501	0.0000	0.1251	0.0000	0.0142
29cm	0.0553	0.0945	0.0000	0.1330	0.0283	0.0000
30cm	0.0283	0.1134	0.0000	0.2330	0.0567	0.0142
31cm	0.0544	0.1397	0.0486	0.2834	0.0283	0.0136
32cm	0.0142	0.0945	0.0113	0.4412	0.1134	0.0377
33cm	0.0213	0.0935	0.0113	0.5951	0.0425	0.0142
34cm	0.0958	0.1572	0.0000	0.9068	0.0567	0.0506
35cm	0.0743	0.1407	0.0227	0.7147	0.0142	0.0283
36cm	0.0887	0.1029	0.0000	0.6659	0.0394	0.0142
37cm	0.0695	0.0853	0.0340	0.5014	0.0278	0.0000
38cm	0.1204	0.0945	0.0113	0.6155	0.0425	0.0000
39cm	0.1748	0.0567	0.0000	0.3400	0.0142	0.0543
40cm	0.1559	0.0283	0.0431	0.2516	0.0242	0.0283
41cm	0.1629	0.0283	0.0227	0.2888	0.0425	0.0364
42cm	0.1771	0.0276	0.0599	0.3103	0.0850	0.0380
43cm	0.1565	0.0378	0.0793	0.2834	0.0425	0.0401
44cm	0.2125	0.0378	0.0907	0.3400	0.0283	0.0222
45cm	0.2287	0.0378	0.0340	0.3280	0.0384	0.0640
46cm	0.2196	0.0283	0.0214	0.2776	0.0283	0.0567
47cm	0.1913	0.0189	0.0340	0.1901	0.0242	0.0000
48cm	0.2371	0.0095	0.0340	0.2692	0.0425	0.0364
49cm	0.2017	0.0283	0.0214	0.2125	0.0343	0.0623
50cm	0.2240	0.0647	0.0793	0.1700	0.0283	0.0647
51cm	0.1845	0.0095	0.0441	0.0951	0.0394	0.0364
52cm	0.3077	0.0953	0.0768	0.1199	0.0778	0.0383
53cm	0.2122	0.0000	0.0680	0.0992	0.0142	0.0425
54cm	0.2517	0.1236	0.0826	0.0809	0.0425	0.0506
55cm	0.3245	0.0322	0.0340	0.0708	0.0384	0.0330
56cm	0.1946	0.0646	0.0700	0.0000	0.0425	0.0599
57cm	0.2046	0.0276	0.0441	0.0492	0.0567	0.0000
58cm	0.2358	0.0370	0.0582	0.0384	0.0242	0.0000
59cm	0.2347	0.0455	0.0000	0.0686	0.0257	0.0161
60cm	0.2537	0.0444	0.0227	0.0425	0.0142	0.0383
61cm	0.2547	0.0000	0.0803	0.0447	0.0242	0.0588
62cm	0.1164	0.0081	0.0214	0.0307	0.0401	0.0383
63cm	0.2003	0.0180	0.0113	0.0142	0.0236	0.0222
64cm	0.1725	0.0227	0.0214	0.0874	0.0142	0.1130
65cm	0.0341	0.0000	0.0302	0.0142	0.0336	0.0222
66cm	0.0611	0.0189	0.0467	0.0667	0.0401	0.0303
67cm	0.0850	0.0544	0.0101	0.0201	0.0242	0.0303
68cm	0.0414	0.0276	0.0227	0.0196	0.0848	0.0401
69cm	0.0370	0.0000	0.0372	0.0142	0.0000	0.0481
70cm	0.0923	0.0632	0.0259	0.0283	0.0201	0.0581
71cm	0.0387	0.0161	0.0101	0.0142	0.0353	0.0283
72cm	0.0287	0.0719	0.0322	0.0696	0.0236	0.0259
73cm	0.0259	0.0322	0.0349	0.0350	0.0310	0.0420
74cm	0.0128	0.0423	0.0113	0.0108	0.0142	0.0081
75cm	0.0199	0.0000	0.0101	0.0101	0.0360	0.0081
76cm	0.0704	0.0081	0.0000	0.0283	0.0840	0.0222
77cm	0.0058	0.0161	0.0000	0.0142	0.0000	0.0222
78cm	0.0115	0.0181	0.0101	0.0000	0.0201	0.0000
79cm	0.0058	0.0563	0.0227	0.0283	0.0283	0.0108
80cm	0.0270	0.0181	0.0101	0.0000	0.0101	0.0000
81cm	0.0270	0.0343	0.0000	0.0000	0.0000	0.0540
82cm	0.0000	0.0000	0.0101	0.0101	0.0000	0.0222
83cm	0.0283	0.0000	0.0000	0.0000	0.0000	0.0161
84cm	0.0115	0.0489	0.0000	0.0000	0.0454	0.0000
85cm	0.0115	0.0081	0.0259	0.0000	0.0236	0.0081
86cm	0.0071	0.0262	0.0101	0.0000	0.0101	0.0000
87cm	0.0186	0.0081	0.0000	0.0000	0.0000	0.0000
88cm	0.0058	0.0000	0.0000	0.0142	0.0101	0.0142
89cm	0.0058	0.0161	0.0000	0.0000	0.0000	0.0000
90cm	0.0071	0.0081	0.0113	0.0101	0.0000	0.0000
91cm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0142
93cm	0.0000	0.0000	0.0000	0.0101	0.0000	0.0081
94cm	0.0058	0.0081	0.0340	0.0000	0.0000	0.0000
95cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0081
96cm	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000
97cm	0.0000	0.0000	0.0000	0.0142	0.0000	0.0000
98cm	0.0000	0.0081	0.0000	0.0000	0.0000	0.0081
99cm	0.0000	0.0175	0.0000	0.0000	0.0000	0.0000
100cm+	0.0115	0.0403	0.0214	0.0000	0.0101	0.0081

Table A10a: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2009						Age						NEFSC Spring, 2010						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	39	24	0	0	0	0	0	0	0	0	0	0	28	11	0	0	0	0	0	0	0	0	0
26	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
27	0	0	4	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
28	0	0	3	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
29	0	0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
30	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
31	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
33	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
34	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
35	0	0	4	3	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
36	0	0	4	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
37	0	0	2	4	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0
38	0	0	2	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
39	0	0	1	2	1	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0
40	0	0	2	6	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
41	0	0	2	2	1	1	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0
42	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	5	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
44	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0	0
45	0	0	1	6	4	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
46	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0
47	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
48	0	0	0	2	4	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
49	0	0	0	3	4	1	2	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0
50	0	0	0	2	5	1	0	0	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0
51	0	0	1	2	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
52	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	4	2	1	0	0	0	0	0	0
53	0	0	0	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	7	1	2	0	0	0	0	0	0
55	0	0	0	5	1	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0
57	0	0	0	2	3	2	1	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
58	0	0	0	0	5	3	1	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0
59	0	0	0	1	3	1	5	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
60	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
61	0	0	0	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
62	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
63	0	0	0	0	3	3	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
64	0	0	0	1	5	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
67	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
68	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0
71	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
72	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0
73	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
77	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
78	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
79	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
80	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0
85	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
86	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
87	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
88	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
90	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
95	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2

Table A10b: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2011						Age						NEFSC Spring, 2012						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	2	0	0	0	0	0	0	0	0	0	0	1	38	3	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
31	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
33	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0
37	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
38	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
40	0	0	1	2	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	0
41	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0
42	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3	7	1	0	0	0	0	0	0	0
43	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	7	2	1	0	0	0	0	0	0
44	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	9	1	0	0	0	0	0	0	0
45	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	5	2	2	0	0	0	0	0	0
46	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0
47	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4	1	0	0	0	0	0	0
48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	0
49	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0
50	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	4	1	3	0	0	0	0	0	0
51	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0
52	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	3	7	4	1	0	0	0	0	0
53	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	5	1	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0
55	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	6	1	0	0	0	0	0	0
56	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	5	4	5	2	0	0	0	0	0
57	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0	0
58	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	6	3	1	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	1	2	0	0	0	0
60	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0
61	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
62	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0
63	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0
64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0
65	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0
66	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
67	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0
68	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
71	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
72	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
79	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
80	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
82	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A11: Age-length keys for NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Autumn, 2009					Age						
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	9	11	2	0	0	0	0	0	0	0	0	0
26	0	4	1	0	0	0	0	0	0	0	0	0
27	0	4	2	0	0	0	0	0	0	0	0	0
28	0	3	0	0	0	0	0	0	0	0	0	0
29	0	4	2	0	0	0	0	0	0	0	0	0
30	0	3	1	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0
32	0	4	1	0	0	0	0	0	0	0	0	0
33	0	2	4	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0
35	0	2	4	0	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	2	0	0	0	0	0	0	0	0	0
38	0	2	5	0	0	0	0	0	0	0	0	0
39	0	1	2	0	0	0	0	0	0	0	0	0
40	0	1	3	0	0	0	0	0	0	0	0	0
41	0	1	1	0	0	0	0	0	0	0	0	0
42	0	0	5	0	0	0	0	0	0	0	0	0
43	0	0	4	0	0	0	0	0	0	0	0	0
44	0	0	1	0	0	0	0	0	0	0	0	0
45	0	0	3	0	0	0	0	0	0	0	0	0
46	0	0	7	0	0	0	0	0	0	0	0	0
47	0	0	3	0	0	0	0	0	0	0	0	0
48	0	0	2	0	0	0	0	0	0	0	0	0
49	0	0	1	1	0	0	0	0	0	0	0	0
50	0	0	2	1	0	0	0	0	0	0	0	0
51	0	0	3	0	1	0	0	0	0	0	0	0
52	0	0	3	0	0	0	0	0	0	0	0	0
53	0	0	0	1	1	0	0	0	0	0	0	0
54	0	0	2	1	0	0	0	0	0	0	0	0
55	0	0	2	1	2	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	1	1	2	0	0	0	0	0	0	0
58	0	0	1	0	2	0	0	0	0	0	0	0
59	0	0	0	4	2	0	0	0	0	0	0	0
60	0	0	0	3	0	0	0	0	0	0	0	0
61	0	0	0	2	1	0	0	0	0	0	0	0
62	0	0	0	2	0	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	1	1	3	0	0	0	0	0	0	0
65	0	0	0	0	0	0	1	0	0	0	0	0
66	0	0	0	2	2	0	0	0	0	0	0	0
67	0	0	0	0	1	1	0	0	0	0	0	0
68	0	0	0	0	1	0	0	0	0	0	0	0
69	0	0	0	0	0	1	0	0	0	0	0	0
70	0	0	0	2	0	0	0	0	0	0	0	0
71	0	0	0	1	0	0	0	0	0	0	0	0
72	0	0	0	2	2	0	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0
74	0	0	0	0	1	0	0	0	0	0	0	0
75	0	0	0	0	1	0	0	0	0	0	0	0
76	0	0	0	0	0	0	2	0	0	0	0	0
77	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	1	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	1	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	1	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	0

	NEFSC Autumn, 2010					Age						
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	2	1	0	0	0	0	0	0	0	0	0	0
26	0	2	0	0	0	0	0	0	0	0	0	0
27	0	1	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	2	0	0	0	0	0	0	0	0	0	0
30	0	3	0	0	0	0	0	0	0	0	0	0
31	0	5	0	0	0	0	0	0	0	0	0	0
32	0	5	0	0	0	0	0	0	0	0	0	0
33	0	1	1	0	0	0	0	0	0	0	0	0
34	0	2	2	0	0	0	0	0	0	0	0	0
35	0	0	1	0	0	0	0	0	0	0	0	0
36	0	2	0	0	0	0	0	0	0	0	0	0
37	0	1	1	0	0	0	0	0	0	0	0	0
38	0	0	2	1	0	0	0	0	0	0	0	0
39	0	1	0	0	0	0	0	0	0	0	0	0
40	0	0	2	1	0	0	0	0	0	0	0	0
41	0	0	1	2	0	0	0	0	0	0	0	0
42	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	1	0	0	0	0	0	0	0	0
44	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	1	2	0	0	0	0	0	0	0	0
46	0	0	1	1	0	0	0	0	0	0	0	0
47	0	0	1	1	0	0	0	0	0	0	0	0
48	0	0	0	3	0	0	0	0	0	0	0	0
49	0	0	1	2	0	0	0	0	0	0	0	0
50	0	0	0	2	0	0	0	0	0	0	0	0
51	0	0	1	1	0	0	0	0	0	0	0	0
52	0	0	1	3	0	0	0	0	0	0	0	0
53	0	0	1	1	0	0	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0
55	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	1	0	0	0	0	0	0	0
57	0	0	1	0	1	0	0	0	0	0	0	0
58	0	0	1	0	1	0	0	0	0	0	0	0
59	0	0	1	1	2	0	0	0	0	0	0	0
60	0	0	0	1	0	1	0	0	0	0	0	0
61	0	0	0	1	1	0	1	0	0	0	0	0
62	0	0	0	0	2	0	0	0	0	0	0	0
63	0	0	0	1	0	0	0	0	0	0	0	0
64	0	0	0	0	1	0	1	0	0	0	0	0
65	0	0	0	2	0	1	0	0	0	0	0	0
66	0	0	0	3	0	0	0	0	0	0	0	0
67	0	0	0	1	3	0	0	0	0	0	0	0
68	0	0	0	0	3	0	0	1	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	2	0	0	0	0	0	0
71	0	0	0	1	0	1	0	0	0	0	0	0
72	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	1	0	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	0	1	0	0	0	0	0
76	0	0	0	0	4	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0
78	0	0	0	0	1	1	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0
80	0	0	0	0	1	0	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0
82	0	0	0	0	1	1	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	1	2	0	0	0	0	0	0
85	0	0	0	0	1	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	1	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	1

	NEFSC Autumn, 2011					Age						
Length	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	15	4	0	0	0	0	0	0	0	0	0	0
26	0	4	0	0	0	0	0	0	0	0	0	0
27	0	1	0	0	0	0	0	0	0	0	0	0
28	0	0	1	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	1	0	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0
32	0	2	0	0	0	0	0	0	0	0	0	0
33	0	1	0	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	2	1	0	0	0	0	0	0	0	0
40	0	0	1	0	0	0	0	0	0	0	0	0
41	0	0	2	1	0	0	0	0	0	0	0	0
42	0	1	0	1	0	0	0	0	0	0	0	0
43	0	0	1	1	0	0	0	0	0	0	0	0
44	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	2	3	0	0	0	0	0	0	0	0
46	0	0	0	1	3	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	1	2	1	0	0	0	0	0	0	0
49	0	0	0	1	3	0	0	0	0	0	0	0
50	0	0	1	3	0	1	0	0	0	0	0	0
51	0	0	1	1	1	0	0	0	0	0	0	0
52	0	0	1	1	3	0	0	0	0	0	0	0
53	0	0	0	1	2	0	0	0	0	0	0	0
54	0	0	0	1	2	0	1	0	0	0	0	0
55	0	0	0	0	3	0	0	0	0	0	0	0
56	0	0	0	2	1	0	0	0	0	0	0	0
57	0	0	1	0	0	0	0	0	0	0	0	0
58	0	0	2	0	0	0	0	0	0	0	0	0
59	0	0	0	0	2	0	0	0	0	0	0	0
60	0	0	0	0	3	0	1	0	0	0	0	0
61	0	0	1	2	2	0	0	0	0	0	0	0
62	0	0	0	2	2	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	0	4	6	1	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0
66	0	0	0	0	2	0	1	0	0	0	0	0
67	0	0	0	1	1	0	1	0	0	0	0	0
68	0	0	0	0	1	0	0	0	1	0	0	0
69	0	0	0	1	0	2	0	0	0	0	0	0
70	0	0	0	0	3	2	0	0	0	0	0	0
71	0	0	0	0	1	1	0	0	0	0	0	0
72	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	0	2	1	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0
75	0	0	0	0	0	1	0	0	0	0	0	0
76	0	0	0	0	0	2	0	0	0	0	0	0
77	0	0	0	0	0	2	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	1	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	4	0	0	0	0	0	0
82	0	0	0	0	0	1	1	0	0	0	0	0
83	0	0	0	0	0	1	1	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	1	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	1	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	1	0	0	0	0	0
93	0	0	0	0	0	0	0	0	1	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	1	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	0	0

Table A12a: Mean weight-at-age (kg) from NEFSC offshore spring surveys. Pre-1970, the 1970-1979 average mean weight-at-age is assumed (Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1970	0.043	0.297	0.641	1.562	2.468	4.789	5.327	8.547	12.439
1971	0.201	0.507	1.340	2.225	4.484	3.570	6.379	8.557	9.301
1972	0.046	0.355	1.659	2.512	3.596	5.453	6.227	7.706	10.783
1973	0.043	0.180	0.972	2.898	3.730	4.518	7.229	6.216	13.401
1974	0.035	0.188	0.688	2.706	5.668	8.000	6.874	7.300	13.269
1975	0.030	0.255	1.027	1.898	3.883	7.050	6.874	8.413	14.817
1976	0.101	0.239	0.713	1.692	3.136	5.546	10.777	11.463	16.635
1977	0.112	0.328	0.780	1.058	2.315	4.787	6.874	9.953	21.006
1978	0.131	0.469	1.139	1.813	3.137	5.737	7.694	10.633	14.303
1979	0.078	0.404	1.367	1.972	3.056	4.093	7.685	7.159	17.912
1980	0.047	0.351	1.291	2.143	3.461	3.881	5.574	8.513	11.037
1981	0.125	0.460	1.103	2.477	4.056	6.138	7.568	8.456	11.041
1982	0.106	0.438	1.350	2.579	4.139	4.072	8.031	8.513	12.301
1983	0.094	0.463	1.475	2.513	5.110	6.693	11.352	8.513	20.470
1984	0.071	0.574	1.431	2.551	4.940	4.324	5.035	8.513	14.596
1985	0.045	0.426	1.329	2.707	4.293	5.492	6.065	13.198	16.558
1986	0.086	0.485	1.564	2.955	3.554	7.734	12.633	8.513	20.134
1987	0.065	0.348	0.729	2.585	3.058	5.084	6.378	5.420	25.016
1988	0.049	0.175	1.039	1.724	5.060	5.545	4.947	9.493	7.202
1989	0.043	0.182	0.728	1.828	2.631	6.784	6.874	8.513	14.596
1990	0.076	0.243	0.786	2.029	3.447	6.554	8.200	8.513	14.596
1991	0.078	0.197	0.875	1.190	1.524	2.557	6.008	8.513	14.596
1992	0.061	0.453	1.012	2.871	4.178	5.644	6.721	8.513	13.953
1993	0.057	0.323	1.368	1.963	3.809	5.255	10.622	11.372	16.642
1994	0.033	0.192	0.856	2.318	2.519	2.861	5.654	6.582	7.255
1995	0.111	0.240	0.681	1.277	2.825	3.956	6.874	2.828	20.994
1996	0.076	0.318	1.799	2.068	3.296	4.847	6.874	8.513	14.596
1997	0.064	0.445	1.416	2.658	2.954	3.745	6.749	8.513	14.596
1998	0.057	0.448	1.188	2.033	3.216	4.537	6.502	8.004	14.596
1999	0.088	0.335	0.994	1.949	3.123	5.723	5.574	8.513	31.105
2000	0.079	0.436	1.037	2.482	4.127	5.327	4.540	8.612	14.596
2001	0.119	0.474	1.107	2.738	4.242	8.950	9.035	14.481	16.784
2002	0.069	0.318	1.170	2.718	3.240	6.032	6.014	13.284	3.580
2003	0.123	0.198	0.820	1.588	2.661	3.991	5.783	6.627	10.133
2004	0.044	0.349	0.849	2.536	3.662	4.388	3.764	3.764	11.576
2005	0.031	0.211	1.031	1.739	2.628	3.979	5.597	5.494	14.596
2006	0.070	0.262	0.790	1.862	3.102	6.050	5.442	8.729	9.927
2007	0.092	0.388	0.876	1.649	3.059	3.244	4.130	5.428	14.596
2008	0.049	0.400	1.053	1.655	2.489	5.609	6.928	8.513	14.596
2009	0.031	0.523	1.441	2.067	2.601	2.876	8.067	9.930	12.919
2010	0.076	0.356	1.203	2.805	3.849	4.602	7.314	10.712	15.374
2011	0.064	0.453	1.177	1.717	2.706	3.509	5.906	8.521	14.596

Table A12b: Mean weight-at-age (kg) from NEFSC offshore autumn surveys. Pre-1970, the 1970-1979 average mean weight-at-age is assumed (Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1970	0.199	0.598	1.407	3.840	3.016	6.197	6.925	8.647	12.980
1971	0.241	1.201	1.688	2.916	4.818	5.392	6.853	9.008	14.100
1972	0.136	0.744	2.240	3.570	3.680	6.655	6.631	12.278	12.002
1973	0.111	0.458	2.093	4.229	4.814	5.814	9.916	6.042	10.734
1974	0.076	0.497	1.308	2.759	6.452	6.293	8.010	12.857	12.664
1975	0.249	0.439	1.041	2.290	2.775	5.598	8.472	12.044	14.086
1976	0.348	0.843	1.173	1.481	3.869	7.508	9.737	12.044	17.898
1977	0.201	0.531	1.238	1.843	3.809	5.940	7.696	11.211	15.843
1978	0.202	0.734	1.367	2.270	3.099	4.060	7.607	12.247	17.003
1979	0.385	0.878	2.644	3.347	5.462	6.791	10.187	11.930	21.717
1980	0.324	0.718	1.899	3.071	6.694	5.996	6.408	15.249	16.793
1981	0.232	1.102	2.116	4.419	5.583	8.130	8.390	12.349	22.998
1982	0.493	1.408	2.488	3.320	6.889	6.293	8.131	12.044	16.731
1983	0.236	1.082	1.732	3.583	4.878	9.825	8.131	12.044	20.891
1984	0.287	1.008	2.295	3.699	6.565	7.550	11.342	12.044	20.333
1985	0.208	1.054	2.503	3.879	7.494	10.403	8.131	20.320	23.705
1986	0.347	0.703	2.497	3.339	7.927	8.012	8.131	12.044	13.192
1987	0.151	0.648	1.502	3.596	6.505	6.293	8.131	12.044	16.731
1988	0.175	0.670	1.854	3.195	6.010	6.293	8.841	12.044	12.403
1989	0.276	0.410	1.176	2.727	4.911	3.877	8.131	13.292	16.731
1990	0.225	0.430	0.961	2.562	4.837	4.926	5.448	12.044	16.731
1991	0.172	0.715	1.703	2.566	5.374	6.293	11.513	12.044	16.731
1992	0.213	0.892	1.236	2.689	3.365	4.757	8.131	12.044	16.731
1993	0.122	0.512	1.529	3.547	5.284	1.778	8.131	12.044	16.731
1994	0.289	0.530	1.503	3.483	6.476	6.293	7.058	12.044	16.731
1995	0.125	0.876	1.597	2.612	7.143	4.318	8.131	12.044	16.731
1996	0.283	0.723	2.194	2.414	5.779	6.293	8.131	12.044	16.731
1997	0.151	0.903	1.761	4.593	4.518	6.293	8.131	12.044	16.731
1998	0.192	0.754	1.869	3.286	4.530	7.387	8.131	12.044	16.731
1999	0.302	1.013	2.100	3.862	5.499	7.563	8.131	12.044	16.731
2000	0.220	0.866	1.941	3.699	3.558	9.768	8.131	14.548	16.731
2001	0.239	0.755	1.819	2.721	6.266	9.096	10.713	12.044	11.023
2002	0.140	0.975	2.192	4.091	5.288	7.722	8.395	16.787	16.731
2003	0.373	0.654	2.304	2.708	5.232	6.267	8.633	12.044	19.375
2004	0.125	0.627	1.694	3.452	4.499	4.471	8.560	8.478	18.167
2005	0.109	0.453	1.599	2.162	5.916	3.464	6.592	10.172	17.780
2006	0.207	0.480	1.024	1.715	3.489	5.965	5.126	14.241	14.759
2007	0.166	0.528	1.018	2.639	4.276	6.346	8.131	12.044	16.731
2008	0.317	1.015	1.986	2.486	5.421	6.293	8.131	12.044	16.613
2009	0.555	1.174	3.366	4.503	10.575	6.618	8.131	12.044	16.731
2010	0.335	1.170	1.774	3.904	4.784	4.548	3.461	12.044	24.490
2011	0.286	0.942	1.775	2.323	4.581	4.931	10.775	7.135	16.731

Table A12c: Mean weight-at-age (kg) from State of Massachusetts inshore spring surveys(Michael Palmer, pers. commn). Note that for some years certain values at older ages have been determined by interpolation techniques as there were no data available.

	1	2	3	4	5	6	7	8	9+
1982	0.116	0.453	1.106	2.031	5.606	5.073	6.778	10.426	10.361
1983	0.083	0.388	1.020	1.634	2.381	10.539	4.511	15.422	10.361
1984	0.104	0.415	1.295	1.884	3.717	2.893	4.519	7.652	10.361
1985	0.128	0.517	0.999	2.252	2.829	4.556	4.519	7.652	10.361
1986	0.170	0.453	1.592	2.271	3.638	5.563	4.519	7.652	10.361
1987	0.057	0.564	0.791	3.213	3.963	10.103	4.519	7.652	15.241
1988	0.030	0.335	1.216	2.041	6.171	6.392	4.519	7.652	10.361
1989	0.072	0.340	0.946	1.660	3.709	5.363	4.519	7.652	10.361
1990	0.053	0.409	0.654	1.317	3.311	6.779	4.519	7.652	10.361
1991	0.114	0.331	1.118	1.282	2.609	4.556	4.519	7.652	10.361
1992	0.049	0.447	0.753	1.410	1.716	5.513	3.018	7.652	10.361
1993	0.037	0.355	0.764	1.033	2.839	2.829	4.519	7.652	10.361
1994	0.079	0.279	0.842	1.685	2.791	4.556	4.519	7.652	10.361
1995	0.048	0.395	0.809	1.374	2.555	4.556	4.519	7.652	10.361
1996	0.081	0.426	0.806	1.010	1.664	4.556	4.519	7.652	10.361
1997	0.073	0.555	0.925	1.702	1.328	1.252	4.519	7.652	10.361
1998	0.063	0.390	1.085	1.756	2.496	3.266	2.431	7.652	10.361
1999	0.094	0.484	1.134	2.070	2.904	3.383	4.140	3.869	10.361
2000	0.094	0.466	1.366	2.031	2.802	4.363	5.546	9.013	10.361
2001	0.042	0.470	1.571	2.346	2.738	5.127	3.672	6.875	10.361
2002	0.039	0.230	0.945	1.947	3.012	5.184	5.928	7.440	11.027
2003	0.067	0.216	0.486	1.883	3.100	3.253	5.414	6.562	8.618
2004	0.039	0.383	0.810	1.760	2.143	2.730	3.770	8.342	12.697
2005	0.035	0.177	1.011	1.659	3.125	3.309	5.233	5.913	4.846
2006	0.048	0.116	0.568	1.136	2.048	1.930	4.783	7.652	9.447
2007	0.056	0.172	0.675	1.414	2.317	3.860	3.768	3.446	10.361
2008	0.064	0.277	0.747	1.375	1.013	3.419	5.194	7.652	10.361
2009	0.048	0.199	0.872	1.044	1.357	3.248	4.519	7.652	10.361
2010	0.060	0.230	0.647	1.634	2.482	5.356	4.519	7.652	10.652
2011	0.046	0.291	0.869	1.459	2.494	3.178	3.605	6.869	10.361

Appendix B - The Statistical Catch-at-Age Model

The text following sets out the equations and other general specifications of the SCAA 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 then applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

For the convenience of readers, details which are changed or newly added relative to the specifications used for the analyses reported in Butterworth and Rademeyer (2012) are shown highlighted. Note that summations over ages now all exclude age a=0.

B.1. Population dynamics

B.1.1 Numbers-at-age

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

$$N_{y+1,0} = R_{y+1} \qquad \text{(B1)}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \qquad \text{for } 0 \le a \le m-2 \qquad \text{(B2)}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \qquad \text{(B3)}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y*,

R_y is the recruitment (number of 0-year-old fish) at the start of year *y*,

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

$Z_{y,a} = F_y S_{y,a} + M_a$ is the total mortality in year *y* on fish of age *a*, where

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

F_y is the fishing mortality of a fully selected age class in year *y*, and

$S_{y,a}$ is the commercial selectivity at age *a* for year *y*.

B.1.2. Recruitment

The number of recruits (i.e. new 0-year old) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a standard or adjusted Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

For the modified Ricker:

$$R_y = \alpha B_y^{\text{sp}} \exp\left[-\beta \left(B_y^{\text{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad \text{(B4)}$$

for the (standard) Beverton-Holt:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad \text{(B5)}$$

and for the adjusted Beverton-Holt:

$$R_y = \begin{cases} \dfrac{\alpha B_y^{sp}}{\beta + B_y^{sp}} & \text{if } B_y^{sp} \le B^* \\ \dfrac{\alpha B^*}{\beta + B^*} \exp\left(-\left(\dfrac{B_y^{sp} - B^*}{\sigma_N}\right)^2\right) & \text{if } B_y^{sp} > B^* \end{cases} \qquad \text{(B6)}$$

where

$\alpha, \beta, \gamma, B^*$ and σ_N are spawning biomass-recruitment relationship parameters,

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

B_y^{sp} is the spawning biomass at the start of year *y*, computed as:

$$B_y^{sp} = \sum_{a=1}^{m} f_a w_{y,a}^{strt} N_{y,a} e^{-Z_{y,a}/4} \qquad \text{(B7)}$$

because spawning for the cod stock under consideration is taken to occur three months after the start of the year and some mortality has therefore occurred,

where

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

f_a is the proportion of fish of age *a* that are mature.

Section *B.2.6* details the procedure adopted when recruitment is not assumed to be related to spawning biomass , at least internal to the assessment.

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

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

$$C_y = \sum_{a=1}^{m} w_{y,a}^{mid} C_{y,a} = \sum_{a=1}^{m} w_{y,a}^{mid} N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \qquad \text{(B8)}$$

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*,

The model estimate of survey index is computed as:

$$B_y^{surv} = \sum_{a=1}^{m} w_{y,a}^{surv} S_a^{surv} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \qquad \text{(B9)}$$

for biomass indices and

$$N_y^{\text{surv}} = \sum_{a=1}^{m} S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \quad \text{(B10)}$$

for numbers indices

where

S_a^{surv} is the survey selectivity for age *a*, which is taken to be year-independent.

T^{surv} is the season in which the survey is taking place (T^{surv}=1 for spring surveys and T^{surv}=3 for fall surveys), and

$w_{y,a}^{surv}$ denotes the mass of fish of age *a* from survey *surv* year *y* (Table A12).

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

B.1.4. Initial conditions

For the first year (y_0) considered in the model, the numbers-at-age are estimated directly for ages 0 to a^{est}, with a parameter ϕ mimicking recent average fishing mortality for ages above a^{est}, i.e.

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 0 \le a \le a^{est} \quad \text{(B11)}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \quad \text{(B12)}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \quad \text{(B13)}$$

B.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age and catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated 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. Details related to fitting to CPUE series are not included below, as such series are not considered in the analyses of this paper.

B2.1. Survey abundance data

The likelihood is calculated assuming that a survey biomass index is lognormally distributed about its expected value:

$$I_y^{surv} = \hat{I}_y^{surv} \exp\left(\varepsilon_y^{surv}\right) \quad \text{or} \quad \varepsilon_y^{surv} = \ell\text{n}\left(I_y^{surv}\right) - \ell\text{n}\left(\hat{I}_y^{surv}\right) \quad \text{(B14)}$$

where

I_y^{surv} is the survey biomass index for survey *surv* in year *y*,

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

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

ε_y^{surv} from $N\left(0,\left(\sigma_y^{surv}\right)^2\right)$.

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

$$-\ell\text{n}\,L^{\text{survey}} = \sum_{surv}\sum_{y}\left\{\ell\text{n}\left(\sqrt{\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2}\right) + \left(\varepsilon_y^{surv}\right)^2 / \left[2\left(\left(\sigma_y^{surv}\right)^2 + \left(\sigma_{Add}^{surv}\right)^2\right)\right]\right\} \quad \text{(B15)}$$

where

σ_y^{surv} is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

σ_{Add}^{surv} is the square root of the additional variance for survey biomass series *surv*, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^{surv} for survey biomass index *surv* is estimated by its maximum likelihood value:

$$\ell n\,\hat{q}^{surv} = 1/n_{surv}\sum_{y}\left(\ln I_y^{surv} - \ln \hat{B}_y^{surv}\right) \quad \text{(B16)}$$

B.2.3. 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:

$$-\ell\text{n}\,L^{\text{CAA}} = \sum_{y}\sum_{a}\left[\ell n\left(\sigma_a^{com}/\sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\,\hat{p}_{y,a}\right)^2 / 2\left(\sigma_a^{com}\right)^2\right] \quad \text{(B17)}$$

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

$$\hat{C}_{y,a} = N_{y,a}\; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right)/Z_{y,a} \quad \text{(B18)}$$

and

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

$$\hat{\sigma}_a^{com} = \sqrt{\sum_{y} p_{y,a}\left(\ell n\, p_{y,a} - \ell n\,\hat{p}_{y,a}\right)^2 / \sum_{y} 1} \quad \text{(B19)}$$

Commercial catches-at-age are incorporated in the likelihood function using equation (B17), for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

In application of this approach ages are often aggregated to avoid values of $p_{y,a}$ or $\hat{p}_{y,a}$ that are too small in the interests of estimation robustness. In this paper individual ages have been maintained between the selected minus and plus-groups to provide potential discrimination of different shapes for the selectivity functions at older ages in particular. This however does mean that there are certain cells for which $p_{y,a}$ values are zero. That does not cause any problems because the limit of $p_{y,a}(\ln p_{y,a})^2$ as $p_{y,a} \to 0$ is 0, so these terms can be omitted from the summation in equation B17. One could argue that they should nevertheless be included in the summations in equation B18, but exclusion seems more appropriate as the structural zero contributions then included would seem likely to bias the estimates of $\hat{\sigma}_a^{com}$ downwards.

In addition to this "adjusted" lognormal error distribution, some computations use an alternative "sqrt(p)" formulation, for which equation B20 is modified to:

$$-\ell\text{n}\, L^{\text{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_a^{com}\right) + \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / 2\left(\sigma_a^{\text{com}}\right)^2 \right] \quad \text{(B21)}$$

and equation B21 is adjusted similarly:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / \sum_y 1} \quad \text{(B22)}$$

This formulation mimics a multinomial form for the error distribution by forcing a near-equivalent variance-mean relationship for the error distributions.

B.2.4. 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" lognormal error distribution (equation (B19)) where:

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

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

$$\hat{p}_{y,a}^{surv} = S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \Big/ \sum_{a'=1}^{m} S_{a'}^{\text{surv}} N_{y,a'} e^{-Z_{y,a'} T^{surv}/12} \quad . \quad \text{(B23)}$$

For the Massachusetts spring survey, the summation is taken from age 1 to age 6.

B.2.5. Survey catches-at-length

In some runs, catches-at-length are also incorporated in the likelihood function. These data are incorporated in the similar manner as the catches-at-age. When the model is fit to catches-at-length, the predicted catches-at-age are converted to catches-at-length:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l}^{strt} \quad \text{(B24)}$$

for the spring survey, and

$$\hat{p}^{surv}_{y,l} = \sum_a \hat{p}^{surv}_{y,a} A^{mid}_{a,l} \qquad \text{(B25)}$$

for the fall survey,

where $A^{strt}_{a,l}$ and $A^{mid}_{a,l}$ are the proportions of fish of age *a* that fall in the length group *l* (i.e., $\sum_l A^{strt}_{a,l} = 1$ and $\sum_l A^{mid}_{a,l} = 1$ for all ages) at the beginning of the year and at the middle of the year respectively.

The matrices $A^{strt}_{a,l}$ and $A^{mid}_{a,l}$ are calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L^{strt}_a \sim N\left[L_\infty\left(1-e^{-\kappa(a-t_o)}\right);\left(\theta^{strt}_a\right)^2\right] \qquad \text{(B26)}$$

for the spring survey and

$$L^{mid}_a \sim N\left[L_\infty\left(1-e^{-\kappa(a+0.5-t_o)}\right);\left(\theta^{mid}_a\right)^2\right] \qquad \text{(B27)}$$

for the fall survey,

where

θ^{strt}_a and θ^{mid}_a are the standard deviation of begin and mid-year length-at-age *a* respectively, which are modelled to be proportional to the expected length-at-age *a*, i.e.:

$$\theta^{strt}_a = \beta\left[L_\infty\left(1-e^{-\kappa(a-t_o)}\right)\right]^\gamma \qquad \text{(B28)}$$

and

$$\theta^{mid}_a = \beta\left[L_\infty\left(1-e^{-\kappa(a+0.5-t_o)}\right)\right]^\gamma \qquad \text{(B29)}$$

with β an estimable parameter and $\gamma = 0.5$ (a value which was found to lead to reasonable fits to the data).

$L_\infty = 150.93\, cm$,

$\kappa = 0.11\, yr^{-1}$,

$t_o = 0.13\, yr$,

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

$$-\ell\mathrm{n}\, L^{\mathrm{CAL}} = w_{len} \sum_{surv}\sum_y\sum_l \left[\ell n\left(\sigma^{surv}_{\mathrm{len}} / \sqrt{p^{surv}_{y,l}}\right) + p^{surv}_{y,l}\left(\ell n\, p^{surv}_{y,l} - \ell n\, \hat{p}^{surv}_{y,l}\right)^2 / 2\left(\sigma^{surv}_{\mathrm{len}}\right)^2\right] \qquad \text{(B30)}$$

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups because the length distributions for adjacent ages overlap) to the overall negative log-likelihood compared to that of the CPUE data. The value used for w_{len} is 0.1, being roughly equivalent to the ratio of the number to length groups to the number of age groups considered. Instances of observed proportions of zero are dealt with in the same manner as for catches-at-age, as is the alternative "sqrt(p)" error distribution formulation.

B.2.6. Stock-recruitment function residuals

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

$$-\ell nL^{\text{pen}} = \sum_{y=y_1+1}^{y_2} \left[\varepsilon_y^2 / 2\sigma_{\text{R}}^2\right] \qquad \text{(B31)}$$

where

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

σ_{R} is the standard deviation of the log-residuals, which is input.

Equation B31 is used when the stock-recruitment curve is estimated internally. In some analyses reported in this paper where BRP estimates are based on stock-recruitment curves estimated "externally" using the assessment outputs,, this "stock-recruitment" term is included for the last two years only, simply to stabilise these estimates which are not well determined by the other data. In these cases, the ε_y are calculated as the deviations from the mean log recruitment for the ten preceding years, i.e. recruitment estimates for 2010 and 2011 are shrunk towards the geometric mean recruitment over the preceding decade.

B.2.7. Catches

$$-\ell nL^{\text{Catch}} = \sum_y \left[\frac{\ell nC_y - \ell n\hat{C}_y}{2\sigma_{\text{C}}^2}\right] \qquad \text{(B32)}$$

where

C_y is the observed catch in year *y*,

$\hat{C}_y$ is the predicted catch in year *y* (eqn B8), and

σ_{C} is the CV input: 0.4 for pre-1964 catches, 0.2 for catches between 1964 and 1981 and 0.05 for catches from 1982 onwards.

B.2.8Incorporation of Bigelow vs Albatross survey calibration

The survey data provided are adjusted for the years 2009 to 2012 which were obtained from *Bigelow* surveys have been adjusted to "*Albatross* equivalents" through use of calibration factors estimated independently from paired tow experiments (Miller *et al.*, 2010). However the survey data before and after the switch of vessels also provide information on the calibration factors because they sample the same cohorts. Incorporation of this information in assessments in this paper has been effected by treating the estimates, with their variance-covariance matrix, as a form of "joint-prior" which is effectively updated in the penalised likelihood estimation when fitting the model. The process is as follows.

First *Bigelow* length frequency distributions are converted to *Albatross* equivalent length frequency distributions:

$$C_{y,l}^{surv,A} = C_{y,l}^{surv,B} \Big/ F_l \qquad \text{(B33)}$$

where

$C_{y,l}^{surv,B}$ is the measured catch-at-length for the *Bigelow* in year *y* for survey *surv,*

$C_{y,l}^{surv,A}$ is the inferred catch-at-length for the *Albatross* equivalent in year *y* for survey *surv,*

F_l is the length-based calibration factor (*Bigelow/Albatross*),

The Albatross equivalent length distributions are then converted to age distributions:

$$C_{y,a}^{surv,A} = \sum_l C_{y,l}^{surv,A} ALK_{y,a,l}^{surv} \qquad \text{(B34)}$$

where

$ALK_{y,a,l}^{surv}$ is the age-length key (proportion of fish of length *l* that have age *a*) in year *y* for survey *surv.*

Indices are then obtained from the *Albatross* equivalent age distributions as follows:

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} w_{y,a}^{surv} \qquad \text{(B35)}$$

for biomass indices and

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} \qquad \text{(B36)}$$

for numbers indices,

where

$w_{y,a}^{surv}$ is the weight-at-age in year *y* for survey *surv*.

The calibration factor has four parameters, three of which are estimable and the other input: X_1=20cm, X_2, F_1 and F_2

$$F_l = \begin{cases} F_1 & \text{if } l \le X_1 \\ \dfrac{(F_2 - F_1)}{(X_2 - X_1)} l + \dfrac{(F_1 X_2 - F_2 X_1)}{(X_2 - X_1)} & \text{if } X1 < l < X_2 \\ F_2 & \text{if } l \ge X_2 \end{cases} \qquad \text{(B37)}$$

The following contribution is therefore added to the negative log-likelihood in the assessment:

$$-\ln L^{calib} = \frac{1}{2}\ln|\mathbf{\Sigma}| + \frac{1}{2}(\mathbf{x} - \boldsymbol{\mu})^{\mathrm{T}} \mathbf{\Sigma}^{-1} (\mathbf{x} - \boldsymbol{\mu}) \qquad \text{(B38)}$$

where the parameters X_2, F_1 and F_2 are components of the vector ***x,***

Σ is the variance covariance matrix as estimated by Miller *et al.* (2010), and

μ is a vector which contains the Miller *et al.* (2010) estimates of the parameters.

These estimates and the variance-covariance matrix are given in table B1 below:

Table B1: Estimates and variance-covariance matrix for the calibration parameters (Miller, pers. commn).

μ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
	0.4713	1.4163	3.5086
Σ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
$ln(F_2)$	0.006674	-0.002515	-0.002559
$ln(F_1\text{-}F_2)$	-0.002515	0.051592	-0.007601
$ln(X_2\text{-}X_1)$	-0.002559	-0.007601	0.006757

B.3. Estimation of precision

Where quoted, CV's or 95% probability interval estimates are based on the Hessian.

B.4. Model parameters

B.4.1. Fishing selectivity-at-age:

For the NEFSC offshore surveys, the fishing selectivities are estimated separately for ages 1 to age 6 and are flat thereafter. For the Massachusetts inshore spring survey, the selectivities are estimated separately for ages 1 to 4. The estimated proportional decrease from ages 3 to 4 is assumed to continue multiplicatively to age 6; this decrease parameter is bounded by 0, i.e. no increase is permitted. For all three surveys, age 0 is not considered.

The commercial fishing selectivity, S_a , is estimated separately for ages a_{minus} to a_{plus} (1 to 9) It is taken to differ over four periods: a) pre-1982, b) 1982-1988, c)1989-2004, and d) 2005-present. The selectivities are estimated directly for the last three periods. For the pre-1982 period, the selectivity is taken as that for the 1989-1988 block, but shifted one year to the left. For the implementations in this paper, given that there were difficulties with imprecise estimates at larger ages for period d) given its shortness, a common selectivity at age was estimated across all periods for ages 7 and above.

B.4.2. Other parameters

Model plus group				
	m	9		
Commercial CAA				
	a_{minus}*	1		
	a_{plus}	9		
Survey CAA		NEFSC spr	NEFSC fall	MASS spr
	a_{minus}*	1	1	1
	a_{plus}	9	9	4
Natural mortality:				
	M	Age independent: i) 0.2 for all years ii) 0.2 until 1988, threafter a linear increase to 0.4 in 2003 and constant at 0.4 thereafter		
Proportion mature-at-age:	f_a	input, see Table A8		
Weight-at-age:				
	$w_{y,a}^{strt}$	input, see Table A2		
	$w_{y,a}^{mid}$	input, see Table A3		
	$w_{y,a}^{surv}$	input, see Table A12		
Stock recruit residuals std dev:	σ_R	0.6		
Initial conditions :				
	$N_{y0,a}$	estimated directly for ages 0 to xx depending on AIC criterion		
	ϕ	estimated		

* Strictly not a minus group anymore since the catches at age zero are ignored.

B.5.Biological Reference Points (BRPs)

It is possible to estimate BRPs internally within the assessment by fitting the stock-recruitment relationship directly within the assessment itself.

For some results reported here, however, the stock-recruitment relationships are fitted to the estimates of recruitment and spawning biomass provided by the various assessments to provide a basis to estimate BRPs. The rationale for estimation external to the assessment itself is to avoid assumptions about the form of the relationship influencing the assessment results. These fits are achieved by minimising the following negative log-likelihood, where the $e^{-\frac{\sigma_R^2}{2}}$ term is added for consistency with equation B4, i.e. the stock-recruitment curves estimated are mean-unbiased rather than median unbiased:

$$-\ln L = \sum_{y=y1}^{2009}\left[\frac{\left(\ln(N_{y,0})-\ln\left(\hat{N}_{y,0}e^{-\frac{\sigma_R^2}{2}}\right)\right)^2}{2\left((\sigma_R)^2+(CV_y)^2\right)}\right] \qquad \text{(B39)}$$

where

$N_{y,0}$ is the "observed" (assessment estimated) recruitment in year *y*,

$\hat{N}_{y,0}$ is the stock-recruitment model predicted recruitment in year *y*,

σ_R is the standard deviation of the log-residuals which is input (and set here to 0.6), and

CV_{y} is the Hessian-based CV for the "observed" recruitment in year *y*.

Note that the differential precision of the assessment estimates of recruitment is taken into account, and that the summation ends at 2009 because little by way of direct observation is as yet available to inform estimates of recruitment for 2010 and 2011.